FIRE PROTECTION FOR CHEMICAL PLANTS

Table of Contents

List of Figures

1.0 SCOPE

This data sheet addresses fire and explosion hazards at chemical manufacturing plants and similar processing facilities. In particular, it focuses on the hazards associated with large-scale ignitable liquid, flammable gas, and liquefied flammable gas processing facilities, where large releases or long duration fires are possible.

This data sheet accounts for larger ignitable liquid release volumes, including the potential for continuous releases, by recommending a higher level of passive and active fire protection features than other data sheets covering ignitable liquid hazards.

This data sheet also applies when directed here by other data sheets, such as for very large Heat Transfer Fluid (HTF) systems.

This data sheet does **not** address the following subjects:

A. Dispensing of ignitable liquid and indoor tanks containing ignitable liquids: Use Data Sheet 7-32, *Ignitable Liquid Operations*.

B. Ignitable liquid storage: Use Data Sheet 7-29, *Ignitable Liquid Storage in Portable Containers*, or Data Sheet 7-88, *Outdoor Ignitable Liquid Storage*.

C. Distilleries: Use Data Sheet 7-74, *Distilleries*.

D. Small waste solvent recovery units: Use Data Sheet 7-2, *Waste Solvent Recovery*.

E. Gas fuels: Use Data Sheet 7-54, *Natural Gas and Gas Piping*.

F. Flammable gas storage: Use Data Sheet 7-55, *Liquefied Petroleum Gas (LPG) in Stationary Installations*.

1.1 Application

A direct relationship exists between the volume of ignitable liquid released and the potential fire severity. If the ignitable liquid released is limited via the use of small quantities or automatic shutoffs, the guidance from Data Sheet 7-32, *Ignitable Liquid Operations*, should be applied. Conversely, a large and continuous flow of ignitable liquid can potentially result in a growing and sustained fire condition that will require a more robust protection approach like the one provided in this data sheet.

FM's most fundamental recommendation pertaining to ignitable liquids is to limit the amount of liquid that can become involved in a fire. However, at chemical processing plants this is often not possible.

1.2 Hazards

Fires within chemical processing facilities may be pool fires from released liquids, spray/jet fires from escaping liquids or gases, three dimensional fires from elevated releases of liquids, or a combination of these.

Depending on the amount of material released, scenarios can be severe, resulting in damage to buildings and equipment over an extensive area. To limit damage from these types of fires, a high level of protection is needed where different protection elements or layers may be used.

1.3 Changes

April 2026. This document has been completely revised. The following significant changes were made:

A. Revised the scope and application of this data sheet.

B. Reorganized sections and recommendations to improve the flow of information.

C. Added clarification and additional guidance to existing recommendations, where applicable.

D. Deleted Tables 1a and 1b for approximate space guidance. The facility sitting section was revised and reorganized.

E. Revised the pipe racks protection section to include clarification for cases where pipe rack protection is needed, and developed protection guidance for indoor pipe racks.

F. Added new recommendations and support for recommendations for manual firefighting, steel protection and emergency-controlled shutdown and isolation sections.

G. Added a new protection section for flammable gases.

H. Updated the water-reactive materials and loading/unloading stations section.

I. Added an Appendix for ignitable liquid scenario development.

2.0 LOSS PREVENTION RECOMMENDATIONS

2.1 Introduction

2.1.1 Use FM Approved equipment, materials, and services whenever they are applicable. For a list of products and services that are FM Approved, see the *Approval Guide*, an online resource of FM Approvals.

2.2 Construction and Location

2.2.1 Facility Siting

2.2.1.1 Conduct a comprehensive facility siting study to determine appropriate separation between process units, maintenance and administration buildings, utilities, ignitable liquid storage tanks, yard storage, and other buildings at the plant. Use current best practices in conducting this evaluation. Items to consider in the study include, but are not limited to the following:

A. Drainage, containment, and slope of land

B. Location of flares

C. Potential for explosion or blast overpressure from high hazard operations

D. Potential for pressure vessel rupture

E. Potential for a vapor cloud explosion

2.2.2 Location of Hazardous Processes

2.2.2.1 Where possible, locate processes using large quantities of ignitable liquids, flammable gases or liquefied flammable gases in outdoor open structures with minimal enclosure.

2.2.2.2 For ignitable liquids processes evaluate the potential for a room/building or equipment explosion hazard; and protect accordingly per the guidance provided in Data Sheet 7-32, *Ignitable Liquids Operations* and the ventilation guidance in Section 2.3.2 in this data sheet..

2.2.3 Three-Dimensional Spill Fire Control

2.2.3.1 Design the structure to limit the potential for a 3D spill fire as follows:

A. Locate equipment (vessels, tanks, pumps, etc.) with ignitable liquid holdup at ground level.

B. Provide solid floors with curbing and drainage, rather than open steel grating, beneath equipment located at upper levels.

2.2.4 Emergency Drainage and Containment

2.2.4.1 Provide emergency drainage and containment for processing units that create an ignitable liquid pool fire exposure. As an alternative to containment, arrange the surface grade to direct ignitable liquid releases away from important buildings, equipment, utilities, fire protection equipment, and other critical areas.

2.2.4.2 Design and maintain the emergency drainage and containment systems per Data Sheet 7-83, *Drainage and Containment Systems for Ignitable Liquids*.

2.2.5 Loading and Unloading Stations

2.2.5.1 Locate centralized, multi vehicle railcar or truck stations for shipping/receiving large volumes of liquid at the perimeter of the site, close to an access gate to minimize travel through and exposure to/from important facilities.

2.2.5.2 Provide separation distance for loading/unloading stations according to Data Sheet 7-88, *Outdoor Ignitable Liquid Storage Tanks*. For cases where the separation distance cannot be provided, see Section 2.4.8 for protection guidance.

2.2.5.3 Consider large loading/unloading areas that exceed the capacity of simple areas (i.e., more than two railcars or four trucks of loading/unloading bays) as process units. Refer to Section 2.2.1 for spacing guidance.

2.2.5.4 Arrange loading and unloading stations in accordance with Data Sheet 7-32, *Ignitable Liquid Operations*.

2.2.6 Cable Trays and Safety Critical Cabling

2.2.6.1 Install and protect cable trays in accordance with Data Sheet 5-31, *Cables and Bus Bars* and the following:

A. Do not locate cable trays at the bottom level of a pipe rack.

B. Arrange cable trays horizontally rather than stacking them vertically.

2.2.6.2 Provide the following for safety critical cables. Examples of safety critical cables include those that control safety instrumented system (SIS) valves that do not fail safe, control remotely operated isolation valves, and supply DC power to emergency lubrication pumps.

A. Identify safety critical cables and the potential for fire exposure to these cables as part of a process hazard analysis.

B. Route the cables to minimize exposure to potential gas jet, 3D spills, or ignitable liquid pool fires.

C. Provide a 1-hour fire-rated, FM Approved fire wrap for critical cables required for safe shutdown that cannot be routed away from ignitable liquid exposures. Provide the fire wrap for 20 ft (6.1 m) beyond the exposed area.

2.3 Occupancy

2.3.1 In-Process Ignitable Liquid Storage

2.3.1.1 Limit the amount of in-process storage of ignitable liquids in portable containers to the amount needed in 24 hours or less.

2.3.1.2 Locate and protect the storage of ignitable liquids in portable containers in accordance with Data Sheet 7-29, *Ignitable Liquid Storage in Portable Containers*.

2.3.2 Mechanical Ventilation

2.3.2.1 In buildings and other enclosures where ignitable liquids are processed, provide mechanical ventilation in accordance with Data Sheet 7-32, *Ignitable Liquid Operations*.

2.3.2.1.1 When normally closed vessels or systems are present, non-continuous ventilation is acceptable, provided that ventilation can be activated upon flammable vapors detection (25% of the LEL) and the area is electrically rated in accordance with Data Sheet 5-1, *Electrical Equipment in Hazardous (Classified) Locations*.

2.3.2.1.2 Natural ventilation is acceptable where more than 25% of the enclosure surface area is open to the outside and the openings are located at floor level. For processes involving buoyant gases, such as hydrogen or methane, ensure roof or high elevation ventilation is provided.

2.4 Protection

The recommendations in this section apply to all areas handling ignitable liquids or liquified flammable gas.

2.4.1 General

2.4.1.1 Select and design a sprinkler protection system (automatic wet, preaction, deluge and/or directional water spray) for a process unit or equipment considering the hazard being protected, the potential release scenario, and its location, either indoors or outdoors. See Sections 2.4.2, 2.4.3 and 2.4.4 for additional guidance on indoor, outdoor and directional water spray systems, respectively.

2.4.1.2 For area protection systems, where the distance between a solid floor elevation and area-level protection exceeds 30 ft (9.1 m), additional local directional water spray protection may be needed for important vessels and equipment that are exposed to extended 3D spill or pool fires.

2.4.1.3 Install water spray systems in accordance with Data Sheet 4-1N, *Fixed Water Spray Systems for Fire Protection* and Section 2.4.4.

2.4.1.4 Install automatic sprinkler systems in accordance with Data Sheet 2-0, *Installation Guidelines for Automatic Sprinklers*, and the following considerations:

A. Provide a maximum coverage of 100 ft^2 (9.3 m^2) per sprinkler.

B. Arrange sprinklers with a maximum on-line spacing of 10 ft (3 m). A variation of 1 ft (0.3 m) is permitted on either dimension to avoid obstructions by structural elements.

C. Locate automatic sprinkler control valves outside of the expected fire area. Where it is not practical, provide fire resistance protected areas to ensure valves can easily be accessed and operated.

2.4.1.5 Provide sprinklers, passive (fireproofing) or active (directional water spray) protection below obstructions, inside skirts, equipment and equipment supports exposed to ignitable liquid pool fires. Refer to the sections below for design specifications.

- Process vessels protection/water spray: Section 2.4.4
- Steel protection (passive and active): Section 2.4.5
- Skirts protection: Section 2.4.6
- Other equipment including pumps: Section 2.4.9

2.4.1.5.1 Provide protection below any obstruction to water distribution that exceeds 3 ft (0.9 m) in width or diameter and 10 ft^2 (0.9 m^2) in area. Important structural members or equipment below obstructions may need additional passive or active protection against flame impingement.

2.4.1.5.2 Design sprinklers located below obstructions to provide at least 15 gpm (57 L/min) and maintain a minimum sprinkler discharge pressure of at least 7 psi (0.5 bar).

2.4.1.5.3 Install sprinklers below vessels on a maximum 50 ft^2 (4.6 m^2) spacing.

2.4.1.6 Actuate deluge or preaction systems using pilot sprinklers, flame detection, or heat detection devices installed in accordance with Data Sheet 5-48, *Automatic Fire Detection* and provide spacing according to Data Sheet 2-0, *Installation Guidelines for Automatic Sprinklers*. Design detection systems to transmit an alarm to a constantly attended location, preferably the process control room.

2.4.1.6.1 In addition to automatic activation, provide capabilities for remote manual activation, preferably in the process control room or similar areas that will be accessible in the event of a fire.

2.4.1.7 Where deluge systems are provided, determine the demand flow based on the largest number of systems expected to operate. Assume simultaneous operation of all systems in the room or building within a 50 ft (15 m) distance of the expected fire spread, as defined by containment and drainage systems.

Where pneumatic, fixed temperature/rate-of-rise-type heat actuated devices (HADs) are used to actuate deluge systems, increase this distance to 100 ft (30.5 m). Refer to Section 3.2.2.2 for additional information.

2.4.1.7.1 Ensure the flow of all local sprinklers is included (e.g., protection of equipment or structural steel, beneath vessels or other obstructions, inside skirts, etc.).

2.4.1.8 In addition to the system water demands required for operation, include any hose streams likely to be used, as well as other water demands expected during a fire emergency, to determine the total water demand. At a minimum, provide a hose stream allowance of 500 gpm (1900 L/min).

2.4.1.9 Provide a water supply capable of maintaining discharge and pressure requirements until the ignitable liquid flow can be shut off and the area drained, or until the ignitable liquid is consumed.

2.4.1.9.1 Provide a minimum water duration of 2 hours or the expected fire duration, whichever is greater.

2.4.1.10 Arrange fire protection equipment and piping located in areas exposed to earthquakes in accordance with Data Sheet 2-8, *Earthquake Protection for Water-Based Fire Protection Systems*.

2.4.2 Indoor Protection

2.4.2.1 Install automatic wet, preaction or deluge sprinkler systems when the occupancy to be protected is located inside a building.

2.4.2.1.1 A dry sprinkler system is acceptable only if the operating area is equal to the room's footprint as defined by its noncombustible walls and any solid intermediate floors or ceilings, and water is delivered to the most remote sprinkler within 60 seconds of system activation.

2.4.2.2 Provide sprinkler area coverage below the roof and below solid and open-grated intermediate operating levels. Design the systems for an operating area of 10,000 ft^2 at each level and the densities specified below (see Figures 2.4.2.2-1 and 2.4.2.2-2):

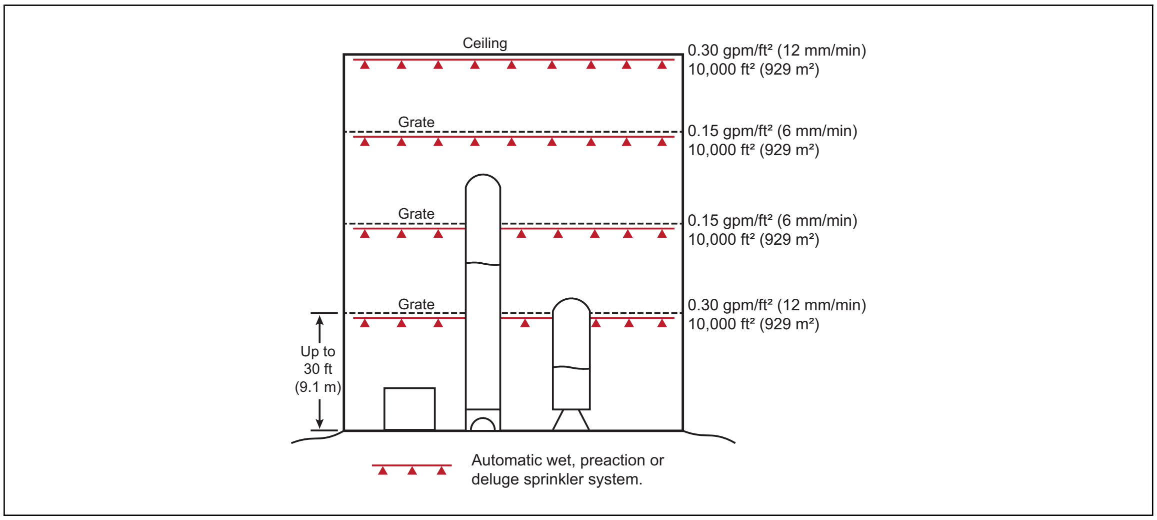

Fig. 2.4.2.2-1. Indoor example of fire protection with grated floors

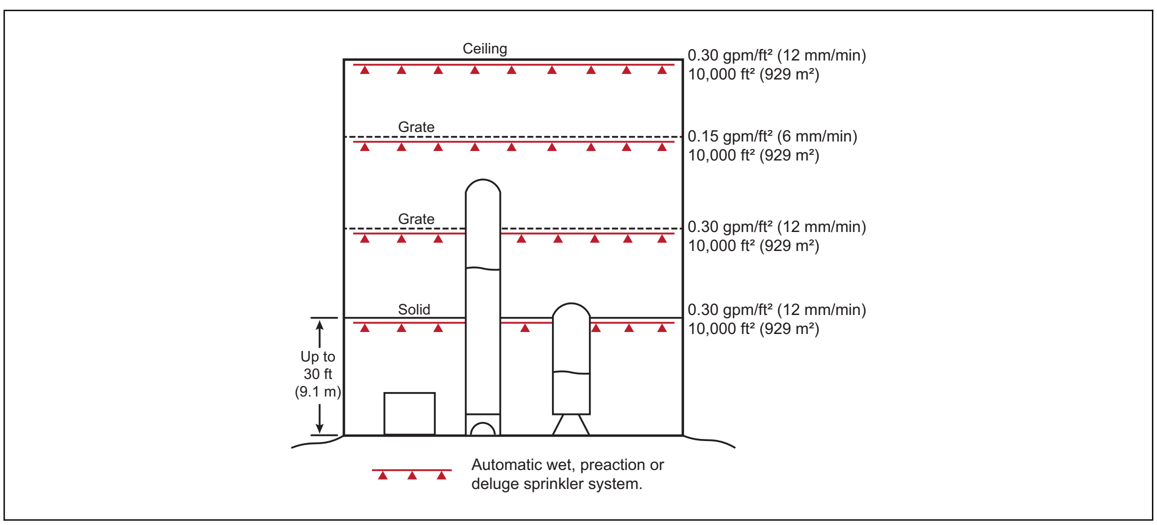

Fig. 2.4.2.2-2. Indoor example of fire protection with grated and solid floors

A. Provide 0.3 gpm/ft^2 (12 mm/min) (K ≥ 5.6 [80]) at each protection level above a solid floor or solid intermediate level.

B. Provide 0.3 gpm/ft^2 (12 mm/min) (K ≥ 5.6 [80]) at the roof and under solid mezzanine levels.

C. Provide 0.15 gpm/ft^2 (6 mm/min) (K ≥ 5.6 [80]) under open-grated, intermediate mezzanine levels.

D. Provide protection below obstructions, inside skirts, and around equipment and equipment supports exposed to ignitable liquid pool fires, according to Section 2.4.1.5.

2.4.2.2.1 For cases where wet or preaction sprinkler systems are used over a grated floor to protect a defined pool fire area that can be contained or provided with emergency drainage, install sprinklers at the intermediate levels with a density of 0.3 gpm/ft^2 (12 mm/min) over a 2,000 ft^2 (190 m^2) demand area, as shown in Figure 2.4.2.2.1.

