# FIRE PROTECTION FOR CHEMICAL PLANTS

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## 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 ignitable liquid, flammable gas, and liquefied flammable gas where a release could result in a fire of long duration. It also covers operations involving reactive chemical hazards.

This data sheet also provides guidance on determining appropriate space separation between chemical process units, and recommendations for the construction of process areas. It also presents recommendations for protecting indoor and outdoor process areas, supporting structures, and processing equipment that handles ignitable liquid, flammable gas, and liquefied flammable gas.

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

A. Dispensing of ignitable liquid: Use Data Sheet 7-32, *Ignitable Liquid Operations.*

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

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

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

E. Aerosol storage: Use Data Sheet 7-31, *Storage of Aerosol Products.*

F. Compressed gas storage: Use Data Sheet 7-50, *Compressed Gases in Portable Cylinders and Bulk Storage.*

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

### 1.1 Where to Use This Data Sheet

Fire scenarios at chemical processing plants include pool fires, three-dimensional (3D) spill fires, jet fires, flash fires, or a combination of these. The type of release and resulting fire depend on factors such as material characteristics, quantities, operating conditions (e.g., temperature, pressure, flow rate), equipment and piping materials of construction, and unit operations and arrangements.

A direct relationship exists between the volume of ignitable liquid released and the resulting fire severity. If the ignitable liquid release is limited, basic fire protection features will serve to control the fire and limit fire spread. Conversely, a large and continuous flow of ignitable liquid can potentially result in a growing and sustained fire condition. Therefore, FM’s most fundamental recommendation pertaining to ignitable liquids is to limit the amount of liquid that can become involved in a fire; this is addressed in detail in Data Sheet 7-32, Ignitable Liquid Operations.

However, at a chemical processing plant, this is often not possible.

This data sheet accounts for larger ignitable liquid release volumes at chemical plants, 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.

### 1.2 Changes

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

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 skirts3. 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.

## 2.0 LOSS PREVENTION RECOMMENDATIONS

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

### 2.1 Construction and Location

#### 2.1.1 Facility Siting

2.1.1.1 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.

2.1.1.1.1 Tables 1a and 1b may be used as a first approximation for layout purposes. Base detailed spacing and location decisions on a formal, documented hazard analysis

*Table 1a. Approximate Spacing Guide (ft)*

| *The spacing in this table is related to fire and explosion protection only, not for the hazards of toxic or corrosive releases.* | *Boiler Houses, Power Generation* | *Electric Substations, Main* | *Service/Administration Buildings* | *Underground High Pressure Flammable4 Gas Lines* | *Fire Protection Water Sources* | *Control Rooms, Central* | *Main Pipe Racks* | *Process Unit, High Hazard* | *Process Unit, Low Hazard* | *Tank Farms, Pressurized Flammable* | *Tank Farms, atmospheric* |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Tank Farms, atmospheric | | | | | | | | | | | C |
| Tank Farms, Pressurized Flammable | | | | | | | | | | B | 100 |
| Process Unit, Low Hazard | | | | | | | | | 100 | 200 | C |
| Process Unit, High Hazard | | | | | | | | 200 | 200 | 200 | C |
| Main Pipe Racks | | | | | | | NA | 100 | 50 | A | 100 |
| Control Rooms, Central | | | | | | A | 100 | 200 | 100 | 200 | 150 |
| Fire Protection Water Sources | | | | | NA | A | 200 | 200 | 100 | 200 | 150(D) |
| Underground High Pressure Flammable Gas Lines | | | | NA | 300 | 300 | A | 150 | 150 | 150 | 100 |
| Service/Administration Buildings | | | NA | 300 | A | A | 100 | 200 | 200 | 200 | C |
| Electric Substations, Main | | A | 100 | 300 | 100 | 100 | 100 | 200 | 100 | 200 | C |
| Boiler Houses, Power Generation | A | A | 100 | 300 | A | 100 | 100 | 200 | 100 | 200 | C |
| A = Space as needed for operation and maintenance. | | | | | | | | | | | |
| B = Refer to Data Sheet 7-55 for limitations on LPG storage and Data Sheet 7-91 for limitations on hydrogen storage. | | | | | | | | | | | |
| C = Refer to Data Sheet 7-88, Tables 2, 3, and 4. No multi tank quantity limit at chemical plants. | | | | | | | | | | | |
| D = One of multiple sources; single source at least 200 ft. | | | | | | | | | | | |

*Table 1b. Approximate Spacing Guide (m)*

| *The spacing in this table is related to fire and explosion protection only, not for the hazards of toxic or corrosive releases.* | *Boiler Houses, Power Generation* | *Electric Substations, Main* | *Service/Administration Buildings* | *Underground High Pressure Flammable Gas Lines* | *Fire Protection Water Sources* | *Control Rooms, Central* | *Main Pipe Racks* | *Process Unit, High Hazard* | *Process Unit, Low Hazard* | *Tank Farms, Pressurized Flammable* | *Tank Farms, atmospheric* |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Tank Farms, atmospheric | | | | | | | | | | | C |
| Tank Farms, Pressurized Flammable | | | | | | | | | | B | 30 |
| Process Unit, Low Hazard | | | | | | | | | 30 | 60 | C |
| Process Unit, High Hazard | | | | | | | | 60 | 60 | 60 | C |
| Main Pipe Racks | | | | | | | NA | 30 | 15 | A | 30 |
| Control Rooms, Central | | | | | | A | 30 | 60 | 30 | 60 | 45 |
| Fire Protection Water Sources | | | | | NA | A | 60 | 60 | 30 | 60 | 45 (D) |
| Underground High Pressure Flammable Gas Lines | | | | NA | 90 | 90 | A | 45 | 45 | 45 | 30 |
| Service/Administration Buildings. | | | NA | 90 | A | A | 30 | 60 | 60 | 60 | C |
| Electric Substations, Main | | A | 30 | 90 | 30 | 30 | 30 | 60 | 30 | 60 | |
| Boiler Houses, Power Generation | A | A | 30 | 90 | A | 30 | 30 | 60 | 30 | 60 | C |

A = Space as needed for operation and maintenance.‘

B = Refer to Data Sheet 7-55 for limitations on LPG storage and Data Sheet 7-91 for limitations on hydrogen storage.