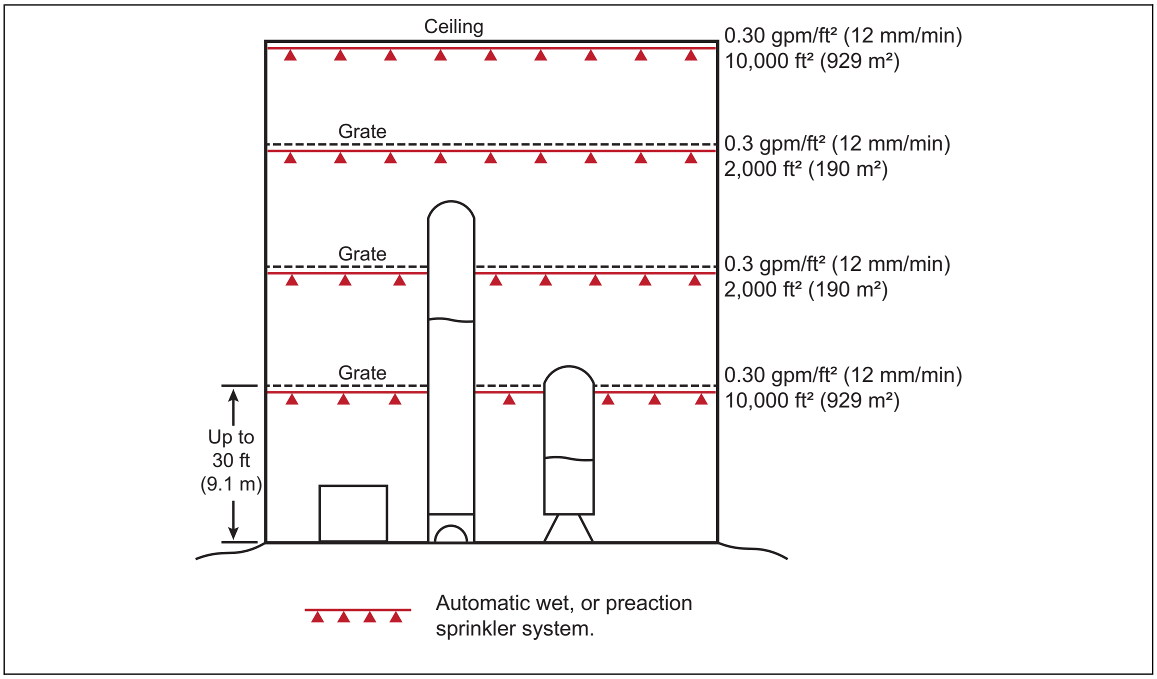

Fig. 2.4.2.2.1. Indoor example of wet or preaction fire protection with grated floors and contained fire area

2.4.2.3 Use high temperature rated, standard response sprinklers or pilot sprinklers where the room or building footprint exceeds 10,000 ft^2 (929 m^2). For smaller areas, use either ordinary or high temperature rated sprinklers or pilot sprinklers.

2.4.2.4 Where wet or preaction systems are provided, design the demand for simultaneous operation of all ceiling and intermediate level sprinklers over the areas listed below. Include the flow for all local sprinklers (e.g., protection of equipment or structural steel, beneath vessels or other obstructions, inside skirts, etc.).

A. Where intermediate floors are grated or not liquid tight, design for a 10,000 ft^2 (929 m^2) operating area on every interconnected floor (Figure 2.4.2.4-1), except for the cases covered in 2.4.2.2.1, where a reduction of 2000 ft^2 (190 m^2) can be applied.

B. Where intermediate floors are solid and liquid tight, design for a 10,000 ft^2 (929 m^2) operating area on one level. See Figure 2.4.2.4-2.

C. Where large (≥400 ft^2 [37 m^2]), liquid tight openings exist on solid floors, design for a 10,000 ft^2 (929 m^2) operating area on the level of fire origin and at the roof level. In addition, design for sprinklers within 20 ft (6.1 m) of each opening to operate on all other connected levels. See Figure 2.4.2.4-3.

D. Where small (<400 ft^2 [37 m^2]), liquid tight openings exist on solid floors, design for a 10,000 ft^2 (929 m^2) operating area on the level of fire origin and 4,000 ft^2 (370 m^2) at the roof level. In addition, design for sprinklers within 20 ft (6.1 m) of each opening to operate on all other connected levels. See Figure 2.4.2.4-4.

E. Where small (less than 6 in. [15 cm] wide), liquid-tight openings exist around vessels, adjusting for the scattered opening of individual sprinklers beyond that stated above is not necessary.

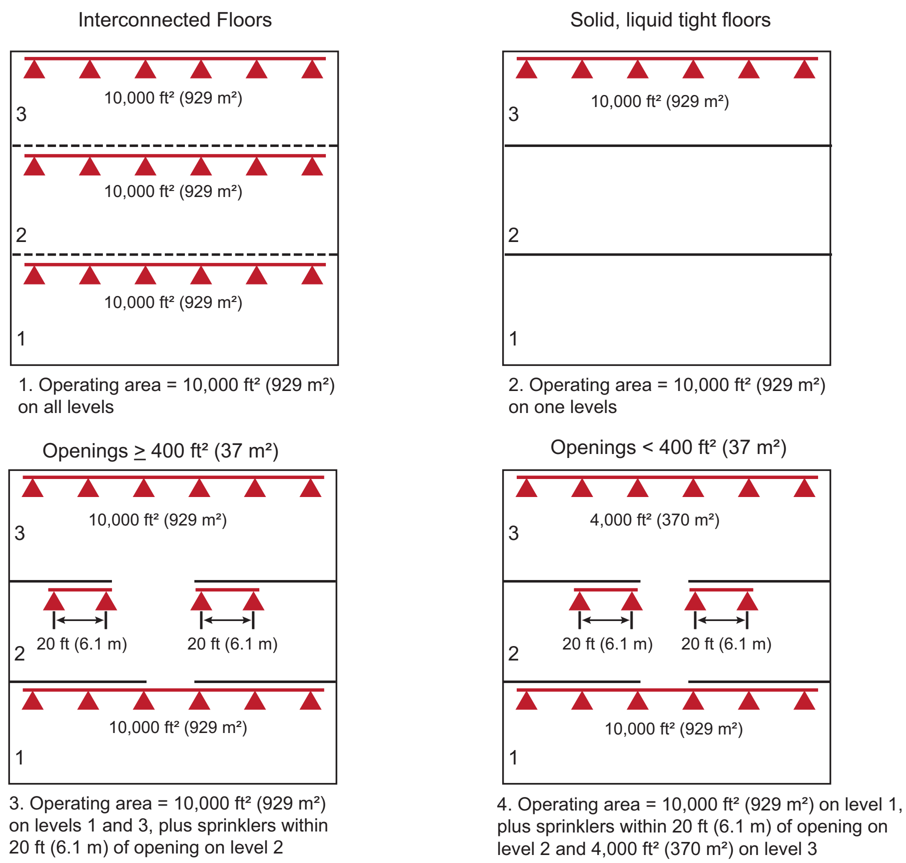

Fig. 2.4.2.4.(1-4). Sprinkler operating areas for indoor chemical plants

2.4.3 Outdoor Protection

Fire protection for outdoor process structures must be carefully designed with sufficient water delivery throughout the structure. To achieve this coverage, deluge and directional water spray systems are typically used.

2.4.3.1 Install automatic deluge and/or directional water spray when the occupancy is located in open process structures or outdoors. Do not use dry pipe systems.

2.4.3.2 Provide protection for all important outdoor process structures and equipment wherever ignitable liquids can flow, following a release. Extend the protection at least 20 ft (6.1 m) beyond the limits of the expected ignitable liquid pool. Base the extent of protection on the layout of the process structure, the presence of features such as containment and emergency drainage, and the location of equipment containing ignitable liquids.

2.4.3.3 Design the deluge system to provide 0.3 gpm/ft^2 (12 mm/min) (K ≥ 5.6 [80]) over an operating area of 10,000 ft^2 (929 m^2) or the entire area per required protection level (Figure 2.4.3.3-1) and the following considerations:

A. Evaluate the appropriate protection for areas with ignitable liquids in vessels or specific types of equipment located more than 30 ft (9.1 m) above ground level. When equipment with significant liquid holdups, high value and long lead times are present above this height, a combination of area and water spray sprinkler systems may be more effective (see Figure 2.4.3.3-2). For additional guidance, refer to Sections 2.4.4 and 3.2.4.

B. Provide water spray protection to a height at least 30 ft (9.1 m) above where an ignitable liquid pool fire may develop or 10 ft (3 m) above credible points of liquid release, whichever is higher.

C. Do not consider ignitable liquid holdup in distillation column trays when determining normal ignitable liquid levels.

D. Provide protection below obstructions, inside skirts, equipment and equipment supports exposed to ignitable liquid pool fires according to Section 2.4.1.5.

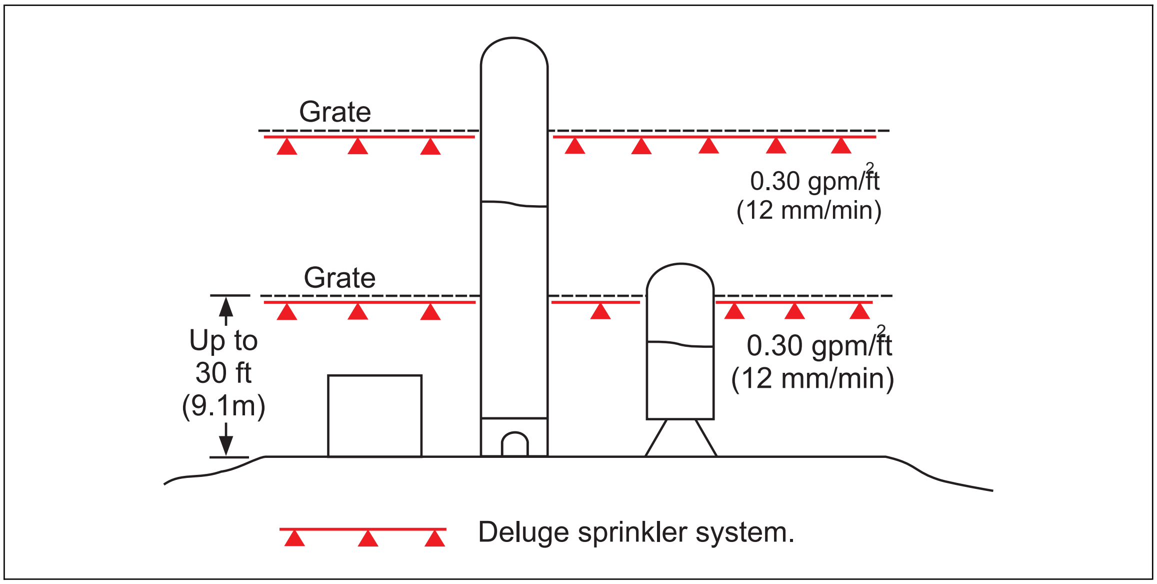

Fig. 2.4.3.3-1. Example of area-level deluge protection

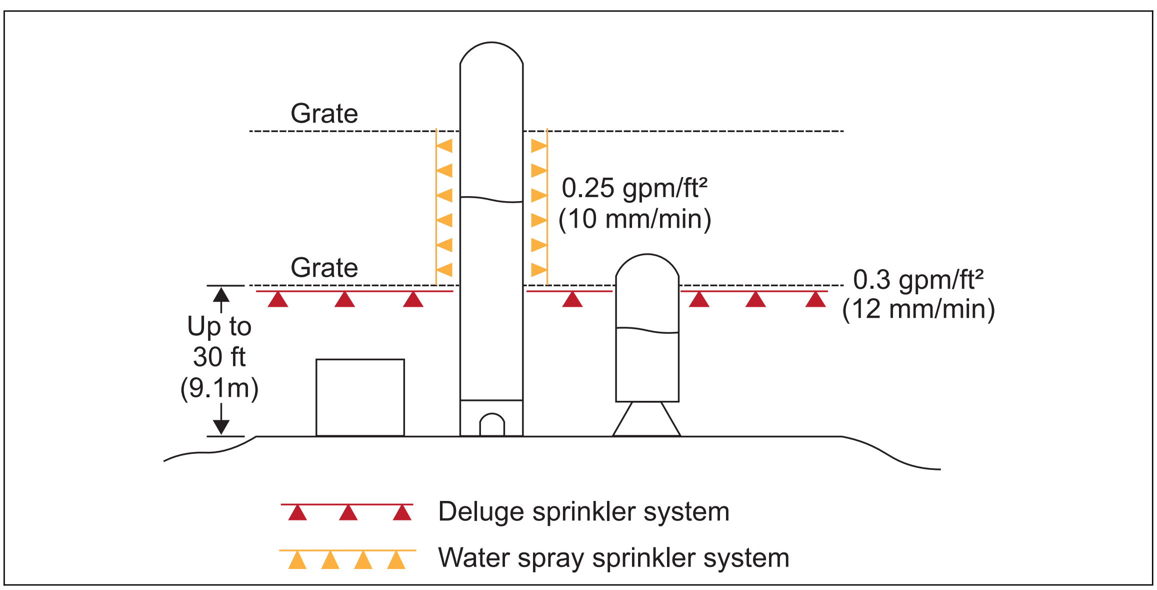

Fig. 2.4.3.3-2. Combined area and water spray sprinkler system

2.4.3.4 For process structures involving water-miscible ignitable liquids, the following protection scheme may be used as an alternative to that in Section 2.4.3.3. See Figure 2.4.3.4 for an example.

A. Install a single level of area deluge protection below the first mezzanine level at a density of 0.4 gpm/ft^2 (16 mm/min).

B. Provide local water spray or fireproofing according to Sections 2.4.4 and 2.4.5.2, respectively, over equipment located above the area protection level and exposed to three-dimensional (3D) spill fires.

See Appendix A for a definition and additional information on water-miscible liquids.

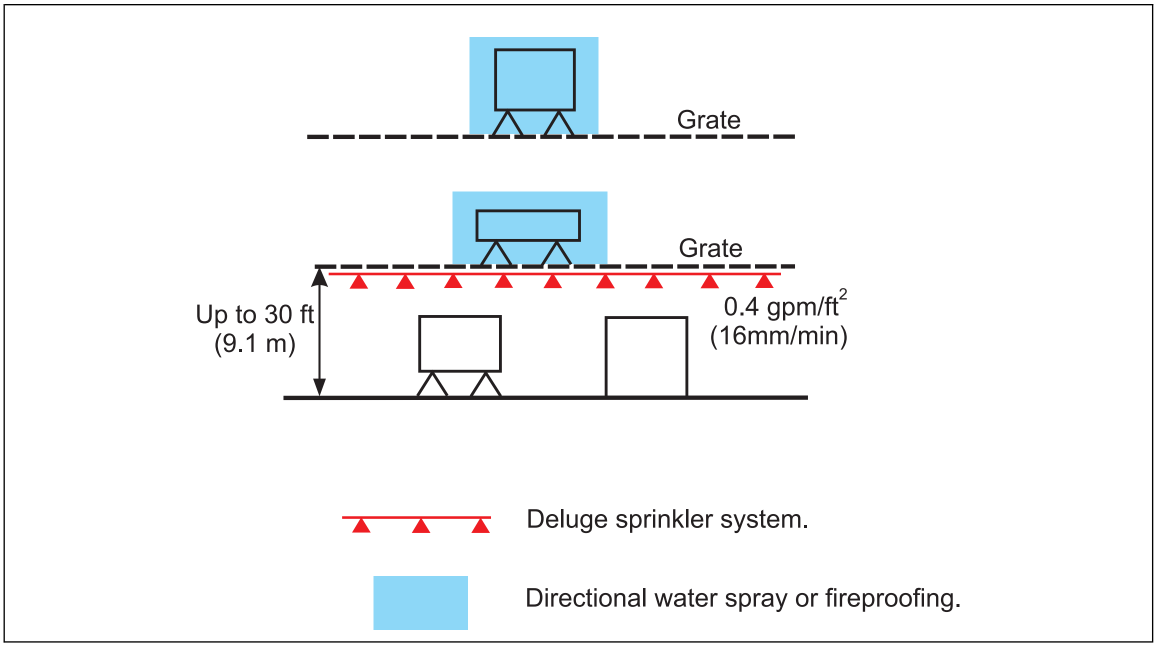

Fig. 2.4.3.4. Single deluge protection level for outdoor process structures with water-miscible ignitable liquids

2.4.4 Directional Water Spray Protection of Process Vessels and Similar Structures.

2.4.4.1 Provide directional water spray coverage for the entire protected surface, using direct impingement or rundown design.

2.4.4.2 Design systems to provide 0.25 gpm/ft^2 (10 mm/min).

A. For indoor locations, provide the application rate listed above at a minimum discharge pressure of 20 psi (1.4 bar), but not less than the minimum pressure specified by the directional water spray nozzle manufacturer's data.

B. For outdoor locations, provide the application rate listed above at a minimum discharge pressure of 30 psi (2.2 bar) for nozzles less than 0.5 in. (12 mm) in diameter. For nozzles equal to or greater than 0.5 in. (12 mm) in diameter, provide a minimum discharge pressure of 20 psi (1.4 bar).

2.4.4.3 Arrange direct impingement system nozzles with proper radial and axial spacing distances, per the nozzle manufacturer's spray profiles design tables and figures.

2.4.4.4 For water spray systems using nozzles of less than 1/2 in. (12 mm) orifice, provide strainers designed to remove particles less than the smallest sprinkler orifice used in the design.

2.4.4.5 Arrange rundown system nozzles as follows:

A. Horizontal spacing for overlapping spray patterns from adjacent nozzles based on radial spray distances, per the nozzle manufacturer's design tables and figures

B. Vertical spacing of no more than 12 ft (3.7 m) between adjacent levels of nozzles.

C. Where obstructions to rundown are present, provide nozzles below the obstructions to cover the shielded areas.

2.4.4.6 Actuate directional water spray systems using pilot sprinklers, flame detection, or heat detection devices installed in accordance with Data Sheet 5-48, *Automatic Fire Detection*. Design any installed detection systems to transmit an alarm to a constantly attended location, preferably in the process control room.

2.4.4.7 In addition to automatic activation of directional water spray systems, provide capabilities for remote manual activation, preferably in the process control room or similar areas that will be accessible in the event of a fire.

2.4.5 Steel Protection

2.4.5.1 General

2.4.5.1.1 Provide passive or active steel protection according to Sections 2.4.5.2 and 2.4.5.3, respectively, for process structures, vessels, equipment and supports where the potential of long-duration pool, 3D spills or jet fires exist. Protection is justified for the following cases:

A. Protection is required by a fire hazard assessment where fire scenarios, vessels holdup and potential release rates have been evaluated. See Section 3.2.3 for additional information.

B. The members are load-bearing structures.

C. The members support structures or equipment are critical to the facility’s operation.

D. The steel can be directly exposed to an ignitable liquid 3D spill, pool or jet fire. In general, the structural element must be surrounded by the spill or pool fire for an extended duration or have direct contact with a jet fire flame to necessitate protection.

2.4.5.1.2 Where required, install active or passive protection to a height of at least 10 ft (3 m) above credible release points or up to 30 ft (9.1 m) above levels where a pool fire can occur.

2.4.5.2 Passive Protection (Fireproofing)

2.4.5.2.1 Where passive steel protection is needed according to Section 2.4.5.1.1, test and install insulation materials or assembly systems to ensure adequacy for the intended application, fire-resistance duration, and environmental conditions. Consider a minimum two-hour hydrocarbon fire exposure or the expected fire duration, whichever is greater. See Section 3.2.3 and Data Sheet 1-21, *Fire Resistance of Building Assemblies*, for additional information.

2.4.5.2.2 Install fireproofing according to manufacturer’s recommendations to prevent corrosion under fireproofing (CUF), including recommended covers and seals for insulation and protective coatings/paints for the structure/equipment.

2.4.5.2.3 Include corrosion under fireproofing (CUF) on the asset integrity program. See Data Sheet 9-0, *Asset Integrity*, for additional guidance on developing an asset integrity program and Data Sheet 12-2, *Vessels and Piping*, for additional information on CUF.

2.4.5.3 Active Fire Protection. Structural Steel

2.4.5.3.1 Vertical Elements

2.4.5.3.1.1 Protect vertical elements using automatic sidewall sprinklers or directional water spray protection as shown in Figure 2.4.5.3.1.1, applying direct impingement or rundown design. The black outline in the top view shows the reentrant space (web and flanges) that must be wetted for the column to be cooled effectively.

2.4.5.3.1.2 Install sprinkler nozzles on a maximum of 12 ft (3.7 m) centers, staggered on alternate sides of the column, such that a separation of 24 ft (7.3 m) exists between nozzles on one side of the column. Provide a minimum of 0.25 gpm/ft^2 (10 mm/min) over the wetted area of one side of the column for the 24 ft (7.3 m) length. Consider the wetted area to be the surface area on the three sides of the reentrant space formed by the column web and flanges.

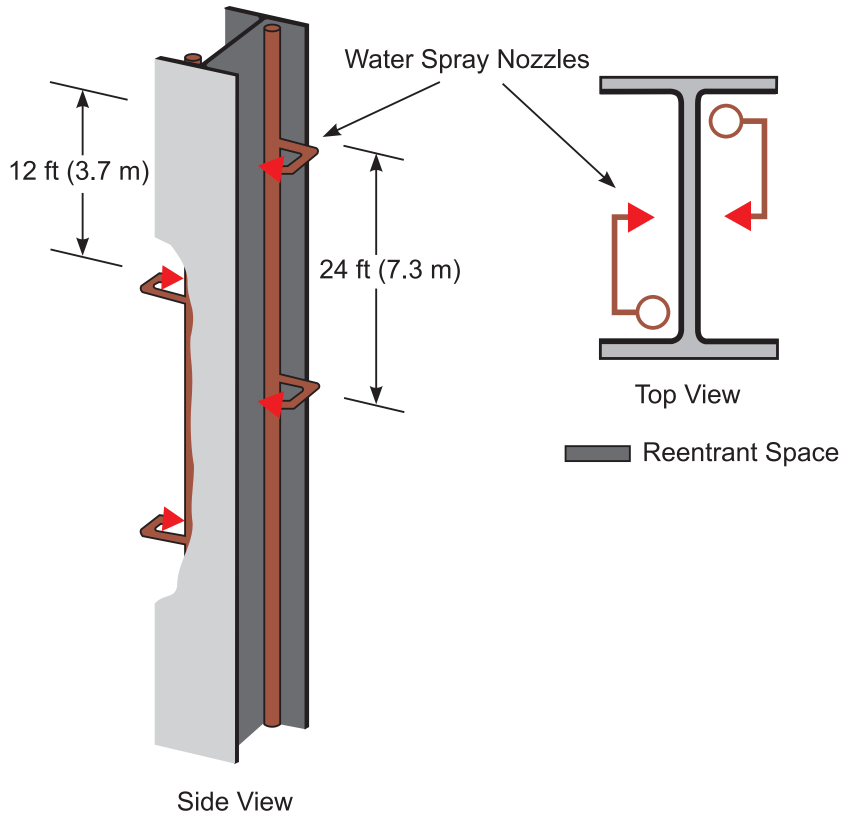

Fig. 2.4.5.3.1.1. Water spray protection for steel columns

2.4.5.3.2 Horizontal Elements

2.4.5.3.2.1 Where area protection is not installed below intermediate operating levels, provide protection for critical horizontal members that could be directly exposed to a 3D spill fire (i.e., immersed within the fire), or within 30 ft (9.1 m) above a pool fire.

2.4.5.3.2.2 Where area protection is provided under a ceiling, canopy, or mezzanine level per Sections 2.4.2 (indoor locations) or 2.4.3 (outdoor locations), additional local water spray protection is not necessary for the steel at that level.

2.4.5.3.2.3 Provide water spray protection for the exposed members with a density of 0.1 gpm/ft^2 (4mm/min). See Section 3.2.4.1 for additional design information.

2.4.6 Interior Skirt Protection

2.4.6.1 Provide protection inside the skirt of columns or similar self-supporting vessels, where the potential of an ignitable liquid release exists inside the skirt, such as cases where valves or flanged connections are present (see Figures 2.4.6.1-1 and 2.4.6.2-2), or where ignitable liquids could enter the skirt enclosure through skirt openings following an external release.

2.4.6.2 Where protection inside the skirts of columns or similar self-supporting vessels is needed according to Section 2.4.6.1, provide one of the following:

A. Passive fire protection in accordance with Section 2.4.5.2.

B. Automatic sprinklers or directional water spray protection installed within the skirt, designed to provide 0.25 gpm/ft^2 (10 mm/min). Install sprinklers on a maximum 50 ft^2 (4.6 m^2) spacing. See Figure 2.4.6.2.

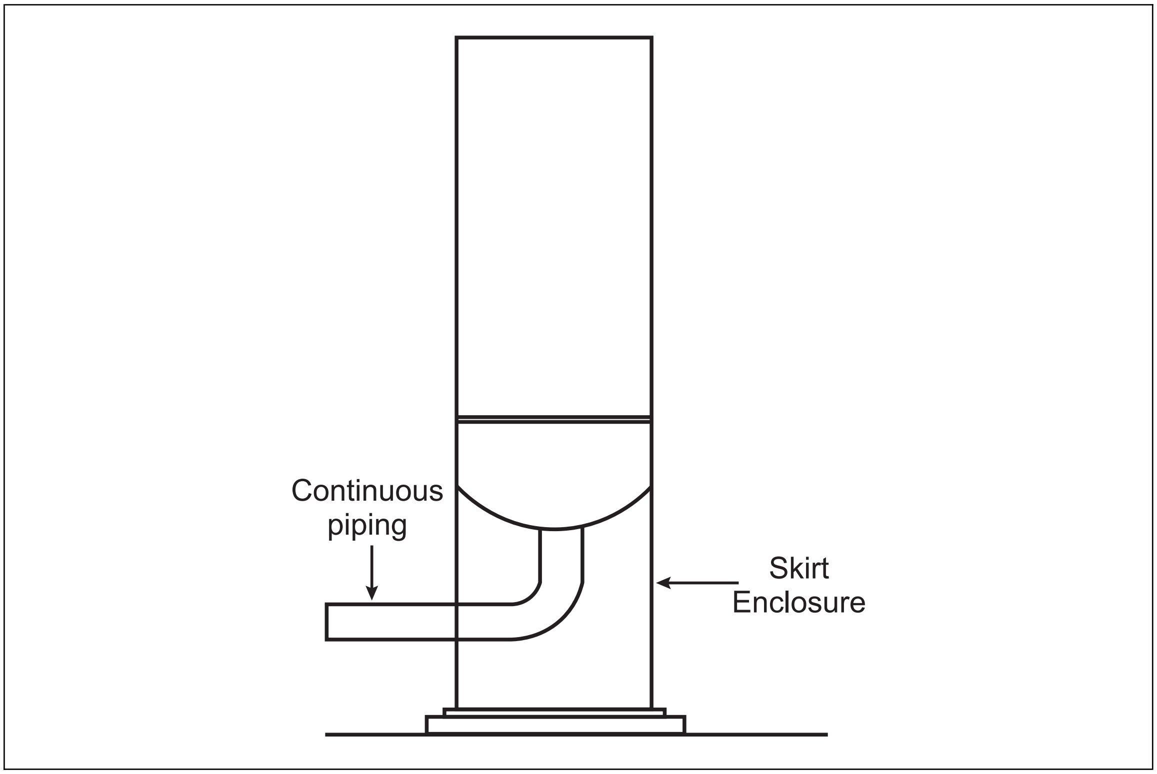

Fig. 2.4.6.1-1. Cases where protection is not required

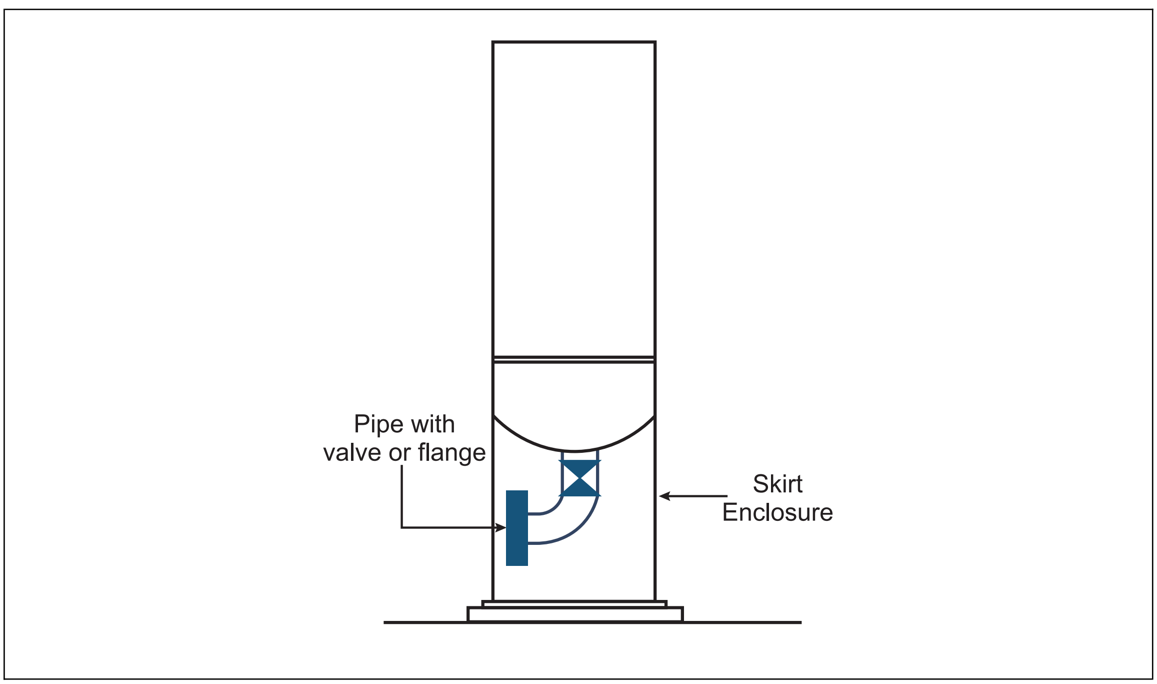

Fig. 2.4.6.1-2. Cases where protection is required

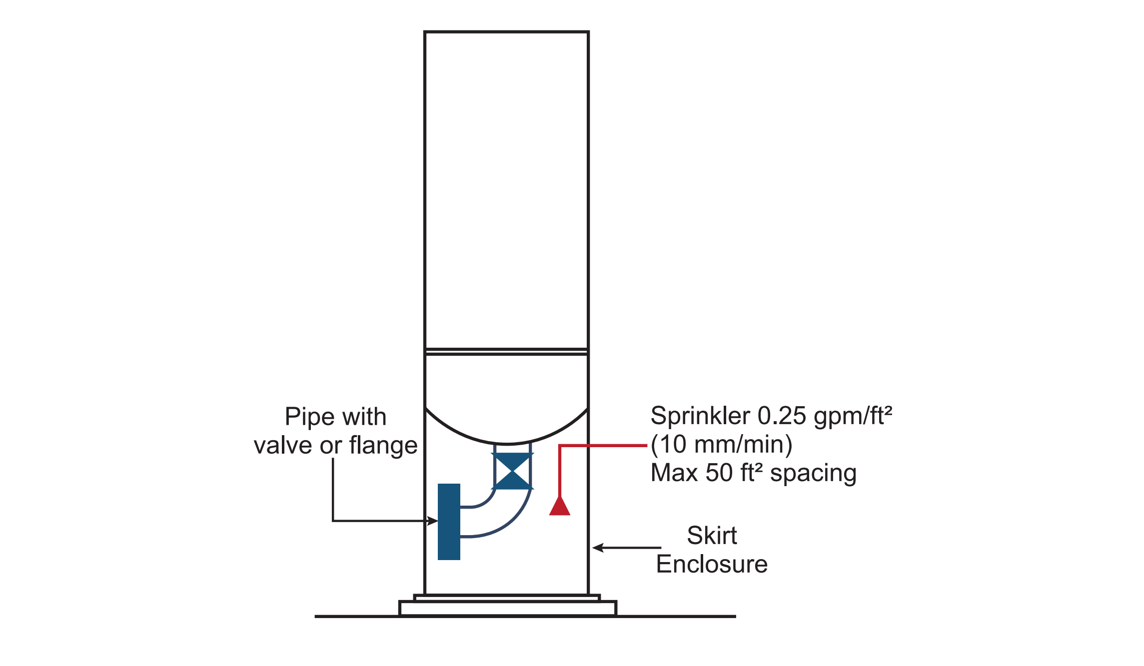

Fig. 2.4.6.2. Interior skirt sprinkler protection

2.4.7 Pipe Rack Protection

2.4.7.1 General

2.4.7.1.1 Provide deluge or water spray protection for multi-tier, ignitable liquid pipe racks located within the process structure and at least 20 ft (6.1 m) beyond its limits. See Figure 2.4.7.1.1 for some examples. Where a pipe rack enters an enclosed building, protection for the pipe rack is not needed unless an ignitable liquid release within the building will expose the exterior pipe rack.

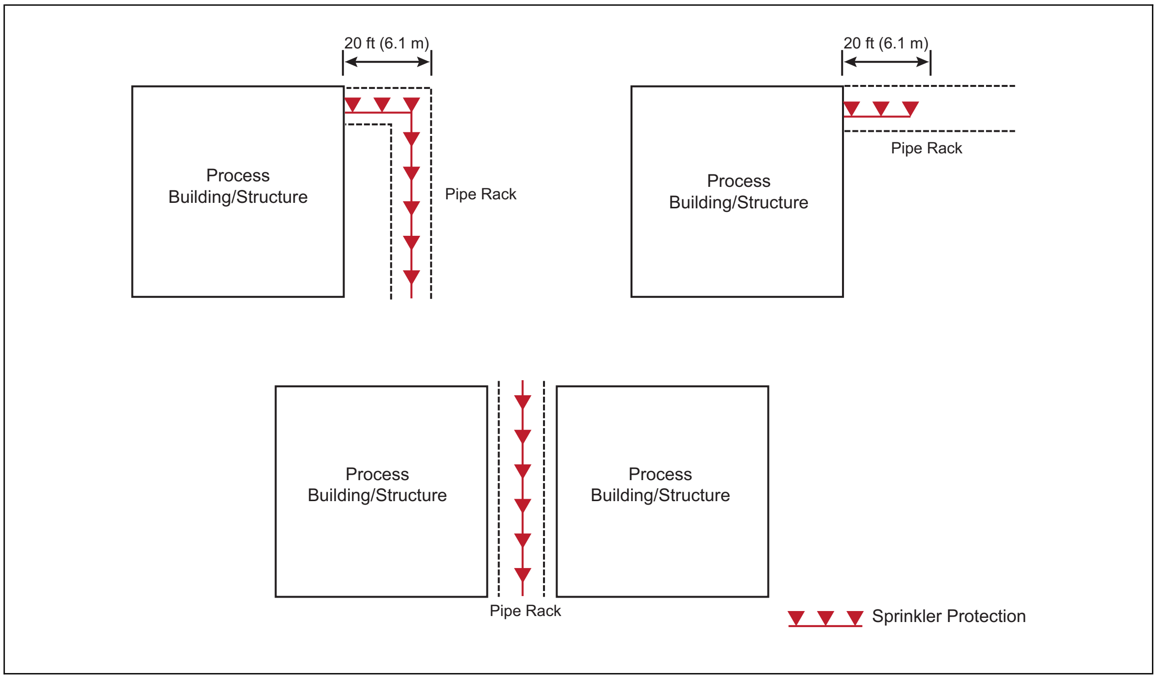

Fig. 2.4.7.1.1. Examples of protection location for ignitable liquid pipe racks outside of process buildings or structures

2.4.7.1.2 Install sprinklers or nozzles below the pipe rack so discharge is directed vertically upward to the underside of the rack. Space sprinklers or nozzles on a maximum head spacing of 10 ft (3 m) centers.