C = Refer to Data Sheet 7-88, Tables 2, 3, and 4. No multi tank quantity limit at chemical plants.

D = One of multiple sources; single source at least 60 m.

2.1.1.1.2 Use a consequence-based evaluation to finalize site-specific spacing distances. Use current best practices in conducting this evaluation, such as those outlined in API RP 752, *Facility Siting Requirements and How They Affect Your Company,* and CCPS, *Guidelines for Evaluating Process Plant Buildings for External Explosions and Fires.* 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 (see API 537, *Flare Details for General Refinery and Petrochemical Service,* for guidance).

C. Potential for explosion or blast overpressure from high hazard operations such as ethylene oxide, hydrogen peroxide, organic peroxides, energetic materials (explosives), ammonium nitrate, etc. (see other applicable FM data sheets).

D. Potential for pressure vessel rupture (see Data Sheet 7-0, *Causes and Effects of Fires and Explosions*).

E. Potential for a vapor cloud explosion (see Data Sheet 7-42, *Evaluating Vapor Cloud Explosions Using a Flame Acceleration Method*).

### 2.1.2 Location of Hazardous Processes

2.1.2.1 Locate processes using large quantities of ignitable liquids, flammable gases or liquefied flammable gases in open structures with minimal enclosure.

2.1.2.2 Where it is not possible to locate processes in open structures and the process or materials handled create a room or building explosion potential, use damage limiting construction (DLC). (See Data Sheet 1-44, *Damage-Limiting Construction.*)

### 2.1.3 Three-Dimensional Spill Fire Control

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

A. Locate equipment (vessels, 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.

### 2.1.4 Containment and Emergency Drainage

2.1.4.1 Provide containment and emergency drainage for processing units that create an ignitable liquid pool fire exposure as follows:

A. Provide containment around any exterior areas with the potential for an ignitable liquid release (e.g., process structures, processing equipment).

B. 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.

C. Design containment and emergency drainage in accordance with Data Sheet 7-83, Drainage and Containment Systems for Ignitable Liquids. Design drainage systems for the maximum anticipated fire protection demand, which may include simultaneous operation of multiple fire protection systems and monitor nozzles.

D. As an alternative to emergency drainage, install an FM Approved foam water sprinkler system or compressed air foam system, designed in accordance with Section 2.3.8.

E. Do not locate equipment with ignitable liquid holdup below grade.

### 2.1.5 Steel Protection

2.1.5.1 Provide steel protection on the main structural steel and equipment supports (load-bearing members) for process areas with the potential for a 3D spill, long-duration pool, or spray fire to occur, including but not limited to the following:

A. Processes using in excess of 2600 gal (10 $m^3$) of ignitable liquid

B. Liquefied flammable gas and flammable gas processing units

2.1.5.2 Protection of specific structural members is justified if all of the following are true:

A. The members are load bearing, and

B. The members support structures or equipment that are critical to the facility’s operation, and

C. The steel can be directly exposed to an ignitable liquid 3D spill or pool fire. In general, the structural element must be immersed in the spill or pool fire for an extended duration to necessitate protection.

2.1.5.3 Where steel protection is needed, provide one of the following:

A. FM Approved fireproofing based on a hydrocarbon fire exposure rated for two hours or the expected fire duration, whichever is greater (see Data Sheet 1-21, *Fire Resistance of Building Assemblies*).

B. Active fire protection installed in accordance with Section 2.3.6.

C. Where recommended above, install passive or active fire protection to a height of at least 10 ft (3 m) above normal ignitable liquid levels in a vessel, or up to 30 ft (9.1 m) above levels where a pool fire can occur.

### 2.1.6 Exothermic Reactions

2.1.6.1 Where adequate overpressure protection cannot be provided, arrange processes involving highly exothermic chemical reactions as follows:

A. Locate away from other processes in a building of fully damage-limiting construction, at a distance sufficient to prevent damage to exposed processes as determined by a formal siting study.

B. Isolate the process from nearby operations with blast or pressure-resistant walls to direct the blast in a safe direction.

Exothermic reactions that are properly protected against overpressure need no special provisions with respect to location (see Data Sheet 7-49, *Emergency Venting of Vessels,* for guidance on overpressure protection).

### 2.1.7 Water-Reactive Chemicals

2.1.7.1 Where water-reactive chemicals are produced or present in significant amounts such that application of water from sprinklers will significantly increase the fire severity, sprinklers may be omitted if the process is isolated from nearby operations by a minimum distance of 100 ft (30 m).

Alternatively, provide all of the following safeguards:

A. Two-hour fire-rated construction for the process area, as well as any walls between the process and lower hazard operations, and

B. Where an explosion hazard exists, damage-limiting construction, and

C. Where ignitable liquids are also present, interlocks (e.g., firesafe shutoff valves) to control the liquid release.

This recommendation does not apply to processes using water-reactive materials as catalysts.