2.4.7.1.3 Design for a single pipe rack level to provide a density of 0.25 gpm/ft^2 (10 mm/min). For a two-pipe rack level structure, design the lower tier to provide a density of 0.25 gpm/ft^2 (10 mm/min) and the upper tier with 0.15 gpm/ft^2 (6 mm/min). Install this protection up to 30 ft (9.1 m) above levels where a pool fire can occur. See Figure 2.4.7.1.3.

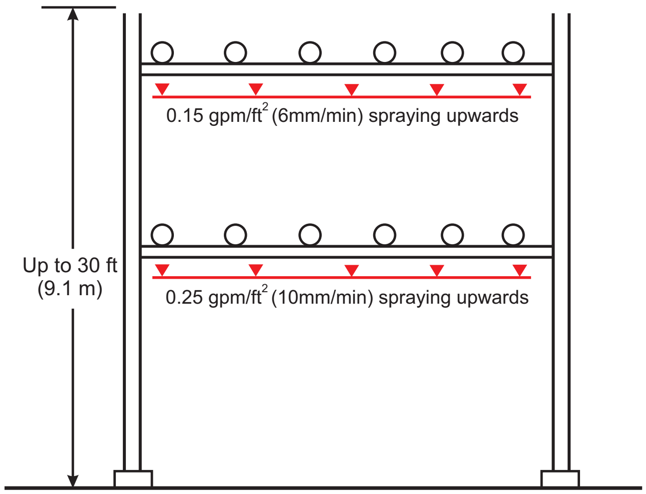

Fig. 2.4.7.1.3. Fire protection of pipe racks

2.4.7.1.4 For pipe racks with more than two levels, install additional levels of sprinklers or nozzles below the first tier and alternate tiers above according to Figure 2.4.7.1.4. Design to provide 0.25 gpm/ft^2 (10 mm/min) at the first tier and 0.15 gpm/ft^2 (6 mm/min) at the alternate tiers. Install this protection up to 30 ft (9.1 m) above levels where a pool fire can occur.

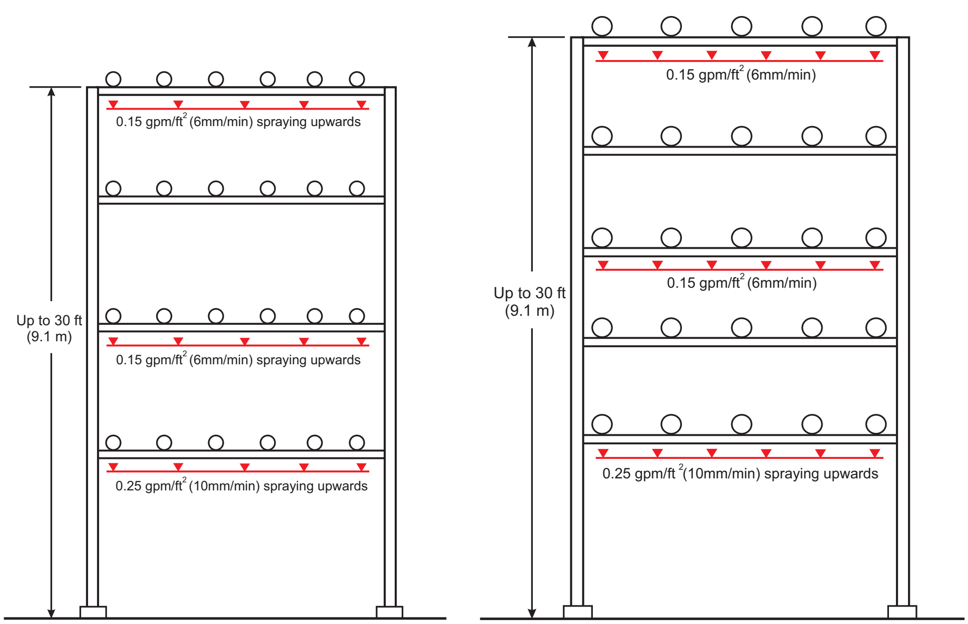

Fig. 2.4.7.1.4. Fire protection of multiple level pipe racks

2.4.7.1.5 Provide protection to pipe rack structural steel supports that are expected to be exposed to 3D spill, jet or pool fires according to Section 2.4.5.

2.4.7.2 Indoor Pipe Racks

2.4.7.2.1 Provide sprinkler area protection per Section 2.4.2 and pipe rack protection per Section 2.4.7.1.4 when three or more levels of pipe rack are present in the area.

2.4.7.2.2 Pipe racks with one or two levels of piping can be exempt from providing local water-spray if adequate ceiling protection is provided. Install additional protection for obstructions to water distributions that exceed 3 ft (0.9 m) in width or diameter and 10 ft^2 (0.9 m^2) in area, according to Section 2.4.1.5.

2.4.8 Loading/Unloading Stations

2.4.8.1 For loading and unloading stations where the separation distance cannot be provided according to Section 2.2.5.2, protect it per the guidance in this Data Sheet, according to the production unit.

2.4.8.2 Where the space separation between loading/unloading stations and exposed buildings of combustible construction is inadequate, sprinkler protection can be provided to the loading/unloading station, the exposed buildings, or both.

2.4.8.3 Consider large loading/unloading areas that exceed the capacity of simple areas (i.e., more than two railcar or four truck loading/unloading bays) as process units. Protect them according to Section 2.4.

2.4.9 Protection of Other Equipment

2.4.9.1 Pumps

2.4.9.1.1 Provide fire protection for pumps that are important to continue operations, high-value or long-lead-time pumps, or those exposed to pool fire engulfment. Where needed, protect pumps as follows:

A. Provide water spray or automatic sprinklers designed to provide 0.5 gpm/ft^2 (20 mm/min).

B. Extend the coverage to protect the pump shaft and seals, as well as high-value or long-lead-time drivers associated with the pump.

C. Locate protection within 2 ft (0.6 m) vertically of the pump.

2.4.9.2 Fin-Fan Coolers

2.4.9.2.1 Provide fire protection for fin-fan coolers that are critical to operations, or that may expose other critical equipment, such as:

A. Fin-fan coolers used to cool ignitable liquids.

B. Fin-fan coolers used to condense flammable gases to liquids.

C. Fin-fan coolers that are potentially exposed to fire from adjacent process equipment.

2.4.9.2.2 Protect fin-fan coolers as follows:

A. Provide directional water spray designed to provide 0.25 gpm/ft^2 (10 mm/min) over the area of the tubes.

B. Direct the water spray upward to impinge on the air-fan tubes.

C. For forced-draft fin-fan coolers, locate the water spray nozzles in the plenum between the tubes and the fan casing (see Figure 2.4.9.2.2).

D. Interlock the fan motor to shut down upon activation of the water spray.

E. If applicable, provide steel protection for the cooler’s vertical supports (refer to Section 2.4.5).

2.4.10 Manual Firefighting

This section provides guidance for the design and location of systems intended for manual firefighting of outdoor processes at chemical plants.

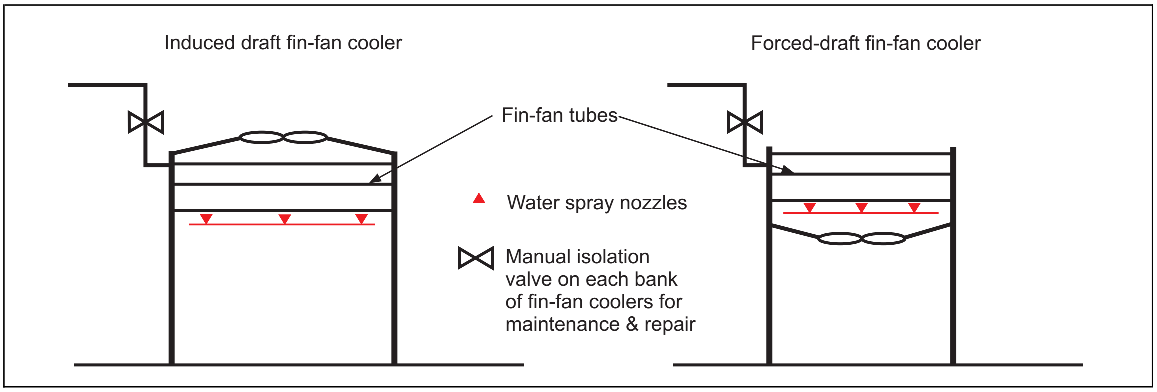

Fig. 2.4.9.2.2. Fire protection of fin-fan coolers

2.4.10.1 General

2.4.10.1.1 Do not locate monitors, hydrants and hose reels in areas that are designated as spill collection areas (i.e., tank dikes, spill curbing, drainage swales, etc.).

2.4.10.1.2 Ensure adequate water supply is provided for manual firefighting activities, independent of local sprinkler/water spray systems. Demand calculations should consider the pressure and flow requirements for hoses, monitor nozzles, hydrants, etc.

2.4.10.1.3 Ensure a minimum two-hour water duration is provided.

2.4.10.2 Monitors

2.4.10.2.1 Provide monitor nozzles for equipment and vessels with large holdups of ignitable liquids/ flammable gases or when cooling may be required.

2.4.10.2.2 Arrange monitor nozzles to ensure all areas of the process unit can be reached by a minimum of two nozzles. Ensure no obstructions can block the water stream coverage of the monitors (i.e., pipes, cable trays, large vessels, etc.).

2.4.10.2.3 Confirm monitor nozzles operate at a residual pressure of no less than 100 psi (6.9 bar). Ensure they are hydraulically balanced with other system demands. In lieu of a hose stream allowance, include the simultaneous operation of two monitor nozzles at their maximum rated capacity, but not less than 500 gpm (1900 L/min).

2.4.10.2.4 Consider wind effects during design and location of the monitors.

2.4.10.3 Hydrants and Hose Reels

2.4.10.3.1 Locate hydrants and hoses at perimeter roads, accessible to fire trucks. Consider a maximum spacing between hydrants of 300 ft (90 m) in outside process areas where equipment is present.

2.4.10.3.2 When hydrants are located in process areas, position them so that any portion of the process unit can be reached from at least two opposite directions, given 250 ft (76 m) of hose lines.

2.4.10.3.3 Provide a normal flow of 750 gpm (2840 L/min) to each hydrant when using three 2½ in. (63 mm) hose lines. This flow rate represents a discharge of 250 gpm (960 L/min) through each 2½ in. house outlet, considering a total head loss at the hydrant not exceeding 2 psi (0.14 bar).

2.4.10.3.4 Ensure hydrant connections are compatible with local and mutual aid mobile firefighting equipment.

2.4.10.3.5 Provide a minimum of two hose reels located at opposite sides in a process unit. Hose reels supplied from a fire main riser should also be provided at all important platforms of major elevated structures such as catalytic cracking units.

2.4.11 Foam-Water Sprinkler Systems

2.4.11.1 If a foam-water system is used, design the sprinkler system in accordance with the applicable section of this data sheet or the FM Approval listing, whichever has the larger density, over the full demand area.

2.4.11.2 If a compressed air foam (CAF) system is used, hydraulically design the system in accordance with the manufacturer's recommendations and its listing in the *Approval Guide*.

2.4.11.3 Use a foam concentrate that is listed in the FM *Approval Guide* and compatible with the materials being handled.

2.4.11.4 Design the foam concentrate duration based on actual sprinkler discharge (not design density), plus any hose streams arranged to provide foam discharge, for the following duration:

A. 10 minutes in areas provided with fully adequate emergency drainage.

B. 20 minutes in areas with limited or no emergency drainage.

C. The ignitable liquid release duration or 20 minutes, whichever is longer, where the potential for a 3D spill fire exists.

2.4.11.5 Where three-dimensional spill fire hazards exist, provide foam for every level of protection.

2.4.11.6 Install the foam water sprinkler system or compressed air foam (CAF) in accordance with Data Sheet 4-12, *Foam Extinguishing Systems*.

2.4.12 Flammable Gases Protection

The protection of facilities processing flammable gases requires a combination of gas detection systems, shutoff valves and de-inventory systems, and local levels of passive or active fire protection for steel structures and equipment with the potential for fire exposure that could compromise steel strength and integrity.

2.4.12.1 Provide an FM Approved combustible gas detection system in areas where flammable gases are present. See also Data Sheet 5-49, *Gas and Vapor Detectors and Analysis Systems*, for additional information.

The installation of combustible gas detection is considered sound property loss prevention guidance. However, the need for this detection will vary in accordance with site-specific conditions and should be based on the results of a process hazard analysis. For example, the use of combustible gas detection will be more prevalent indoors.

2.4.12.1.1 Design the system to sound an alarm to a constantly attended location (e.g., the process control room) upon detection of gas concentrations that are 25% of the lower explosive limit (LEL). If appropriate, interlock detection with emergency safety/block valves to shut off incoming flammable gas to vessels, process units, and other applicable equipment or building areas at 50% of the LEL.

2.4.12.1.2 For indoor locations, interlock detection to any installed ventilation systems. Arrange vents to discharge to a point where ignition of escaping vapors or gases will not seriously expose equipment or structures.

2.4.12.1.2.1 For indoor locations that are not provided with ventilation systems and that have the potential for room explosion, see Data Sheet 1-44, *Damage-Limiting Construction*, for additional protection guidance.

2.4.12.1.3 Select detectors based on the gas or vapor with the highest risk in the area (i.e., lowest LEL, lowest ignition temperature, largest percentage by volume in the stream, etc.).

2.4.12.1.4 Locate detectors at strategic points in the area where gas releases can occur. Consider high and low areas where gas can accumulate. Follow the manufacturer's recommendations for installation and spacing.

2.4.12.2 Where emergency shutdown and isolation measures are needed, refer to Section 2.5.2.

2.4.12.3 Provide passive or active fire protection for exposed structural steel, equipment and vessels with a potential fire exposure that may compromise steel strength and integrity. See Sections 2.4.4 and 2.4.5 for additional information.

2.4.13 Water-Reactive Materials Protection

The recommendations in this section apply to areas where water-reactive materials are produced or present in significant amounts. These recommendations do not apply to processes using water-reactive materials in small quantities, such as for catalysts.

In cases where large amounts of water reactive chemicals are used, sprinkler protection may create a greater hazard than it mitigates. This is particularly true if the hydrolysis reaction can rapidly release flammable gases (such as organometallic materials). In such cases, sprinklers and other water-based fire protection may be omitted, provided that the guidance in this section is followed.

2.4.13.1 Construct process areas with noncombustible materials.

2.4.13.2 Locate areas where water-reactive materials are processed or present, considering any of the following options:

A. Isolation. Determine the separation distance from buildings/operations based on a facility siting study where quantities and all potential scenarios are evaluated (see Section 2.2.1).

B. Two-hour fire-rated construction. This includes the process area as well as any walls between the process area and lower hazard operations.

2.4.13.3 Provide areas with adequate containment or other protection means to prevent fire from spreading to adjacent buildings/operations.

2.4.13.4 Provide processes with automatic shutoffs to limit the release of water reactive materials. See Section 2.5.2 for additional information.

2.4.13.5 When an explosion hazard exists, provide areas with damage-limiting construction (DLC). See Data Sheet 1-44, *Damage-Limiting Construction*, for additional information.

2.4.13.6 Do not store combustible materials or ignitable liquids in the area.

2.4.13.7 Provide process areas with automatic shutoffs (see Section 2.5.2), emergency drainage to control any ignitable liquid release, and mechanical ventilation per Section 2.3.2 where ignitable liquids are used.

2.4.14 Protection of Sprinkler Piping, Valves and Fittings against Damage from Explosion Hazards

2.4.14.1 Bury and loop water supply mains to hazardous process areas. Provide divisional valves, so any breaks due to explosion damage can be isolated.

2.4.14.2 Locate risers in areas isolated by pressure-resistant walls or shielded by structural columns.

2.4.14.3 Provide a readily accessible manual shutoff valve and sprinkler control valve (alarm check, deluge, etc.) for each system.

2.4.14.4 Locate feed and cross mains away from reactors or pressure vessels (e.g., in the aisles or to the sides of reactors or pressure vessels, but never directly above this equipment).

2.4.14.5 Support piping from the building or structural framework. Do not attach piping to pressure relieving walls.

2.4.14.6 Ensure all piping over 2 in. (51 mm) is welded or has welded flanged fittings conforming to applicable ANSI/ASME standards (e.g., ANSI/ASME B31.1, *Power Piping*, ANSI/ASME B16.9, *Factory-Made Wrought Steel Buttwelding Fittings*, and ANSI/ASME B16.25, *Buttwelding Ends*) or international equivalents.

2.4.14.7 Piping of 2 in. (51 mm) or smaller may be welded. Alternatively, use malleable iron or steel fittings of 150 lb steam rating (300 lb W.O.G. rating) conforming to applicable ANSI/ASME standards (e.g., ANSI/ASME B16.3, *Malleable Iron Threaded Fittings 150 and 300 lb*, and ANSI/ASME B16.5, *Steel Pipe Flanges and Flanged Fittings*) or international equivalents.

2.4.14.8 Do not use flexible couplings where an explosion hazard exists.

2.5 Equipment and Processes

2.5.1 Process Piping, Valves and Fittings.

2.5.1.1 Design process piping, valves and fittings to resist working pressures and structural stresses. Ensure materials of construction are compatible with process fluids and adequate for the intended service.

2.5.1.2 Use welded piping for large pipe diameters carrying ignitable liquids and flammable gases. Do not use long, bolted flange joints that may leak when exposed to direct flame.