### 2.1.8 Loading and Unloading Stations

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

2.1.8.2 Single vehicle stations may be located close to the received product's point of end use.

2.1.8.3 For additional spacing guidance, see Data Sheet 7-88, *Ignitable Liquid Storage Tanks.*

### 2.1.9 Cable Trays and Safety Critical Cabling

2.1.9.1 Install and protect cable trays in accordance with Data Sheet 5-31, *Cables and Bus Bars.*

2.1.9.2 Provide the following for safety critical cables:

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

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

C. Provide a 1-hour fire-rated, FM Approved fire wrap for safety 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.

## 2.2 Occupancy

### 2.2.1 In-Process Ignitable Liquid Storage

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

### 2.2.2 Mechanical Ventilation

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

2.2.1.1.1 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.

## 2.3 Protection

### 2.3.1 General

2.3.1.1 The recommendations in this section are applicable to 3D spill and pool fire scenarios involving ignitable liquids and liquefied flammable gases.

2.3.1.2 This section does not apply where the only hazard present is flammable gas. Facilities processing only flammable gas may require local levels of passive or active fire protection, but the higher levels of sprinkler and water spray protection outlined in this section are not applicable. Refer to Section 2.1.5.

### 2.3.2 Indoor Fire Protection

#### 2.3.2.1 Indoor Fire Protection: General

Install automatic wet, deluge, or preaction sprinkler systems when the occupancy to be protected is located inside a building. 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. Refer to Figures 1 and 2 for examples of fire protection layout and design for indoor locations.

A. Provide area coverage below the roof and below solid- and open-grated intermediate operating levels.

B. 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.

C. 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. Install sprinklers below vessels on a maximum 50 $ft^2$ (4.6 $m^2$) spacing. Important structural members or equipment below obstructions may need additional passive or active protection against flame impingement.

D. Provide protection inside nonfireproofed skirts of columns or similar self-supporting vessels where valves or flanged connections are present inside the skirt enclosure, or where ignitable liquids could enter the skirt enclosure through skirt openings following an external release.

E. Where active or passive protection of critical steel elements (including structural elements and equipment supports) is necessary in accordance with Section 2.1.5, provide active fire protection for elements where fireproofing is not applied.

#### 2.3.2.2 Indoor Fire Protection: Design

2.3.2.2.1 Design area protection of indoor processes as follows:

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

E. Arrange sprinklers with an on-line spacing of 10 ft (3 m). For cases where obstructions exist, increased or decreased spacing is acceptable provided good sprinkler coverage is achieved.

F. 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.

G. Design sprinklers located below obstructions to provide at least 30 gpm (114 L/min) and maintain a minimum sprinkler discharge pressure of at least 7 psi (0.5 bar).

H. 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.* Design detection systems to transmit an alarm to a constantly attended location, preferably the process control room.

I. Space detectors for preaction systems as follows:

1. Install electric or pneumatic detectors at a spacing of one-half the listed linear detector spacing, or the full sprinkler spacing, whichever is greater. For design purposes, treat preaction systems with this detector spacing the same as wet systems. If a preaction system has a detector spacing greater than the above spacing, consider it a dry system for design purposes. Refer to the *Approval Guide for the maximum allowable spacing.*