2.5.2 Emergency Controlled Shutdown and Isolation (ECS&I)

2.5.2.1 General

2.5.2.1.1 Provide processes or equipment containing ignitable liquids or flammable gases with emergency controlled shutdown and isolation (ECS&I) systems to achieve the following objectives in the event of an emergency or release:

A. Stop the transfer of material in a safe and controlled manner.

B. Confine the liquid and vapor within the equipment; or quickly drain escaping liquid, or vent equipment and systems handling gases to a safe location.

C. Limit escaping material to a minimum, and prevent its spread. Limit the expected release and associated fire duration to less than the duration of the fire protection water supply.

2.5.2.1.2 Perform an emergency shutdown assessment to ensure liquid and gas are confined to the smallest area possible.

2.5.2.1.3 Develop a facility-specific emergency response plan for isolation of ignitable liquid and liquefied flammable gas holdup.

2.5.2.2 Isolation Design

2.5.2.2.1 Provide process equipment with block or emergency isolation valves (EIVs), vents to flare stacks or incinerators (i.e., depressurization system), dump or salvage systems, and quench or purging systems to minimize the quantity of material released in the event of equipment failure or emergency. The exact type, extent and arrangement of such protective equipment will depend on the process involved and is often determined through a process hazard analysis. See Figure 2.5.2.2.1 for typical isolation arrangements of different process equipment.

Refer to API 521, *Pressure Relieving and Depressuring Systems*, and API 537, *Flare Details for General Refinery and Petrochemical Service*, as applicable, for further guidance.

2.5.2.2.2 Activate the emergency controlled shutdown and isolation (ECS&I), by one of the following options:

A. Automatic activation, either by fire or leak detection according to Data Sheet 7-32, *Ignitable Liquid Operations*.

B. Manual activation from a safe location where all the following are considered:

- An assessment is conducted to determine the maximum expected release under manual activation, consequences and the duration of the fire relative to fire protection water supply.
- The system requires minimal action from operators to activate.
- The system alarms to a constantly attended location.
- Emergency stop buttons (E-stops) are located at the battery limits or within a control room.
- Operators are qualified, trained, and available on all shifts and provided with adequate personal protective equipment (PPE).
- Tasks performed for manual activation are included in the emergency operating procedures, and drills are conducted regularly.

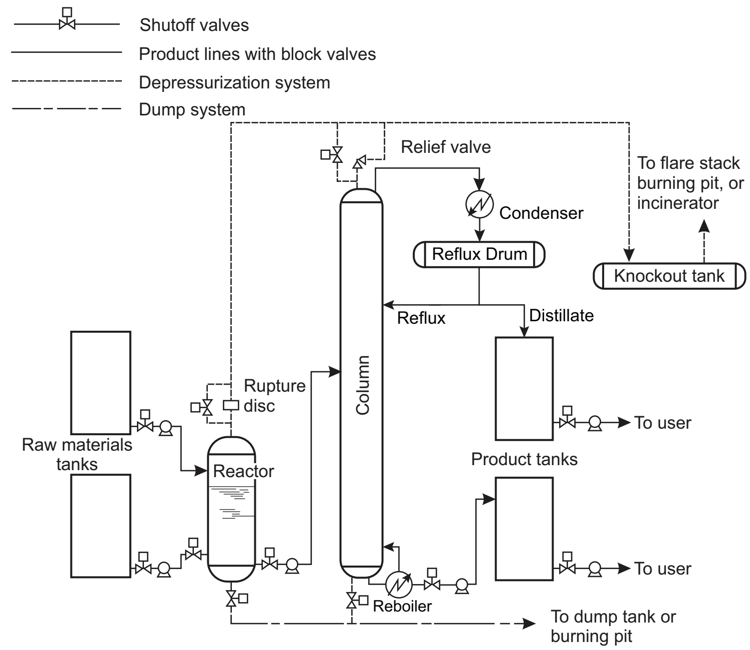

Fig. 2.5.2.2.1. Typical process equipment isolation arrangements

- The shutdown can be initiated in 10 minutes or less. Once initiated, all pumps and valves associated with the shutdown/isolation reach their safe positions within 20 minutes, completing the process in a total of 30 minutes.

2.5.2.2.3 Provide FM Approved emergency isolation valves (EIVs) that are fire-rated or protected by a minimum of 2-hour fireproofing material.

2.5.2.2.3.1 Arrange valves to fail in a safe position.

2.5.2.2.3.2 Provide a means to identify EIVs in the field and ensure their position can be monitored from the control room.

2.6 Operation and Maintenance

2.6.1 Inspect, test and maintain fire protection systems according to Data Sheet 2-81, *Fire Protection Systems Inspection, Testing and Maintenance*.

2.7 Human Factor

2.7.1 Prepare detailed emergency response procedures and conduct periodic drills. Ensure onsite responders are familiar with the operation and design of the fire protection systems, including areas of coverage and where manual response may be relied upon as part of the protection strategy. Emergency responders should be trained on the location of emergency isolation valves (EIVs). See Data Sheet 10-2, *Emergency Response*.

2.7.2 Establish a safe work permit program that includes, but is not limited to:

A. Hot work permitting

B. Line breaking

C. Lock-out/tag-out

D. Vehicle entry control

E. Crane permitting

F. Excavation permitting

G. Hot tap permitting

H. Temporary structure control

2.8 Utilities

2.8.1 Identify critical utilities and develop load shedding procedures to allow for the controlled shutdown of chemical processes in the event of an emergency.

2.8.2 Include utilities in Process Hazard Analysis (PHAs). See Data Sheet 7-43, *Process Safety*, for further information.

2.8.3 Provide separate process water and fire protection water supplies. Where a common source is provided, such as a river or large reservoir, provide separate process water and fire protection water suction lines. Locate the process water suction line at a higher level than the fire water line to ensure an adequate fire water reserve.

2.8.4 Limit use of fire protection water to fire protection systems. Fire protection water connections may be provided for safety critical applications such as flare seal water, emergency scrubbing, or backup reactor cooling as an exception.

2.9 Contingency Planning

2.9.1 Provide reliability and redundancy in fire protection water supply pumping systems.

A. Locate fire pump houses outside of high hazard areas or design the building to withstand anticipated damage.

B. Arrange fire systems and fire pump houses to minimize common impairments. See Data Sheet 3-10, *Private Fire Service Mains and Connections*.

C. Size fire pumps so that the maximum water demand can still be met with the largest pump out of service.

2.10 Ignition Source Control

2.10.1 Establish a hot work policy as part of the safe work permitting program. Use the FM Hot Work Permit System (or an alternative system that meets the intent of the FM Hot Work Permit) to control all hot work. Refer to Data Sheet 10-3, *Hot Work Management*, for additional information.

2.10.2 Provide hazardous location rated electrical equipment in accordance with Data Sheet 5-1, *Electrical Equipment in Hazardous (Classified) Locations*, and the requirements of local or national electrical codes.

2.10.3 Provide grounding and bonding for process equipment in accordance with Data Sheet 5-8, *Static Electricity*.

2.10.4 Provide stray current protection and static dissipation controls for ignitable liquid transfers to rail cars and trucks in accordance with Data Sheet 7-32, *Ignitable Liquid Operations*.

See Data Sheet 7-32, *Ignitable Liquid Operations*, and 10-3, *Hot Work Management*, for additional guidance and recommendations on ignition source control.

3.0 SUPPORT FOR RECOMMENDATIONS

Chemical facilities that use or process large quantities of ignitable liquids, flammable gases, and liquefied flammable gases present significant protection challenges. These challenges arise not only from the inherent hazards of these substances but also from the diverse construction features and complex equipment/piping layouts that may be present.

These facilities can include structures that vary widely in shape and size. Some structures may lack walls or roofs but often have high elevations and small floor areas. Work floors, made of solid or open-grating construction, may be located at various levels. These floors can be incomplete or interrupted by stairs, piping, and equipment. Tanks, reactors, condensers, stills, and pipe racks may be arranged irregularly throughout or adjacent to the structures.

Protection in these facilities is often achieved by a combination of elements or protection methods. These may include active and passive protection such as automatic area sprinkler systems, fixed directional water spray systems, emergency drainage and containment, fireproofing, shutoffs, space separation, manual firefighting, etc.

Design of protection systems for fires and explosions in chemical facilities is not a straightforward process, and designs can vary significantly.

3.1 Construction and Location

3.1.1 Fire and Explosion Events

The extent of a fire or explosion loss in a chemical plant can be minimized by providing separation between process units, storage facilities, and other important buildings. The spacing needed is based on many factors, including:

A. The severity and probability of potential fires or explosions

B. The relative value of the unit and importance of facilities

C. The susceptibility of buildings and equipment to direct or indirect damage (fire following)

3.1.1.1 Flammable Vapor or Gas Explosions in Process Equipment

Where the vapor space of a process vessel is in the explosive range and ignited, the confined hot gases will cause a buildup of pressure. Ultimately, the vessel will reach its failure pressure and will fail catastrophically. A relatively weak vessel may only release a fireball and its contents. A stronger vessel could fail and create a shock wave similar to that produced by detonation with vessel parts becoming missiles that may cause damage some distance from the event. A fireball that can ignite other fires in the affected area is also likely. In existing plants, providing the additional separation required to reduce the loss to adjoining process units is usually impractical.

When an exothermic reaction occurs in a vessel without sufficient cooling, venting and/or agitation, the reaction may accelerate, generating pressure from boiling vapors or decomposition products, until the vessel reaches its failure pressure. Allowing a pressure vessel to experience pressures above the design can cause a similar catastrophic rupture (without directly creating a fireball) due to the sudden pressure release. Data Sheet 7-0, *Causes and Effects of Fires and Explosions*, provides additional guidance.

3.1.2 Spacing and Layout of Facilities

3.1.2.1 General

Chemical plants are typically laid out in blocks over the site area (see Figures 3.1.2.1-1 and 3.1.2.1-2). These figures represent very broad, general concepts. The outer boundary of Figure 3.1.2.1-1 only represents property boundaries and, within each block, an imaginary footprint of the operation. Ideally, major blocks are devoted to operations of similar hazard or function. Typical blocks could be processing areas, storage tanks, utilities, administration/office buildings, maintenance shops/buildings, warehouses and waste handling operations. Major blocks are commonly defined by roadways and open space. Smaller unit blocks with smaller access ways and clear space may exist within blocks.

Chemical plant spacing and layout is often a compromise between many factors such as geographical limitations, material transfer considerations, plant operability, plant maintenance, on-site or off-site utilities, off-site exposures and emergency access.

Sufficient spacing between major process blocks, tank farms, important buildings, and major plant utilities is needed to prevent an event from escalating to nearby areas from the unit of origin.

Within process units, spacing is often arranged in blocks with access for operation, maintenance and firefighting. These access routes can be approximately 20 ft (6 m) wide and arranged so the shortest block dimension would be 100 ft (30 m). The largest dimension is limited mainly by water supply considerations (i.e., the volume of fire protection water needed to protect the largest area that could be involved in a potential incident). The hazard of the occupancy/process and physical barriers that limit fire spread should also be considered.

Process units containing equipment such as reactors, distillation towers, large pumps and compressors, and fired process heaters are preferably located on the perimeter. Equipment stacking (one piece of equipment supported directly on a lower one) is a common practice for space economy and other reasons. However, this arrangement can potentially increase fire development.

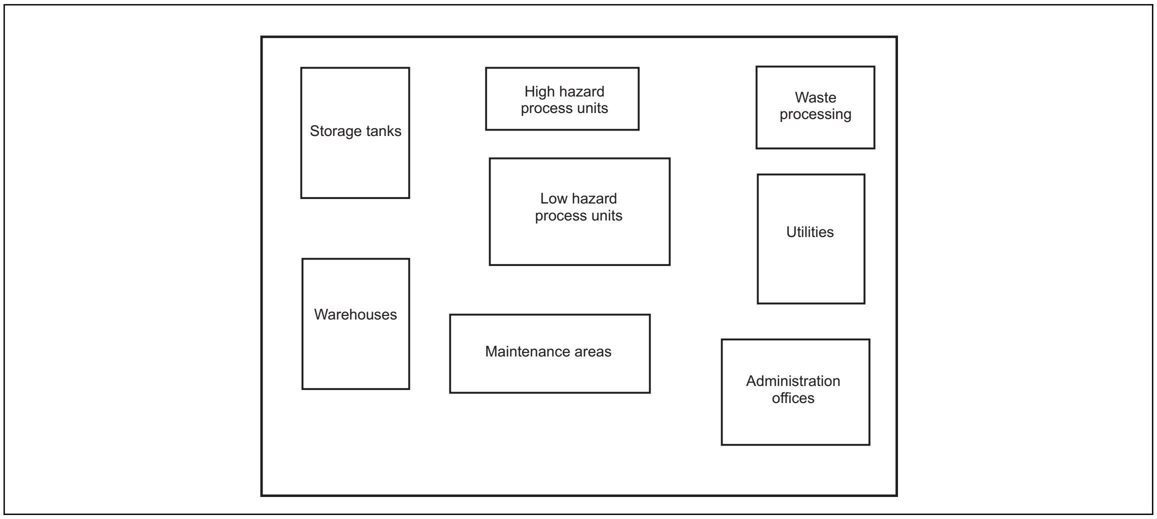

Fig. 3.1.2.1-1. Typical site layout

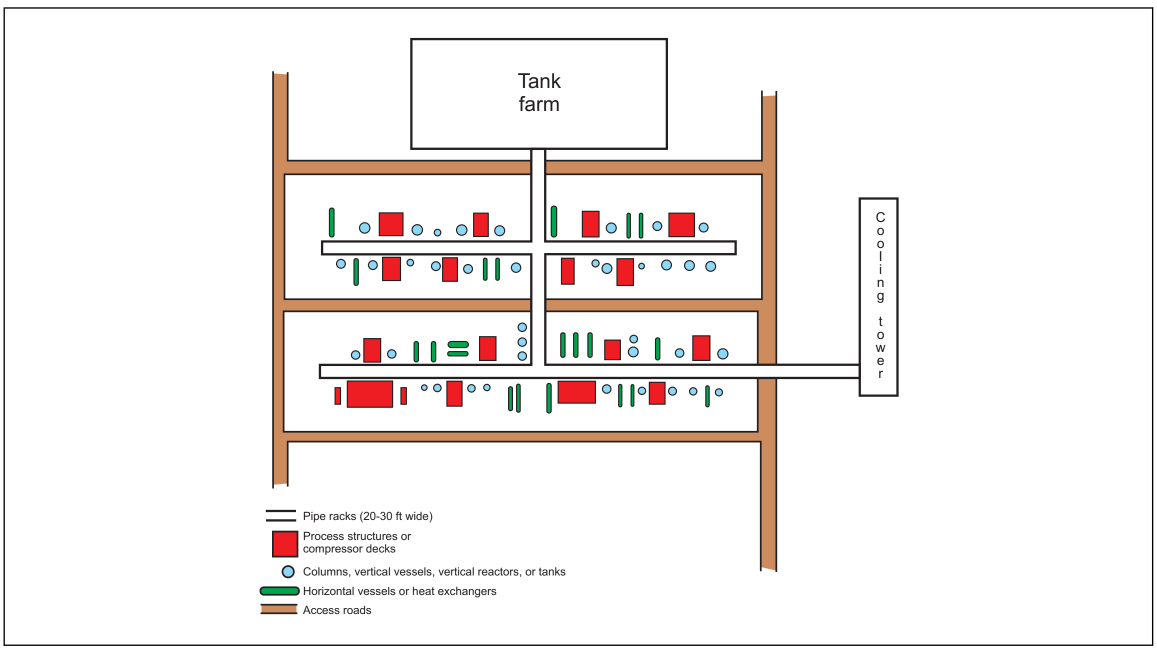

Fig. 3.1.2.1-2. Typical layout of process structures, tanks, and vessels

A recommended practice for equipment stacking outside of process structures is to limit the stacking height to no more than three levels. However, pumps and compressors handling flammable materials, air fin exchangers and heat exchangers, or in-process tanks with operating temperatures over 600°F (315°C) should not have other equipment stacked above them. In open steel process structures, large amounts of ignitable liquid holdup should be kept near ground level to reduce the potential for a three-dimensional fire.

A control room in a chemical plant is crucial for safe operations. Therefore, it should be located beyond the battery limits of the process area. Additionally, when an explosion risk exists, the control room may need to be structurally reinforced or provided with blast resistance.

Site-specific analyses for spacing and layout need to be conducted in the initial design phase. Modifications to existing facilities are rarely practical except during major upgrade projects.

3.1.2.2 Specific Considerations

3.1.2.2.1 Reactors

Reactors operating with unstable reactions or products, and highly exothermic reactions requiring considerable controls may need isolation. Where large energy releases would cause widespread damage, blast-resistant barricades may reduce the loss potential.

Reactors of low hazard need spacing primarily related to their potential for large ignitable liquid releases.

3.1.2.2.2 Fired Process Heaters

Fired equipment presents a ready ignition source and should be upwind (i.e., in the direction of the prevailing wind) from related equipment and operational facilities.

3.1.2.2.3 Compressors

For process gas compressors, separation from operational facilities will reduce related fire exposures. Grouping compressors for maintenance and operation is acceptable with proper consideration for lubrication oil system fires, massive mechanical failures, and accessibility for manual firefighting from at least two sides.

Air compressors for process use need to be located to minimize the intake of flammable gases. Intakes elevated 10 ft (3 m) or more and located away from vapor sources can help alleviate this problem.

Other air compressors would normally be in the unit utility area.

3.1.2.2.4 Cable Trays

Exposed cables will be damaged quickly by ignitable liquid spill and pool fires, even if adequate sprinkler or water spray protection is provided. This fact is particularly important for critical cables required for a safe shutdown and relative to potential business interruption due to the loss of these cables. While sprinklers or water spray may reduce the extent of fire spread, the protection may not be sufficient to avert loss of the cable. Only proper routing of cables away from the ignitable liquid exposure or the application of an FM Approved fire wrap will ensure continued operation of the cables in the event of an ignitable liquid fire.

3.1.3 Emergency Drainage and Containment

Emergency drainage and containment as a secondary (mitigating) layer of protection is intended to handle large accidental releases of ignitable liquid that may occur if the primary prevention safeguards fail. The emergency drainage and containment systems are designed based on the location, size and duration of the expected release scenario in each process area.