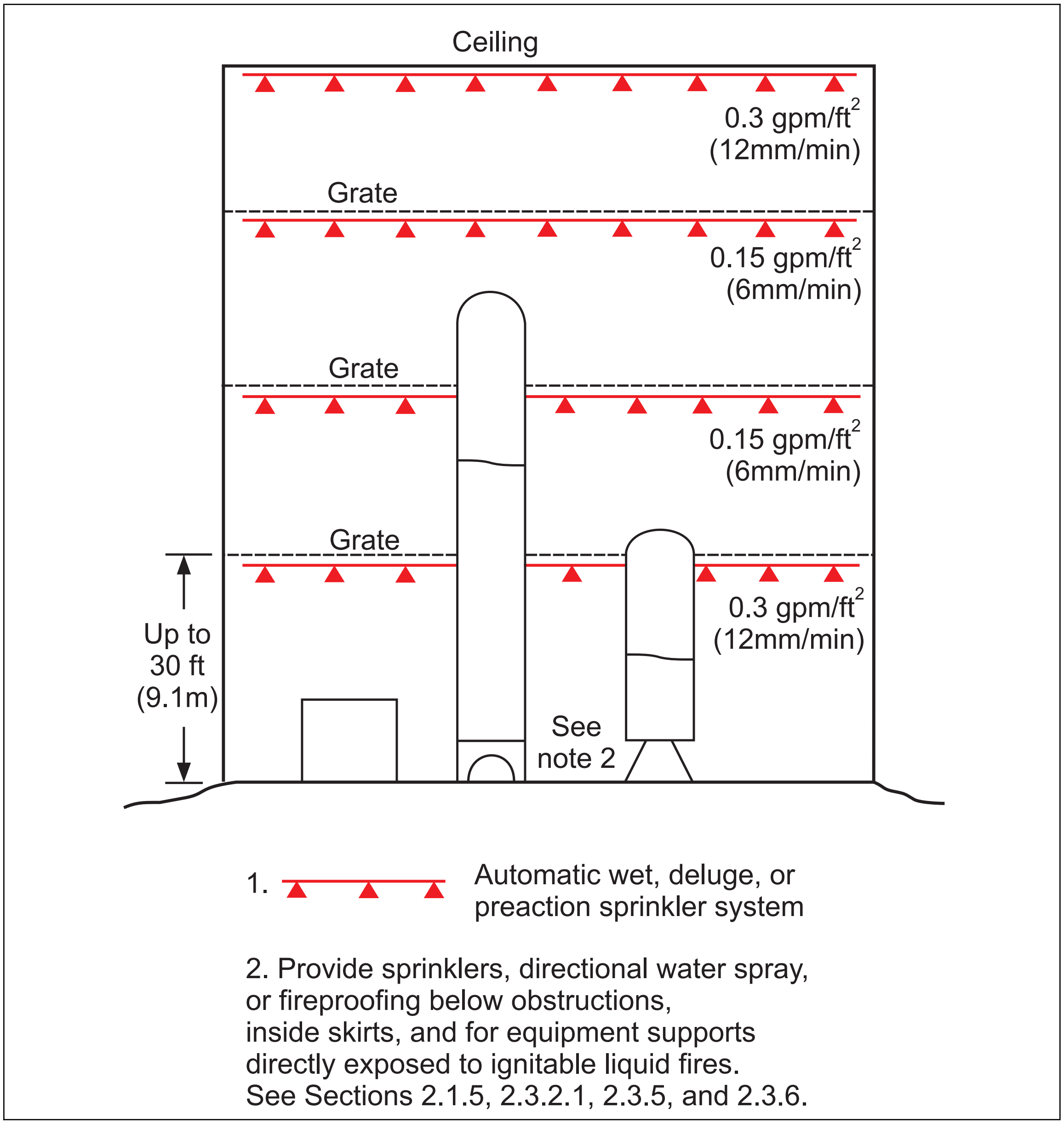



*Fig. 1. Indoor processing structures: example of fire protection with grated floors*

2. Install pilot sprinklers on the same spacing as the sprinklers. For design purposes, treat preaction systems with this pilot sprinkler spacing the same as wet systems. If a preaction system has a pilot sprinkler spacing greater than the sprinkler spacing, consider it a dry system for design purposes.

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

2.3.2.2.2 Design sprinkler or water spray systems for the protection of other structures or equipment as follows:

- Process vessels: Section 2.3.4
- Skirts: Section 2.3.5
- Structural steel: Section 2.3.6
- Other equipment (pipe racks, pumps, air-fin coolers, etc.): Section 2.3.7

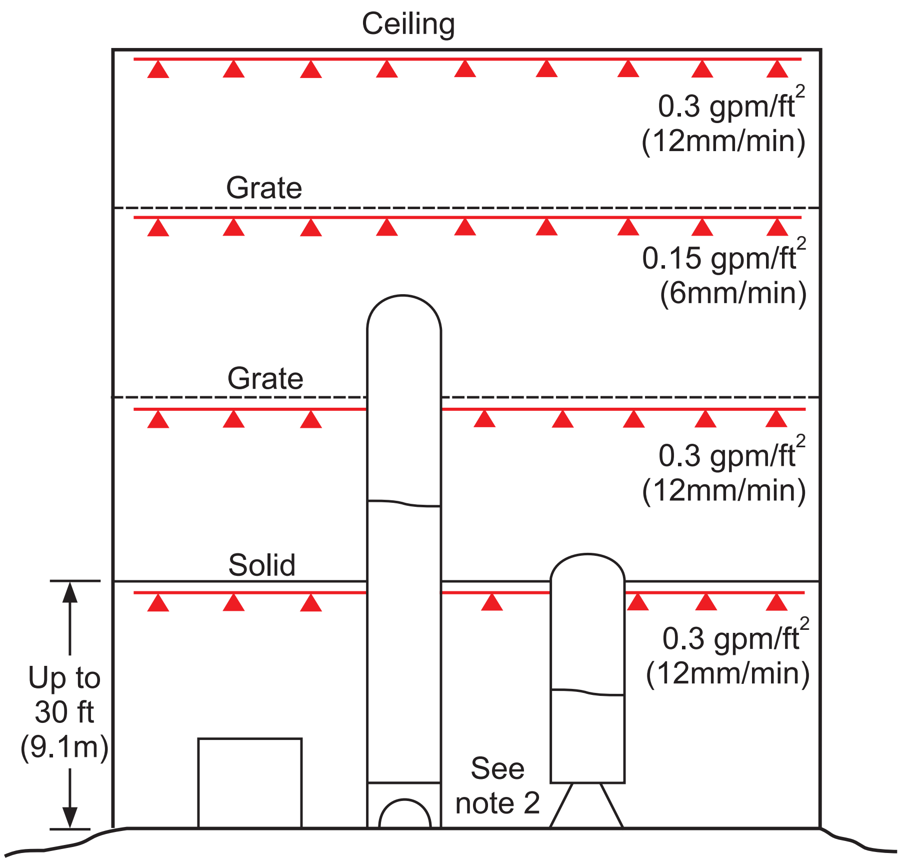



*Fig. 2. Indoor processing structures: example of fire protection with grated and solid floors*

### 2.3.2.3 Indoor Fire Protection: Demand

2.3.2.3.1 Where wet or preaction systems are provided, design for simultaneous operation of all ceiling- and intermediate-level sprinklers over the following areas:

- 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. See Figure 3a.
- 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 3b.
- Where large (>400 $ft^2$ [37 $m^2$]), liquid tight openings exist in 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 3c.

- Where small (<400 $ft^2$ [37 $m^2$]), liquid tight openings exist in solild floors, design for a 10,000 $ft^2$ (929 $m^2$) operating area on the hydraulically most remote level. In addition, design for sprinklers with 20 ft (6.1 m) of each opening to operate on all other connected levels. See Figure 3d.
- Where small (less than 6 in. [15 cm] wide), liquid-tight openings exist around vessels, there is no need to adjust for the opening of scattered individual sprinklers that may occur beyond that stated above.

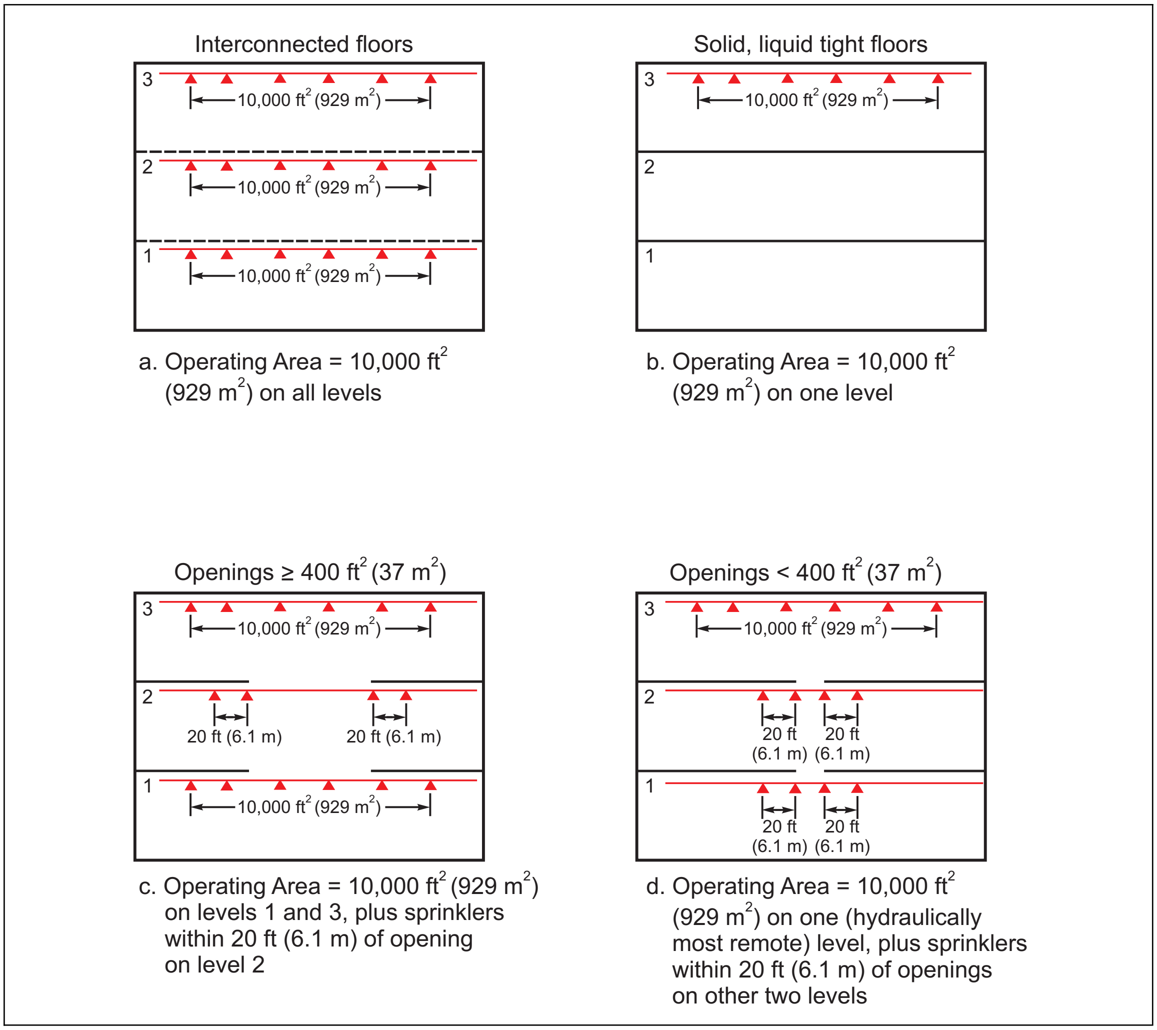



*Fig. 3. Sprinkler operating areas for indoor chemical plants*

2.3.2.3.2 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 extent of 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).

2.3.2.3.3 Include the flow for all local sprinklers (e.g., protection of equipment or structural steel, beneath vessels or other obstructions, inside skirts, etc.) in the demand specified in Sections 2.3.2.3.1 and 2.3.2.3.2.

2.3.2.3.4 In addition to the above, 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).

### 2.3.2.4 Indoor Fire Protection: Duration

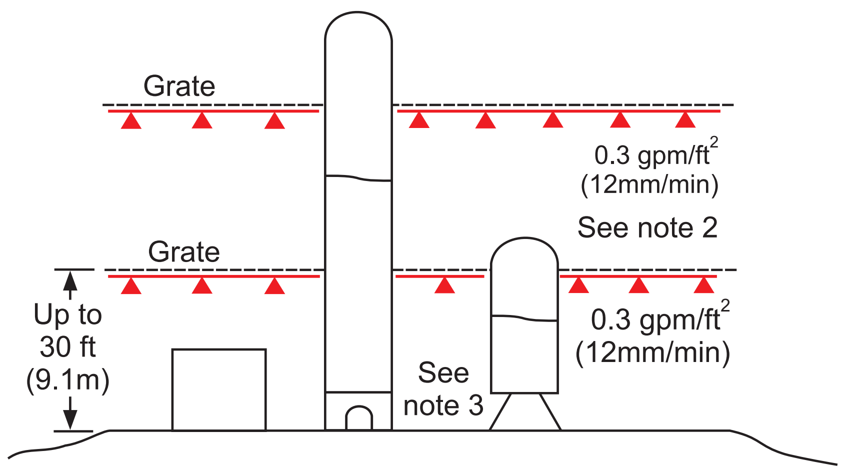
2.3.2.4.1 Provide a water supply capable of maintaining discharge and pressure requirements until the ignitable liquid flow can be shut off and the area drained, or the ignitable liquid is consumed. Requirements will vary with each installation.