Properly engineered emergency drainage and containment is vital to limit the extent of damage that could result from ignitable liquid fires. The key objectives of spill emergency drainage and containment are to:

A. Effectively direct the combined ignitable liquid and sprinkler water discharge from the area to an acceptable location that will not impact equipment or structures.

B. Limit pool fire size.

C. Provide a short flow path for ignitable liquids to reach the drains.

D. Contain spills to the area and equipment of origin.

E. Prevent fire spread to areas that are not protected by water-spray, deluge systems or sprinklers.

Where well-designed emergency drainage is provided, three-dimensional spill fire hazards within a process structure must be accounted for and protected against. However, pool fire hazards become more manageable; as ignitable liquid will be drained away from equipment and structures. Refer to Figure 3.1.3-1 for an example of well-designed drainage.

Conversely, where drainage is not provided or is located within or directly adjacent to the process structure, the impact of a long duration pool fire on equipment beyond the process structure must be considered. An example of this configuration is provided in Figure 3.1.3-2.

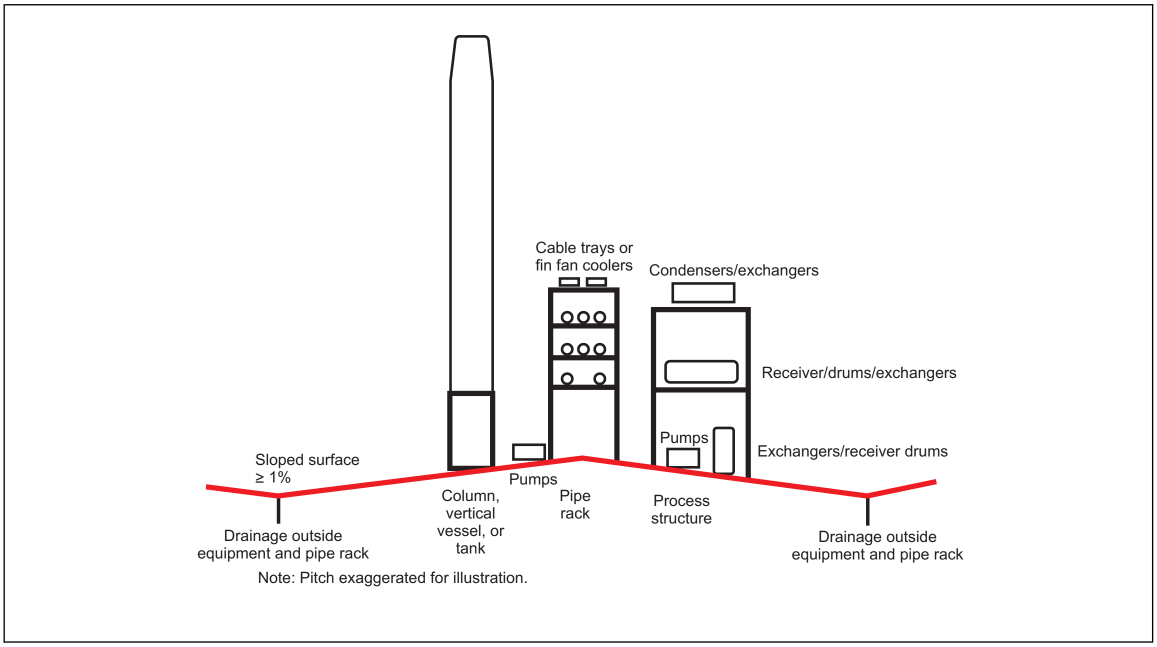

Fig. 3.1.3-1. Example of suitably arranged emergency drainage

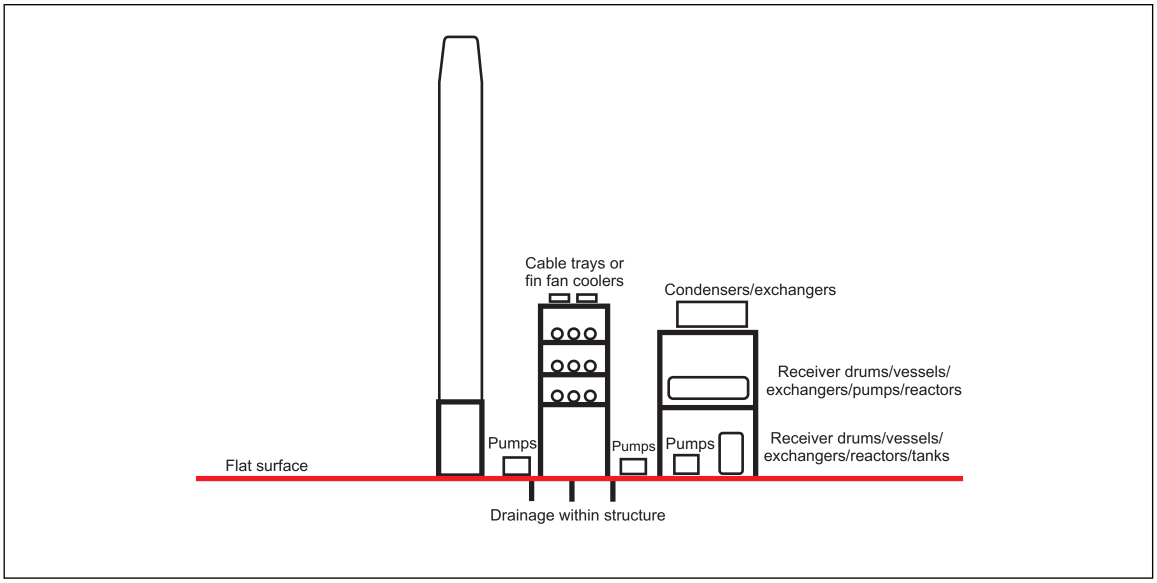

Fig. 3.1.3-2. Example of less-desirable emergency drainage design

3.1.4 Damage-Limiting Construction (DLC)

By definition, DLC is a secondary layer of protection that is provided based on recognition of the following:

A. Primary prevention layers may fail to avert deflagration.

B. Overpressure caused by a vapor-air deflagration inside ordinary industrial buildings can easily result in severe structural damage, loss of content due to collapse and subsequent fire, and extended production outage during the cleanup and rebuilding/repair period.

C. By maintaining overall structural integrity following a deflagration, DLC will often help prevent much additional loss of equipment and shorten the restoration period.

DLC, as described in Data Sheet 1-44, *Damage Limiting Construction*, consists of an engineered combination of explosion venting and pressure-resistant walls that are provided to limit the extent of structural damage in case deflagration occurs inside a room or main building.

Severity and likelihood of deflagration damage are subject to many random contributing factors, but DLC can be designed to preserve structural integrity for most foreseeable events.

3.2 Protection

The scale of fire protection is much more significant at chemical plants than at other industrial facilities due to the extreme operating parameters (ignitable liquid flow rates, pressures, and temperatures) and the inability to rapidly shut down the release of fuel in some processes. In the event of an upset condition, a very large pool or spill fire could develop within a few minutes following an initial release.

Automatic sprinklers or deluge protection, combined with emergency drainage and containment as recommended in this data sheet, provide a critical layer of protection to help mitigate the extent of loss in the case of a large ignitable liquid release and subsequent fire. Adequate fire protection is dependent on:

A. Directional water-spray, deluge and/or sprinkler systems covering all areas where released ignitable liquid may flow, and is supplied by a dedicated, adequate, reliable fire protection water supply, and

B. Emergency drainage and containment is capable of promptly removing the released ignitable liquid and discharged water to an impoundment area away from equipment and buildings.

Water will not, in general, extinguish fires involving flammable gases, liquefied flammable gases, and ignitable liquids having flash points below 200°F (93°C). Automatic sprinklers and/or water spray will, however, provide a combination of general area cooling and actual wetting of equipment and structures to prevent weakening of the metal by overheating. The cooling and wetting will also prevent load displacement caused by thermal expansion of structural members and rupture of process tanks and piping.

3.2.1 FM Large-Scale Fire Tests

3.2.1.1 Heptane Fire Tests

FM conducted a fire test program to evaluate the effectiveness of foam-water sprinkler protection, standard sprinkler protection and combinations of both for a multilevel ignitable liquid process steel structure 40 ft (12.2 m) high.

Two basic types of fire tests were conducted using heptane as a fuel source: two-dimensional pool fires and three-dimensional spill fires involving a fuel spill at an upper level of the process structure.

Three important findings of the test program were:

1. Three-dimensional (i.e., upper open level) spill fires create a more severe fire exposure than floor spill fires. Three-dimensional fires produce a much higher heat release rate than a pool fire, because the liquid is vaporized at a higher rate. The potential for thermal damage from these types of fire is severe.

2. Foam-water sprinklers can control and extinguish a pool fire but are not very effective in reducing exposure from a 3D (upper open level) spill fire. The spilling liquid constantly breaks the foam surface, preventing complete blanketing of the spill fire.

3. Foam-water sprinklers and/or standard sprinklers installed in accordance with this data sheet can protect process structures against pool fires.

The results of these findings indicate that automatic sprinklers can control or even extinguish ignitable liquid pool fires but cannot extinguish a three-dimensional spill fire. Therefore, fire protection guidelines for process structures should emphasize locating equipment with ignitable liquid holdup at ground level, and providing solid floors with curbing and drainage beneath such equipment, rather than open steel grating, when located at upper levels.

These test results also validate the need to provide a high level of fire protection where the potential for 3D spill fires exist. While the protection criteria listed in this data sheet will not extinguish a 3D spill fire, it will ensure adequate cooling and prevent collapse from overheated steel until the fuel is removed (either by drainage or due to fuel consumption).

3.2.1.2 Ethanol Fire Tests

In 2009, FM conducted large-scale tests to simulate the types of ethanol fires that may occur in process structures where ethanol fuel is produced by distillation. The main objectives were to better understand the exposure to structural steel and process equipment from engulfment in large ethanol spill fires and to evaluate the effectiveness of fire protection on these fires. Ethanol is a low flash point (less than 100°F [38°C]), water miscible ignitable liquid with a low chemical heat of combustion relative to many other ignitable liquids (approximately 25 kJ/g).

3.2.1.2.1 Process Structure Tests

A series of large-scale ethanol tests was conducted using a 25 ft x 25 ft (7.6 m x 7.6 m) pan on the floor, inside a simulated 28 ft x 28 ft (8.5 m x 8.5 m) steel process structure with grated mezzanines at the 20 ft (6.1 m) and 30 ft (9.1 m) elevations (Figure 3.2.1.2.1). The purpose of these tests was to evaluate the effectiveness of several single and multilevel sprinkler protection schemes at protecting the structural members when exposed to a large ethanol pool fire. Temperatures of horizontal beams on the two mezzanines were continuously recorded as a measure of the effectiveness of the sprinkler arrangement provided in each test.

Fig. 3.2.1.2.1. Process structure test, ethanol fire in 25 ft x 25 ft (7.6 m x 7.6 m) pan with one level of sprinklers

As a reference case, one test was conducted with the structure sprinklered on each mezzanine level. Additional tests were conducted with the same fire size as the reference case, but with a missing level of sprinkler protection. The findings confirmed that the process structure sprinkler protection recommended in this data sheet, in combination with good emergency drainage and prompt process shutdown, is appropriate for cooling the mezzanine level structural steel when exposed to large ethanol spill and pool fires. In contrast, excessive steel temperatures were reached when protection was provided at a density of 0.3 gpm/ft^2 (12 mm/min) under one mezzanine only.

3.2.1.2.2 Three-Dimensional Spill Fire

An additional test was conducted using the same process structure as described above, but with a 22 gpm (84 L/min) (approximate) ethanol spill fire originating at the lower mezzanine level (20 ft [6.1 m]) and cascading down to the floor. For this test, a simulated process column was located inside the process structure (Figures 3.2.1.2.2-1 and 3.2.1.2.2-2). Sprinkler protection (0.3 gpm/ft [12 mm/min]) was provided at the 20 ft (6.1 m) mezzanine level.

Excessive steel temperatures were reached at both mezzanine levels and on the simulated process column above and below the sprinkler level.

Fig. 3.2.1.2.2-1. Ethanol spill in process structure prior to ignition

Fig. 3.2.1.2.2-2. Three-dimensional spill fire before sprinkler activation (22 gpm [83 L/min] ethanol flow rate)

3.2.2 Area Protection

3.2.2.1 General

The design of area protection will vary depending on whether the facility is located indoors or outdoors. For indoor locations, automatic wet sprinklers, deluge, or preaction systems may be installed. When the occupancy to be protected is located outdoors, the installation of deluge systems is recommended for area protection. Automatic sprinklers are not recommended because of wind effects and the potential for delayed actuation. However, if the outdoor unit is provided with solid floors, automatic sprinkler may be installed. The design will also depend on the presence of intermediate floors or mezzanines.

3.2.2.2 Deluge Systems

Section 2.4.1.7 recommends the design operating area for deluge systems be based on simultaneous operation of all deluge or water spray systems within 50 ft (15 m) of the fire. This recommendation is predicated on the use of detection devices that will limit actuation of adjacent deluge systems, such as spot-type, fixed temperature heat detectors or pilot sprinklers. Recent testing has demonstrated that automatic sprinklers will not actuate unless directly exposed to flames or to the hot gases of a ceiling jet.

Conversely, pneumatic heat actuated devices (HADs) that operate on a fixed temperature and rate-of-rise method are much more sensitive and may actuate at significant distances from a fire. A pneumatic HAD is a spot-type detection device attached to a length of pneumatic tubing. When exposed to heat or temperature increase from a fire or explosion, the pressure inside the HAD increases. This pressure increase is transmitted through the pneumatic tubing to a control panel that actuates the deluge system.

3.2.3 Passive Protection (Fireproofing)

Passive protection refers to the application of fireproofing materials to provide thermal insulation to structural components and vessels, or to maintain the integrity of emergency control systems or mechanisms. Specifically, unprotected structural steel supports engulfed in flames from an ignitable liquid fire can quickly (within a few minutes) reach temperatures where the steel can no longer support the design loads. Fireproofing of structural steel provides a thermal barrier to limit temperature rise and maintain structural integrity for the duration of the rating under specified time-temperature conditions. Fireproofing is preferred for structural steel exposed to severe ignitable liquid fire hazards.

The need for fireproofing protection for structural steel and critical equipment/vessels is primarily determined by a fire hazard assessment. API 2218, *Fireproofing Practices in Petroleum and Petrochemical Processing Plants*, provides guidance on the different factors that should be considered in this assessment. The first step in the evaluation is the identification, usually through a process hazard analysis (PHA), of the location and type of fire hazard areas and scenarios, including the capacity and flow pattern of associated drainage areas. Examples of equipment with different fire potential hazards based on operational conditions, type of material, flow rates or equipment prone to failures where large spills may be expected are also included in the standard.

Fireproofing systems use a different combination of materials, with a variety of chemical and physical properties and arrangements. Therefore, close evaluation is required when designing and selecting a fireproofing system to determine its adequacy for the intended application, fire-resistance duration, potential corrosion development under fireproofing and resistance to environmental conditions. For instance, when designing for hydrocarbon pool fire scenarios, the following should be taken into consideration:

- The system should be able to function effectively at temperatures up to 1660°F (904°C) for up to two hours.
- The system should remain intact and not be dislodged by high-pressure water streams during firefighting operations.
- The insulation system should be able to withstand direct flame impingement.
- When insulation banding and cladding are required, the insulation should be attached with stainless steel bands and then clad with stainless steel jacketing. Aluminum banding and/or jacketing are not acceptable because they will melt at 1,220°F (660°C).

Typically, fireproofing materials are specified for either ordinary (cellulosic) or hydrocarbon fire exposures at different durations. Fireproofing materials commonly used in the chemical or petrochemical industries for steel structures include but are not limited to:

- Cementitious products
- Intumescent coatings
- Mineral and fiber board systems

Data Sheet 1-21, *Fire Resistance of Building Assemblies*, provides additional information on these specific fireproofing materials and their application.

Cementitious concrete is very effective at reducing heat input to steel due to its high mass and low thermal conductivity. The concrete can be cast/poured in place or pre-cast, mostly for columns and beams. For equipment or structures with complicated shapes (i.e., spheres) or where the use of poured-in-place concrete forms is impractical, a special mix of cement, sand and water can be applied in layers using a specialized spray gun, which allows better adherence to vertical surfaces and curves.

3.2.3.1 Failure Modes of Fireproofing

Fireproofing can fail for several reasons, including poor application and installation, damage during construction or maintenance, environmental exposure (like moisture), inadequate thickness, improper material selection for the environment, breaches in the fireproofing layer, corrosion under fireproofing (CUF), and degradation from weathering. All of these can significantly reduce its fire-resistant capabilities and compromise the structural integrity of the protected element in a fire event.

Corrosion under fireproofing (CUF) is one of the most common indications of fireproofing failure and usually manifests as cracks and staining of the fireproofing. Generally, the extent of degradation is impossible to determine through visual inspection alone. Different inspection tools and methods can be applied to determine the level of corrosion damage. API 583, Corrosion Under Insulation and Fireproofing, provides additional guidance for design, maintenance, inspection and mitigation practices to address external corrosion under fireproofing.

3.2.4 Directional Water Spray Protection.

The effectiveness of area protection to provide cooling for equipment and structures is vastly diminished as the clearance between the sprinklers and the fire increases. Therefore, supplemental water spray is necessary to protect equipment and supports exposed to an ignitable liquid spill or pool fire when an excessive clearance exists below a level of area protection.

Additionally, chemical plants may have a significant quantity of conduits, piping, and other obstructions. If these items obstruct the roof or mezzanine level sprinklers, supplemental protection is necessary. This protection may include placement of additional sprinklers below the obstructions or local water spray protection of structural elements and equipment.

In many cases, a combination of area protection and local, directional water spray will be necessary for exposed equipment and structures. Physical arrangement of the processing structure and equipment will determine which type of protection (i.e., area protection, directional water spray, or a combination of the two) is most practical.

For example, the first several levels of an outdoor process structure may be protected with an area deluge system 30 ft (9.1 m) above areas of significant ignitable liquid holdup or 10 ft (3 m) above credible release points, whichever is greater. To supplement this protection, local water spray may be provided for vessels or other equipment containing ignitable liquids at higher levels.

In some cases, local, directional water spray may be used exclusively to protect process structures and exposed equipment.

3.2.4.1 Design of Water Spray Systems

This data sheet provides basic recommendations regarding the design of water spray protection, including recommended coverage, densities, and water demands. Within these parameters, the specific design of water spray systems may vary considerably by manufacturer. Nozzle orifice sizes, spray profiles, spray angles and the axial distance from the nozzle to the protected surface (among other factors) will all impact the performance of the protection system. To determine the proper design of local water spray systems, the recommendations in this data sheet should be provided to system manufacturers or qualified design specialists to develop detailed design information.

3.2.5 Pipe Racks

As with other process structures or equipment containing ignitable liquids, pipe racks require some form of active fire protection to cool the piping and piping contents. Heating of materials within the piping could cause overpressure of piping systems due to flame impingement. Additional pipe breaks or leaks at flanges could spread the ignitable liquid release to the existing fire. Additionally, an exposure fire may cause heating of unstable materials within the piping, such that a runaway reaction could occur within the system.

Drainage surrounding the pipe racks may limit the exposure and potential overheating of the structure and piping. Some units are designed with pipe racks at a high point and drains located outside the central pipe rack. Other units are designed with drainage located in the middle or along the vertical columns of the pipe rack.

The impact of manual firefighting should also be analyzed. Often, pipe racks will be shielded from manual firefighting by multi-level process structures, compressor buildings, or several tall distillation columns or vertical vessels in a row.

3.2.6 Fin-Fan Coolers

Air fin-fan coolers are used to cool liquids or cool and condense gases. Leaks can occur in the tubes from corrosion, poor design, or poor flange connections. Where ignitable liquids are being cooled or a gas is being condensed so that the liquids are above or near their flash points, water spray protection is warranted. Gas-filled (tube side) fin-fan coolers generally do not warrant protection unless exposed to fire from nearby equipment or if the gas is being condensed to a liquid within the tubes.

3.2.7 Cost of Fire Protection Systems

The installation of fire protection systems at chemical plants is not as straightforward as in other industrial occupancies. Chemical plants have complex configurations, including tall structures, numerous potential obstructions to sprinkler discharge, and typically lack support structures for sprinkler piping. Unlike a standard warehouse or office building where sprinklers can be installed in a standard grid, the placement of sprinklers at chemical plants is often non-uniform. Additionally, due to the unique design and hazards at these facilities, contractors must often undergo specialized safety training and background checks, and complete their work using specialized safety clothing and equipment.

3.2.8 Manual Firefighting

Firefighting involves the manual application of cooling and extinguishing media to a fire. This task can be performed by employees, contractors or emergency service organizations (ESOs), such as the local fire department or mutual aid organizations.

Firefighting efforts can vary significantly in complexity. They may include simple actions, such as a staff member using a handheld fire extinguisher on a trash can fire—known as incipient firefighting. More complex actions may involve applying firefighting foam to a fully engaged storage tank fire, utilizing multiple fire trucks operated by various agencies. This method is commonly referred to as structural firefighting in the chemical industry.

3.2.8.1 Monitors

Monitors are fixed, manually adjustable water units with adjustable nozzles that are recommended for installation at strategic points around areas with identified fire hazards. Monitors discharge large volumes of water and have a good straight-stream range. They should be positioned to provide adequate coverage with no obstructions, under adverse wind conditions, which often requires multiple units. Standard monitors have a water capacity of 530 gpm (2010 L/min) at a working pressure of 150 psi (10 bar). However, monitors with a different capacity may be necessary for certain applications.

Additionally, many organizations utilize portable monitors that can be connected to hydrants and directed into the fire or onto nearby equipment/structures for cooling purposes. Special installations may also require elevated monitors to protect inaccessible areas, remote control monitors or oscillating monitors.

3.2.8.2 Hydrants and Hose Reels

Hydrants are vertical steel pipes with two to four outlets to which hoses can be connected. Hose connections should be compatible with those used by local fire departments and mutual aid organizations, or adapters need be provided. Hydrants should be strategically placed to protect multiple process units or tanks. They should be close to the equipment and buildings they protect but far enough to ensure the safety of operators and responders. Without booster pumps, hydrants should generally be located no more than 150-300 ft (45-90 m) apart—preferably less around ignitable liquid process structures/units or buildings.

Water supply design should consider hose stream and monitor allowances.

Hose reels are frequently located near hydrants. These reels allow hoses to be connected and water directed at the fire's base. Hoses are usually classified as attack or supply, according to their size. Standard attack hoses (commonly used in chemical facilities) are 2½ in. (64 mm), 1¾ in. (44 mm) and 1½ in. (38 mm). The 2½ in. (64 mm) hose is primarily used for heavy cooling streams, requiring three or more people to handle hose lines, depending upon the system pressure.

Fixed fire monitors are typically used in conjunction with hose reels in many facilities to achieve better coverage and protection.

3.2.8.3 Fire Brigades

Specialized fire brigades, whether onsite, part of a mutual aid agreement, or from local fire departments, require specific knowledge and equipment for chemical plants. These brigades must have a clear organizational structure, covering firefighter expectations, training, and staffing levels.

Fire response is generally identified in three levels:

1. Incipient: Initial stage

2. Exterior: Common at chemical facilities and often referred to as structural firefighting

3. Interior Structural: Requires the highest level of staffing, training, and equipment due to the hazards of enclosed fires

Industry specific training and equipment are often recommended. For instance, the tactics and equipment required to control a fire in a petrochemical plant, where large volumes of ignitable liquids and gases are present, are different than the ones used in a general manufacturing plants or office buildings.

Training and education of the fire brigade should include (at a minimum) the following:

- Chain of command and lines of communication. The speed and effectiveness of the response is dependent on the availability of a reliable communications system. This item can also be referred to as an incident command system.
- Capabilities and operation of firewater systems, foam systems, fixed/mobile monitors, hydrants, hose reels, firefighting vehicles, etc.
- Use, maintenance and inspection of firefighting equipment
- Fire response procedures and tactics
- Knowledge of the site, hazardous materials and operations
- Shutoff valve locations and activation procedures
- Documented prefire plans for fire scenarios identified in each process unit, tank farm, building or hazardous chemical operation

Training is not the only requirement for effective performance of fire brigades. Regular drills are a vital component for practicing scenarios that represent similar conditions to those encountered during actual fires. Various training and education programs for fire brigade members that support chemical facilities are offered at institutes and universities in the United States, including Texas A & M University, Lamar University, Reno Fire School, Delaware State Fire School, etc.

Personal protective equipment (PPE) is another important element that defines the level of response provided by the fire brigade personnel. Common PPE includes helmets, coats, trousers, boots, eye protection, hearing protection, protective gloves and protective hoods. Different emergency operations require different kinds of PPE. All PPE designed for structural and proximity firefighting must meet the requirements of NFPA 1971, *Standard on Protective Ensembles for Structural Fire Fighting and Proximity Fire Fighting*.

3.2.9 Water-Reactive Materials.

Water-reactive chemicals are substances that react violently to water. These reactions produce heat, often releasing flammable or toxic gases, and can sometimes lead to fires or explosions from the rapid heat generation. Reactions usually result in the formation of a metal hydroxide and hydrogen gas, especially when dealing with reactive metals like sodium or potassium. Many types of water reactive materials exist, including alkali metals such as lithium, alkali metal amides, Grignard reagents, etc.

Maintaining safe practices to prevent any contact with water or moisture is the recommended protection for areas where these materials are stored or handled. Examples of such practices include:

- Storing in a cool, dry place away from any sources of moisture.
- Using airtight containers, preferably under an inert atmosphere.
- Using dry methods, such as scooping or sweeping up the material with non-sparking tools.

In addition, spacing, fire resistive barriers, and barricades also represent good practices to protect adjacent areas or equipment.

3.3 Equipment and Processes

3.3.1 Emergency-Controlled Shutdown and Isolation (ECS&I)

Emergency shutdown and isolation systems are essential components in chemical plants to mitigate the impact of emergency situations and ensure a rapid and effective response. These systems are designed to shutdown processes or equipment in a safe and controlled manner (ECS) in response to a hazardous condition. They also isolate parts of the plant or specific pieces of equipment from the rest of the system to contain hazardous substances and prevent the spread of dangerous conditions.

In a well-designed chemical plant, these systems are integrated into the overall safety management system. They often work in conjunction with other safety measures like fire suppression systems, gas detection systems, and emergency response plans.

The objective of the emergency shutdown systems is to shutdown processes or equipment and stop the flow of liquids or gases. These systems are usually integrated by sensors or detectors to monitor different process parameters, control systems that interpret the data from the sensors, valves, and alarms. Once activated, the shutdown sequence follows a specific order to ensure safety.

Isolation systems may involve isolation valves or physical barriers and containment systems. Emergency isolation valves (EIVs) either stop the flow of liquids and gases or direct the inventory to a safe location. Isolation valves can be manually or remotely operated. Remote isolation may require operator intervention or may be activated automatically using different types of detection systems (i.e., leak detection, heat detection, flame detection, etc.).

Emergency Isolation Valves (EIVs) should be located in areas where they can be easily and safely accessed during emergencies and protected from fire or explosion effects. A remote indication of valve positions should be available in the control room, and emergency responders should be trained on their location. Where EIVs are not easily accessible, fireproofing and protection measures are necessary for the valves, cables (power and control) and actuators. Where EIVs are instrument air driven, fireproofing may still be needed for the valve, actuator and instruments driving the actuators.

3.4 Chemical Plant Utilities

3.4.1 Typical Utilities

Typical utilities at chemical plants can include, but are not limited to:

- Water (raw, clarified, demineralized, soft, boiler feed water [BFW], potable)
- Cooling tower water
- Steam
- Electricity
- Air (process, instrument, plant-use)
- Natural gas (combustion equipment and process feed)
- Nitrogen
- Special utility gas (nitrogen/low oxygen mixture for tank purging with some stabilizers)
- Heat-transfer systems (other than steam)
- Refrigeration systems
- Waste streams – gaseous/liquids (incinerators, thermal oxidizers, flares, scrubbers, high chimneys)
- Wastewater (process, rain, sewage)
- Communications (on-site LAN, on-site telephone system, external internet, external phone system)
- Computer systems (process controllers, administration servers, engineering servers, PSM servers)

3.4.2 Load Shedding

At chemical processing sites that can lose a major portion of a utility suddenly, load shed priority plans are critical. These plans help prevent sudden shutdown of processing units that are susceptible to plugging, solidification, contamination, runaway reactions, significant equipment damage or loss of quality (high-value batch reactions). Units that can drop offline and be restarted quickly with little to no production or physical damage implications should be shut down first.

3.5 Loss History

3.5.1 FM Loss History

The percentage of fire and explosion losses in chemical plants from 2014 to 2023 is shown in Figure 3.5.1-1. Out of a total of 212 reported losses, 60% were due to fires and 40% were due to explosions. Among the fire-related losses, 44% involved specific equipment (i.e., cooling towers, dryers, distillation columns, reactors, etc.), 11% were electrical fires, and 45% were fires associated with various manufacturing or storage areas.

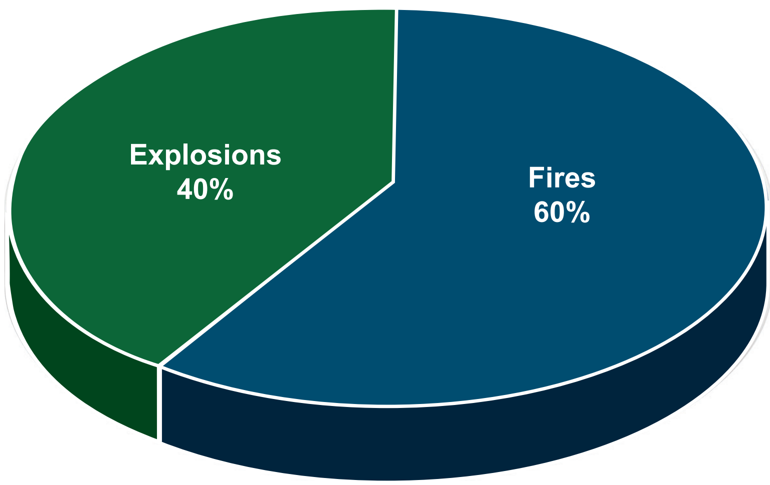

Fig. 3.5.1-1. Percentage of fire and explosion losses from 2014 to 2023

4.0 REFERENCES

4.1 FM

Data Sheet 1-21, *Fire Resistance of Building Assemblies*
Data Sheet 1-44, *Damage-Limiting Construction*
Data Sheet 2-0, *Installation Guidelines for Automatic Sprinklers*
Data Sheet 2-8, *Earthquake Protection for Water-Based Fire Protection Systems*
Data Sheet 2-81, *Fire Protection System Inspection, Testing and Maintenance*
Data Sheet 3-10 *Private Fire Service Mains and Connections*
Data Sheet 4-1N, *Fixed Water Spray Systems for Fire Protection*
Data Sheet 4-12, *Foam Extinguishing Systems*
Data Sheet 5-1, *Electrical Equipment in Hazardous (Classified) Locations*
Data Sheet 5-8, *Static Electricity*
Data Sheet 5-31, *Cables and Bus Bars*
Data Sheet 5-48, *Automatic Fire Detection*
Data Sheet 5-49, *Gas and Vapor Detectors and Analysis Systems*
Data Sheet 7-0, *Causes and Effects of Fires and Explosions*
Data Sheet 7-2, *Waste Solvent Recovery*
Data Sheet 7-29, *Ignitable Liquid Storage in Portable Containers*
Data Sheet 7-32, *Ignitable Liquid Operations*
Data Sheet 7-42, *Vapor Cloud Explosions*
Data Sheet 7-43, *Process Safety*
Data Sheet 7-55, *Liquefied Petroleum Gas (LPG) in Stationary Installations*
Data Sheet 7-74, *Distilleries*

Data Sheet 7-83, *Drainage and Containment Systems for Ignitable Liquids*
Data Sheet 7-88, *Outdoor Ignitable Liquid Storage Tanks*
Data Sheet 9-0, *Asset Integrity*
Data Sheet 10-3, *Hot Work Management*
Data Sheet 12-2, *Vessels and Piping*

4.2 Other

4.2.1 American Society of Mechanical Engineers (ASME)

ASME Boiler and Pressure Vessel Code
ANSI/ASME B31.1, *Power Piping*
ANSI/ASME B16.9, *Factory-Made Wrought Steel Buttwelding Fittings*
ANSI/ASME B16.25, *Buttwelding Ends*
ANSI/ASME B16.3, *Malleable Iron Threaded Fittings 150 and 300 lb*
ANSI/ASME B16.5, *Steel Pipe Flanges and Flanged Fittings*

4.2.2 American Petroleum Institute (API)

API 521, *Pressure Relieving and Depressuring Systems*
API 537, *Flare Details for General Refinery and Petrochemical Service*
API RP 752, *Facility Siting Requirements and How They Affect Your Company*
API 583, *Corrosion under Insulation and Fireproofing*
API 2218, *Fireproofing Practices in Petroleum and Petrochemical Processing Plants*

4.2.3 Center for Chemical Process Safety (CCPS)

Guidelines for Evaluating Process Plant Buildings for External Explosions and Fires.

APPENDIX A GLOSSARY OF TERMS

For the purposes of this document, the term ignitable liquid is defined as any liquid that has a measurable fire point. Also, the term flash point refers to the closed-cup flash point unless otherwise indicated.

Battery limits: An area within a chemical plant containing equipment for a specific process unit that is directly related to the production of a single product or related group of products.

Damage-limiting construction (DLC): A type of construction that consists of both pressure-resistant and pressure-relieving ceiling and/or walls that allows the internal pressure buildup from a deflagration explosion to release safely to a designated external area. See FM Data Sheet 1-44, *Damage-Limiting Construction*, for further details.

Explosion hazard, equipment: Exists when any of the following are true:

A. An ignitable liquid is handled/processed/used at or above its closed-cup flash point and there is a vapor space within the equipment.

B. An ignitable liquid exists as a mist within the equipment due to a mechanical process (e.g., spraying, mixing).

C. A vessel contains a process with an exothermic chemical reaction for which multiple controls are needed to prevent a runaway reaction that could cause rupture of the vessel even where adequately designed overpressure protection exists

Explosion hazard, room/building: Exists when any of the following are true:

A. An ignitable liquid is handled/processed/used at or above its atmospheric boiling point, and has a closed-cup flash point at or below 425°F (218°C).

B. A process uses an ignitable liquid with a boiling point at or below 100°F (38°C).

C. A process uses a liquefied flammable gas.

D. A piece of equipment with a defined equipment explosion hazard occupies more than 10% of the room/building's volume and is not protected for explosion by venting, containment, inerting, or suppression.

FM Approved: Products or services that have satisfied the criteria for Approval by FM Approvals. Refer to the *Approval Guide,* an online resource of FM Approvals, for a complete list of products and services that are FM Approved.

Ignitable liquid: Any liquid or liquid mixture that is capable of fueling a fire. Whether described as flammable, inflammable, or combustible, any liquid that has a fire point is an ignitable liquid.

Jet fire: A jet fire results from the release and ignition of a pressurized flammable substance, typically a gas or volatile liquid, through a nozzle or rupture. It can spontaneously produce a high-velocity, high-temperature flame due to the friction of the leaking material against the edge of the hole.

Pool fire: An ignitable liquid fire that takes the form of a spreading pool on a solid floor or intermediate level. Examples include a leak from a flange at the bottom of a vessel near ground level, leaks from vessels where solid intermediate floors are present to capture the spilling leak, and elevated incoming raw material lines.