2.3.2.4.2 Provide a minimum duration of two hours.

### 2.3.3 Outdoor Fire Protection

### 2.3.3.1 Outdoor Fire Protection: General

2.3.3.1.1 Install automatic deluge and/or directional water spray when the occupancy to be protected is located outdoors. Do not use dry pipe systems. Refer to Figures 4 and 5 for examples of fire protection layout and design for outdoor locations.




1. Deluge area protection

2. Protection may or may not be needed more than 30 ft (9.1 m) above grade, depending on the height of ignitable liquid in vessels or equipment. Providing directional water spray on liquid filled, high value and long leadtime equipment above the 30 ft (9.1) level may be more practical.

3. Provide sprinklers, directional water spray, or fireproofing below obstructions, inside skirts, and for equipment supports directly exposed to ignitable liquid fires. See Sections 2.1.5, 2.3.3.3, 2.3.5, and 2.3.5.

*Fig. 4. Outdoor processing structure: example of area-level deluge protection*

2.3.3.1.2 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 release. 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.

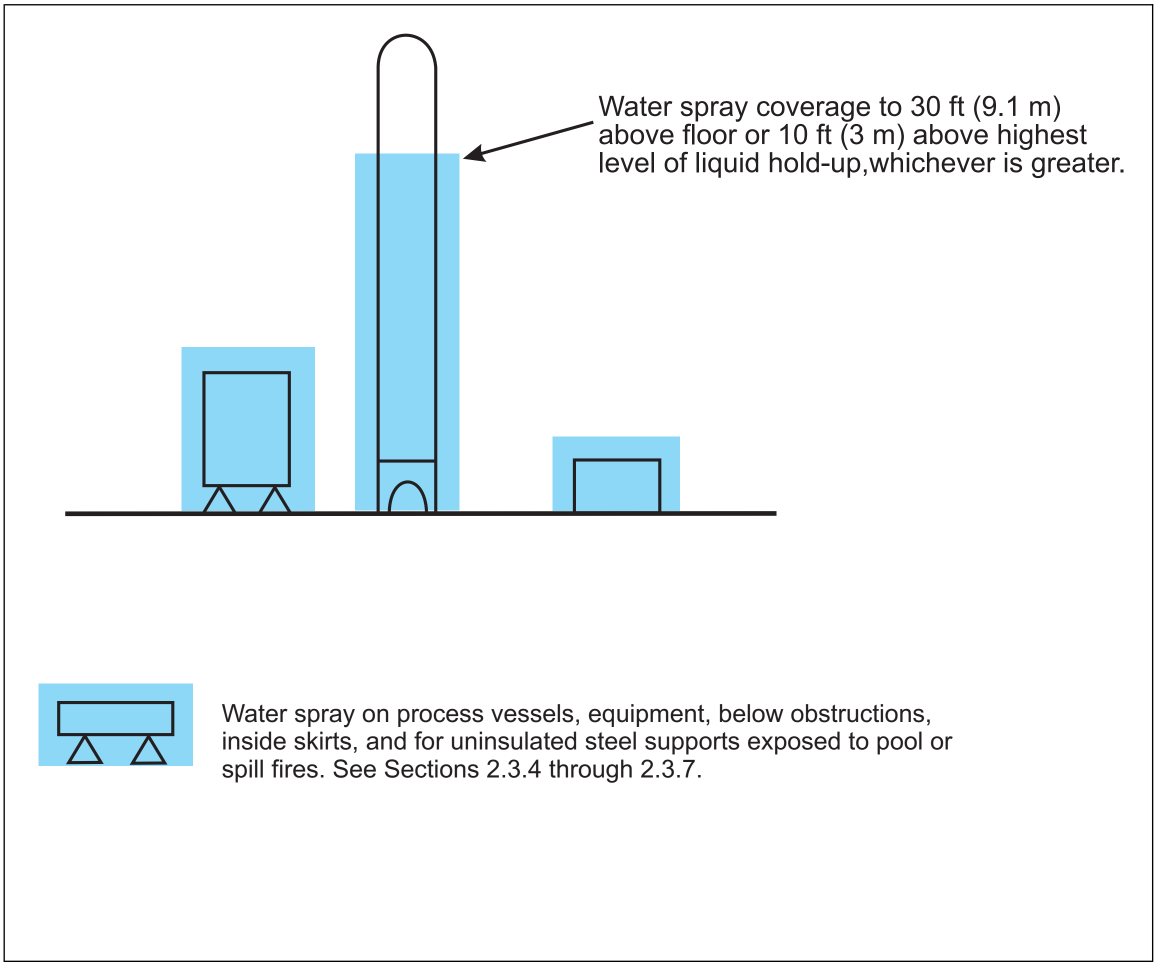



*Fig. 5. Outdoor processing structure: example of directional water spray protection of vessels*

2.3.3.1.3 Where fire protection is deemed necessary to protect the ignitable liquid fire hazard, locate and arrange the protection as follows:

A. Provide protection at least to a height of 10 ft (3.0 m) above normal ignitable liquid levels within the vessels, or up to 30 ft (9.1 m) above the height where an ignitable liquid pool fire may develop, whichever is higher (see Figure 5). Physical arrangement of the process structure and equipment will determine which protection arrangement (i.e., area protection, directional water spray, or a combination of the two) is most practical.