Process building (indoor): An indoor chemical process building refers to a facility designed specifically to house manufacturing processes that occur within a controlled indoor environment. These buildings typically consist of walls, floors, roofs, doors, windows and other components that form a complete and enclosed space where process equipment such as reactors, mixing tanks, and other equipment necessary for specific manufacturing processes can be found.

Process structure (outdoor): Outdoor chemical process structures refer to areas designed to facilitate manufacturing processes. These structures typically include large vessels, reactors, storage tanks, and associated piping, often exposed to the elements, with minimal enclosure to facilitate ventilation and other safety measures in case of a release.

Process unit: Refers to the area and equipment which are dependent upon one another in the production of a single product or related group of products. This could include self supported or steel supported equipment on open pads or in groups of inter exposed buildings. Commonly this would be referred to as ″inside the battery limits″.

Three-dimensional (3D) spill fire: An ignitable liquid fire that initiates from a leak at an elevated source and continues for an extended period without a means to shut down the release. In Data Sheet 7-14, a 3D spill fire typically involves a multilevel process structure with primarily open grated construction, and an elevated, large liquid holdup or high process flow rates, with the potential for an extended uncontrolled release of ignitable liquids. Given this context, an indoor tank room with feed pipes at roof level may not qualify as a 3D spill fire.

Unstable material: A material that, in the pure state or as commercially produced, will vigorously polymerize, decompose or condense, become self-reactive, or otherwise undergo a violent chemical change under conditions of shock, pressure or temperature. Some raw materials like styrene are stored with inhibitors present and are not considered as unstable in storage.

Water-miscible liquid: A water-miscible liquid mixes in all proportions with water. When water-miscible ignitable liquids are mixed with water, a homogeneous solution is formed. The flash point, fire point, heat of combustion and heat release rate of the solution will be different from that of the pure ignitable liquid. The flash point and fire point of the solution will increase as the water concentration increases. At a certain water concentration (which varies for different ignitable liquids), the fire point will no longer exist; and the solution will no longer present a fire hazard (e.g., 15% ethyl alcohol in water, 15% acetone in water).

For additional information on water-miscible, ignitable liquids, see Data Sheet 7-32, *Ignitable Liquid Operations*.

APPENDIX B DOCUMENT REVISION HISTORY

The purpose of this appendix is to capture the changes that were made to this document each time it was published. Please note that section numbers refer specifically to those in the version published on the date shown (i.e., the section numbers are not always the same from version to version).

April 2026. This document has been completely revised. The following significant changes were made:

A. Revised the scope and application of this data sheet.

B. Reorganized sections and recommendations to improve the flow of information.

C. Added clarification and additional guidance to existing recommendations, where applicable.

D. Deleted Tables 1a and 1b for approximate space guidance. The facility sitting section was revised and reorganized.

E. Revised the pipe racks protection section to include clarification for cases where pipe rack protection is needed, and developed protection guidance for indoor pipe racks.

F. Added new recommendations and support for recommendations for manual firefighting, steel protection and emergency-controlled shutdown and isolation sections.

G. Added a new protection section for flammable gases.

H. Updated the water-reactive materials and loading/unloading stations section.

I. Added an Appendix for ignitable liquid scenario development.

July 2019. Interim revision. Minor editorial changes were made.

January 2018. Interim revision. Minor editorial changes were made to be consistent with Data Sheet 1-22, *Maximum Foreseeable Loss*

July 2015. This entire data sheet has been revised. The following major changes were made:

A. Redefined the scope of the data sheet, including differentiating between Data Sheet 7-14 and Data Sheet 7-32, *Ignitable Liquid Operations.*

B. Redefined where passive steel protection is needed, including elimination of a previous reference to a “greater than average explosion hazard or severe three-dimensional fire hazard” in determining the need for fireproofing.

C. Incorporated guidance on facility siting from Data Sheet 7-44, *Spacing of Facilities in Outdoor Chemical Plants,* including the need to conduct a comprehensive study to determine appropriate separation between process units and other areas of a plant.

D. Added information on the use of sprinklers over water-reactive materials.

E. Added guidance on proper routing and protection of process safety critical cables.

F. Deleted the ignitable liquid volume thresholds for indoor locations (200 gal [0.8 m^3] for any one container or 2000 gal [7.6 m^3] in separate containers) and outdoor locations (400 to 500 gal [1.5 to 1.9 m^3] for any one container or 4000 to 5000 gal [15.1 to 18.9 m^3] in separate containers), instead relying on the revised scope of the document to determine fire protection needs.

G. Modified the vertical distance that area protection sprinkler design will effectively protect from 15 ft (4.6 m) to 30 ft (9.1 m).

H. Added specific guidance on the design of water spray systems rather than referring to Data Sheet 4-1, *Fixed Water Spray Systems for Fire Protection.* This includes information on the protection of the following components:

1. Below obstructions

2. Within vessel skirts

3. Vertical and horizontal structural steel

4. Process vessels and similar structures

5. Specific equipment such as pipe racks, pumps, fin-fin coolers, cable trays, and loading/unloading stations

I. Changed the demand for indoor sprinkler systems from simultaneous operation of all sprinklers over an area of 10,000 ft^2 (929 m^2) to a demand area based on the interconnectivity of levels (i.e., solid vs. grated floors, the presence of openings in levels, etc.)

J. Changed the demand for deluge systems from simultaneous operation of all systems within 100 ft (30.5 m) of the first involved deluge or water spray system to all systems within 50 ft (15 m). Where pneumatic heat actuated devices (HADs) are used to actuate deluge systems, the 100 ft (30.5 m) distance remains unchanged.

K. Incorporated information from Data Sheet 7-38, *Loss Prevention in Ethanol Fuel Production Facilities,* regarding the protection of processes using water miscible ignitable liquids.

L. Incorporated information from Data Sheet 7-47, *Physical Operations in Chemical Plants.*

M. Added guidance on the use of foam-water sprinkler systems and compressed air foam.

N. Deleted a recommendation for the use of automatic sprinklers in conjunction with draft curtains for outdoor locations.

O. Added new figures to assist in developing fire protection for indoor and outdoor facilities.

P. Added basic guidance on the design of process controls and process vessels, with reference to other data sheets for additional details.

Q. Provided additional information on the objectives of equipment to limit accidental releases of ignitable liquids, liquefied flammable gases, and flammable gases, including the need for facility specific standards and emergency response plans for isolation of such releases.

R. Added basic information on human factors (e.g., safety culture, emergency response, safe work permitting), with reference to other data sheets for additional details.

S. Added basic information on utilities (e.g., types of utilities, integrity of fire protection water supplies, load shedding), with reference to other data sheets for additional details.

T. Added basic information on contingency planning, including the integrity and reliability of deluge pilot systems, and the reliability of water supply pumping systems.

U. Expanded the guidance on ignition source control, with reference to other data sheets for additional details.

V. Expanded the information in Section 3, Support for Recommendations, including background information on passive fire protection (e.g., spacing and layout of chemical plants, drainage and containment, damage limiting construction, fireproofing), active fire protection (e.g., inclusion of recent fire test results for ethanol process structures, design of directional water spray systems), and information on the cost to complete installations of fire protection systems at chemical plants.

January 2013. Terminology and guidance related to ignitable liquids has been revised to provide increased clarity and consistency with FM Global's loss prevention recommendations for ignitable liquid hazards. In addition, the following significant changes have been made:

A. Changed the name of the data sheet from "Fire and Explosion Protection for Flammable Liquid, Flammable Gas, and Liquefied Flammable Gas Processing Equipment and Supporting Structures" to "Fire Protection for Chemical Plants."

B. Reorganized the document to be consistent with other data sheets.

C. Replaced references to "flammable" and "combustible" liquids with "ignitable liquids" throughout the document.

May 2004. References to various applicable ANSI/ASME standards were updated.

January 2000. This revision of the document has been reorganized to provide a consistent format.

APPENDIX C IGNITABLE LIQUID SCENARIO DEVELOPMENT

Processing facilities that handle large quantities of ignitable liquids or liquefied flammable gases present significant fire protection challenges. A thorough understanding of potential fire scenarios, along with available prevention and mitigation strategies, is essential for evaluating the potential impact of each scenario.

Protection schemes in such facilities typically consist of multiple protection layers designed to prevent incipient fires from escalating and causing severe damage to buildings, structures and equipment. These layers may include sprinkler systems, emergency drainage and containment, fireproofing, shutoffs and manual response capabilities.

Although scenario development involves a degree of subjectivity, it should follow a structured framework (see Figure C). The general steps include:

1. Initial Release and Pool Formation
2. Ignition and Fire Development
3. Escalation or De-escalation
4. Damage Assessment

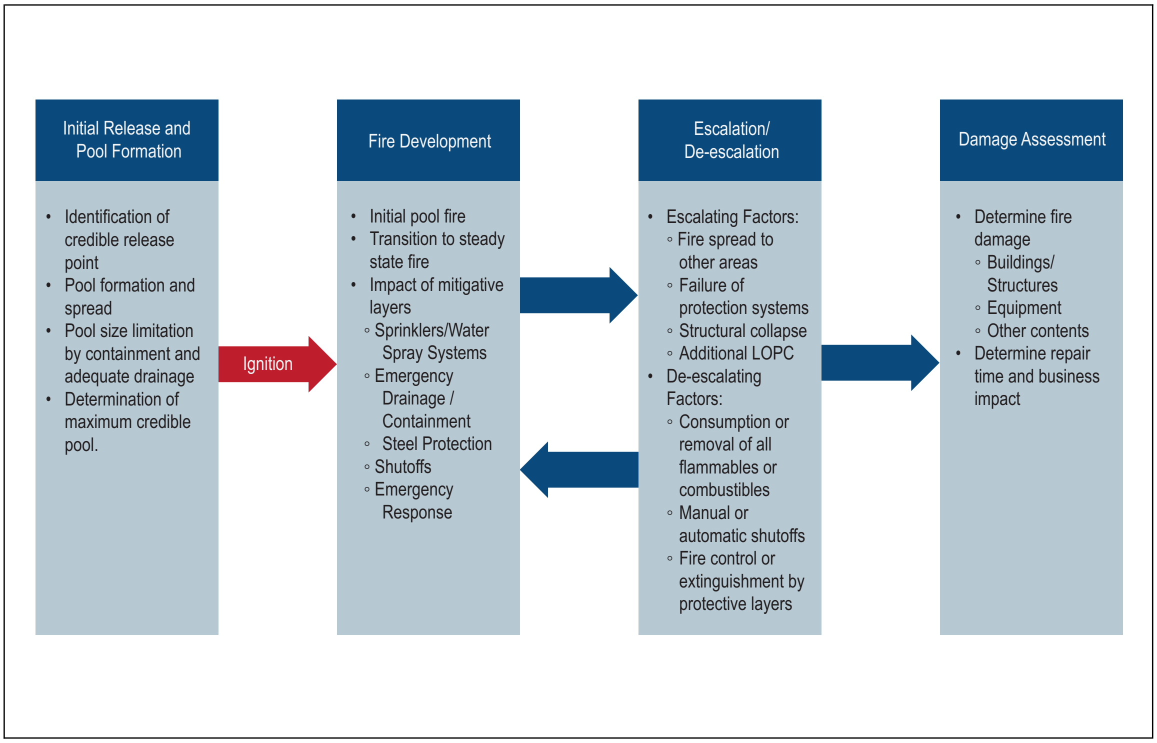

Fig. C. General steps for loss scenario development and damage assessment

C.1 Initial Release and Pool Formation.

This step focuses on identifying a credible release event that initiates a fire scenario, along with the factors that contribute to or limit the type and size of the expected release. The process begins with the initial loss of containment and outlines how the spill or release progresses before ignition. Protective layers at this stage intend to prevent the preignition release from escalating to a point where it becomes uncontrollable if ignited.

The first step in scenario development is to identify credible release points and assess the nature of the release before ignition. Consider the following:

A. **Credible Release Points:** Identifying a credible event is the starting point. It involves identifying potential areas capable of releasing large quantities of ignitable liquid. Common release points include bolted flanges, pump seals, fuel-fired heaters, sampling points, reactor seals, valves and frequently connected components. Failures in small-bore piping due to mechanical impact or breakage can also be considered as credible initiating event.

B. **Release Rate and Duration:** Determining the pool dimensions and any factors that can limit its size (i.e., emergency drainage, containment or leak detection systems) is crucial. Leak detection interlocked to shutoffs allow for early shutdown and can limit the release size.

C. **Spill Spread:** Evaluates how the released material may spread or accumulate, including the flow of the initial spill within the area and its potential spread to other areas where liquids may accumulate. Properly designed drainage can significantly limit pool development. On a flat surface, pools can spread to a thickness as little as 1/8th in. (3.17 mm) and still sustain combustion. Volatile liquids may vaporize, reducing total accumulation (e.g., LPGs).

Ignition may occur promptly or be significantly delayed following the initial release. Either scenario can result in a fire that is challenging to control, depending on the overall situation. Without proper drainage, containment or other spill control measures, a prolonged release can lead to large pools and potentially unprotectable fires.

C.2 Ignition and Fire Development

In this step, the expected type of ignition should be clearly defined, followed by a fire characterization. Ignition of the release can occur either immediately or after a significant delay, which will determine the nature of the resulting event. Immediate ignition typically leads to pool fires for liquid releases and jet fires for gas releases. In contrast, delayed ignition can result in explosions or vapor cloud explosions (VCEs) when the right conditions of confinement and congestion are present.

Ignition can occur at any point in the release cycle. If the initial release is contained in a thick and well-developed pool, the fire can burn for a significant period of time until the material is consumed. If the initial pool is a thinner film, the fire will ultimately burn back to the point of release. This situation will resolve into a steady-state fire, where the fire size stabilizes; and the amount of fuel being added and the material consumed by the fire are equal. As the fire develops, fire protection and other mitigating measures will impact the overall scenario. The following considerations can be applied:

A. Initial Pool Fire. Once the initial pool scenarios are developed, the initial fire can be characterized. The fire will spread throughout the footprint of spilled material. Depending on depth, the fire duration can be estimated. Most hydrocarbons will consume approximately 1/7th in. (3.5 mm) of material per minute. Thick pools can burn for long periods. This is particularly true of large spills into contained areas. Thin films will quickly burn back to the point of release.

B. Steady State Fire. Once thin film fires are ignited or deeper pools are consumed, the fire will resolve to a steady state fire (pool, jet or 3D), where the fuel is consumed at the same rate in which it is flowing into the fire. This fire size will be sustained until the flow of liquids can be stopped, or the fire is otherwise suppressed. The pool fire size may be truncated because of drainage, containment or similar physical factors. A 3D fire will form a steady state dynamic over a smaller area, as much of the material will be consumed before it reaches the ground. If trench drains are close enough to the spill source to intercept the flow, the footprint will be accordingly reduced. The footprint may be similarly impacted by other geometric factors in the process area.

To determine the steady state area of a continuous burning spill, the SFPE Handbook of Fire Protection Engineering provides guidance. A steady state burning spill area results due to a balance between the volumetric flow rate of the liquid release and the volumetric burning rate of the fire as described in Equation 1.

$$A_{SS} = V_L \times \rho / \dot{m}'' \qquad \text{Equation 1}$$

Where:

A_{SS} = Steady state area of a continuously burning fuel spill
V_L = Volumetric flow rate of the liquid fuel
$\dot{m}''$ = Fuel mass burning rate per unit area
ρ = Fuel density

Provided or lacking fire protection layers will impact the developed initial and steady state fires. For instance, sprinkler/water spray systems can cool buildings and equipment, while drainage systems can remove pre-spill and some of the mass of continuing spills. Fireproofing can minimize the damage and potential failure of structures or equipment. Ultimately, the fire will burn until the flow of materials is stopped, or all the material is consumed. The ability to shut off the flow of material is critical to terminate the event in a reasonable period.

C.3 Escalation/De-escalation

Escalation/de-escalation is a critical component of the assessment where a determination is made as to whether the event will materially escalate. This component includes the potential for additional piping or vessels to fail or protective systems to fail or be overwhelmed. Escalation can result in a minor or significant enlargement of the fire scenario.

After the initial pool fire and steady state fire have been characterized and the protective layers considered, additional evaluation is needed to determine whether escalation will occur or if the fire will reduce in size.

A. Escalation can be expected when the following factors are present:

- Inadequate fire protection
- Fire spread to additional areas
- Structural collapse of buildings or process areas
- Inadequate over-pressure protection for process equipment
- Failure of additional piping or vessels
- Failure to shut off the flow of material before water for fire protection systems and firefighting activities is consumed
- Initiating events beyond the capabilities of the installed protection

Indoor process areas are more likely to have escalation scenarios if protection deficiencies exist. Heat is trapped in this environment, and manual firefighting is difficult. If the fire progresses to the point where portions of the building start to collapse, rapid uncontrolled escalation is likely. Such fires can spread throughout the building, resulting in total loss to both building and equipment.

Escalation in outdoor fires is usually more limited. Heat is vented and access for manual response is better. The key consideration is whether additional piping or vessels will become involved, resulting in a larger steady state fire. Failure (BLEVE) of large vessels has also been a key point of escalation in significant events. The level of escalation is typically defined by the total volume available to burn, drainage, containment, etc.

B. De-escalation. Some of the de-escalating factors may include:

- Consumption of all fuel in the fire
- Shutting off the flow of materials (shutoffs)
- Effective fire protection or manual response, resulting in a reduction in size of the fire.

In most cases, very large flammable gas or ignitable liquid fires will continue to burn until the fuel source is isolated. Automatic shutoff often provides the most effective and reliable way to isolate flow, especially in buildings or other difficult-to-access areas. Manual shutoffs may also be effective; if they are accessible during the fire, and responders are properly trained on their location and use.

C.4 Damage Assessment

Once the scenario is developed and the consequences evaluated, understanding the impact of the potential damage to the area is important, including the business impact while production is being restored.