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

C. 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.

D. 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. Install sprinklers below vessels on a maximum 50 $ft^2$ (4.6 $m^2$) spacing. Important structural members or equipment below obstructions may need additional passive or active protection against flame impingement.

E. Provide protection inside nonfireproofed skirts of columns or similar self-supporting vessels where valves or flanged connections are present inside the skirt enclosure, or where ignitable liquids could enter the skirt enclosure through skirt openings following an external release.

F. Where active or passive protection of critical steel elements (including structural elements and equipment supports) is necessary in accordance with Section 2.1.5, provide active fire protection for elements where fireproofing is not applied.

### 2.3.3.2 Outdoor Fire Protection: Design

2.3.3.2.1 Design area deluge protection of outdoor process structures as follows:

A. Provide 0.3 gpm/ft$^2$ (12 mm/min) (K ≥ 5.6 [80]) per required protection level.

B. For process structures involving water-miscible ignitable liquids (with the exception of acetone), the following protection scheme may be used as an alternative to part A above:

1. 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).

2. Provide local water spray over equipment that is located above the area protection level and is exposed to three dimensional spill fires.

See Figure 6 for an example. See Appendix A for a complete list of water-miscible liquids. For acetone, which creates a more severe fire than other water-miscible liquids, follow the guidance in this data sheet for non-water-miscible liquids.

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

D. Arrange sprinklers with a maximum on-line spacing of 10 ft (3 m). For cases where obstructions exist, increased or decreased spacing is acceptable provided good sprinkler coverage is achieved.

E. Design open sprinklers located below obstructions to provide at least 30 gpm (114 L/min) and maintain a minimum discharge pressure of at least 7 psi (0.5 bar).

F. Actuate deluge systems using pilot sprinklers, or via 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.

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

H. For water spray systems using nozzles with less than 3/8 in. (9.5 mm) orifice, provide strainers designed to remove particles less than the smallest sprinkler orifice used in the design.

2.3.3.2.2 Design sprinkler or water spray systems for the protection of other structures or equipment as follows:

- Process vessels: per Section 2.3.4
- Skirts: per Section 2.3.5
- Structural steel: per Section 2.3.6
- Other equipment (pipe racks, pumps, air-fin coolers, etc.): per Section 2.3.7

### 2.3.3.3 Outdoor Fire Protection: Demand

2.3.3.3.1 Determine the design operating area based on largest number of systems expected to operate. Assume simultaneous operation of all systems within a 50 ft (15 m) distance of the extent of 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).

2.3.3.3.2 In addition to the above, 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).

2.3.3.3.3 At large hydrocarbon processing facilities, providing fixed monitor nozzles is considered a best practice. Where provided, arrange monitor nozzles to ensure all areas of the process unit can be reached by a minimum of two nozzles. Where provided, 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 (L/min).

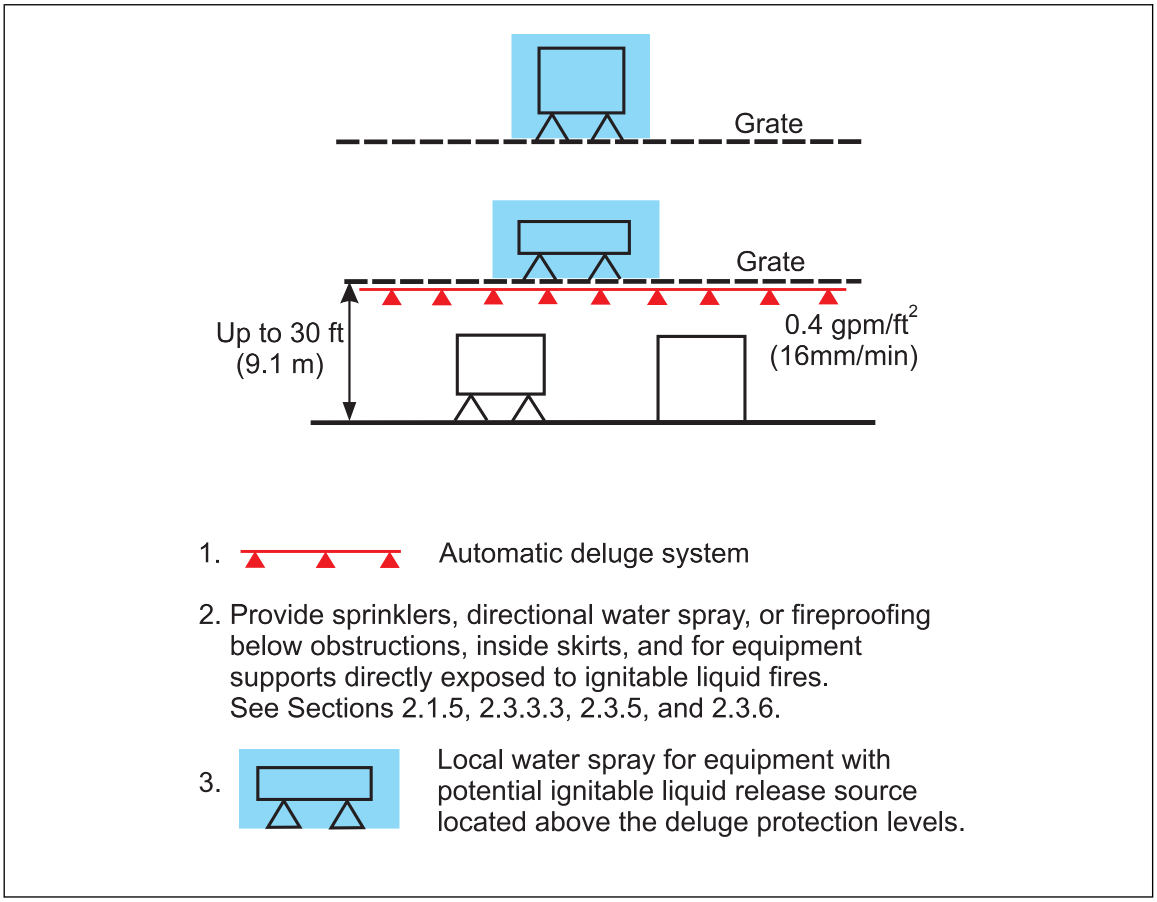



*Fig. 6. Single deluge protection level for outdoor process structures with water/miscible ignitable liquids*

#### 2.3.3.4 Outdoor Fire Protection: Duration

2.3.3.4.1 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 the ignitable liquid is consumed. Requirements will vary with each installation.

2.3.3.4.2 Provide a minimum duration of two hours.

### 2.3.4 Directional Water Spray Protection of Process Vessels and Similar Structures

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

Section 3.4.4.2 provides a comparison of rundown and direct impingement design concepts.

2.3.4.2 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 10 psi (0.7 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 rates 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).

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

2.3.4.4 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 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.

2.3.4.5 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.

2.3.4.6 Refer to Data Sheet 4-1N, *Fixed Water Spray Systems for Fire Protection,* for piping and other general recommendations for directional water spray systems.

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

### 2.3.5 Interior Skirt Protection

2.3.5.1 Where protection inside the skirts of columns or similar self-supporting vessels is needed, provide one of the following:

A. Passive fire protection in accordance with Section 2.1.5.

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.

### 2.3.6 Protection of Structural Steel

#### 2.3.6.1 Vertical Elements

Where protection of structural steel is needed (refer to Section 2.1.5), provide one of the following:

A. Passive fire protection in accordance with Section 2.1.5.

B. Automatic sidewall sprinklers or directional water spray protection, as shown in Figure 7, using direct impingement or rundown design.

Figure 7 shows nozzles installed 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. 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. Provide a minimum 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 ("wetted area" is the surface area on the three sides of the reentrant space formed by the column web and flanges).

#### 2.3.6.2 Horizontal Elements

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

2.3.6.2.2 Where area protection is provided under a ceiling, canopy, or mezzanine level per Sections 2.3.2.2.1 (indoor locations) or 2.3.3.2.1 (outdoor locations), additional local water spray protection is not necessary for the steel at that level.

2.3.6.2.3 Where additional protection is needed for horizontal members, provide one of the following:

A. Passive fire protection in accordance with Section 2.1.5.

B. Water spray protection for the exposed members designed to provide 0.1 gpm/ft$^2$ (4mm/min).

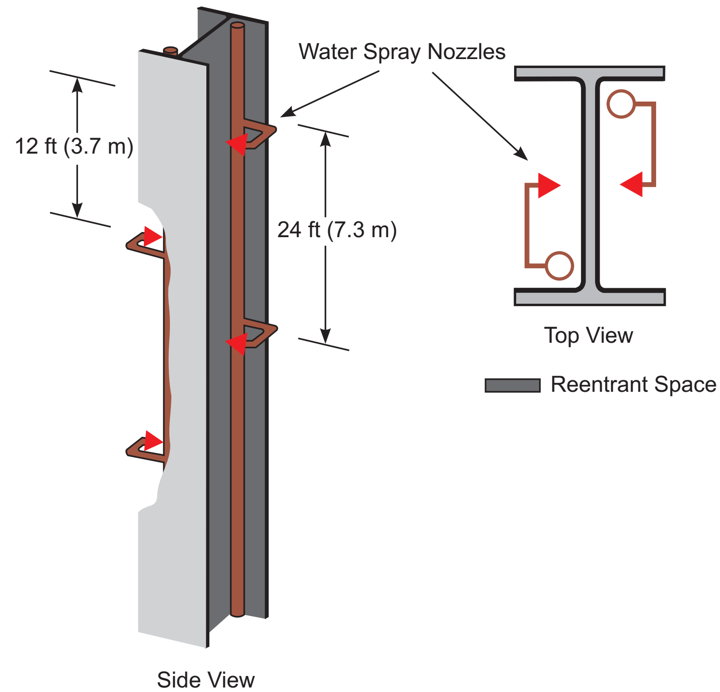



*Fig. 7. Water spray protection for steel columns*

### 2.3.7 Protection of Other Equipment

#### 2.3.7.1 Pipe Racks

2.3.7.1.1 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 the limits of the outdoor process structure. 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.

2.3.7.1.2 Install sprinklers or nozzles below the pipe rack so discharge is directed vertically upward to the underside of the rack. Design to provide 0.25 gpm/ft$^2$ (10 mm/min).

2.3.7.1.3 Install additional levels of sprinklers or nozzles above the first tier and alternate tiers above. Direct the water discharge vertically upward to the underside of the rack, designed to provide 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. Refer to Figure 8 for an example.

2.3.7.1.4 Do not locate cables at the bottom level of a pipe rack.

2.3.7.1.5 Arrange cable trays horizontally rather than stacking them vertically.

#### 2.3.7.2 Pumps

2.3.7.2.1 Provide fire protection for pumps that are important to continued 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.

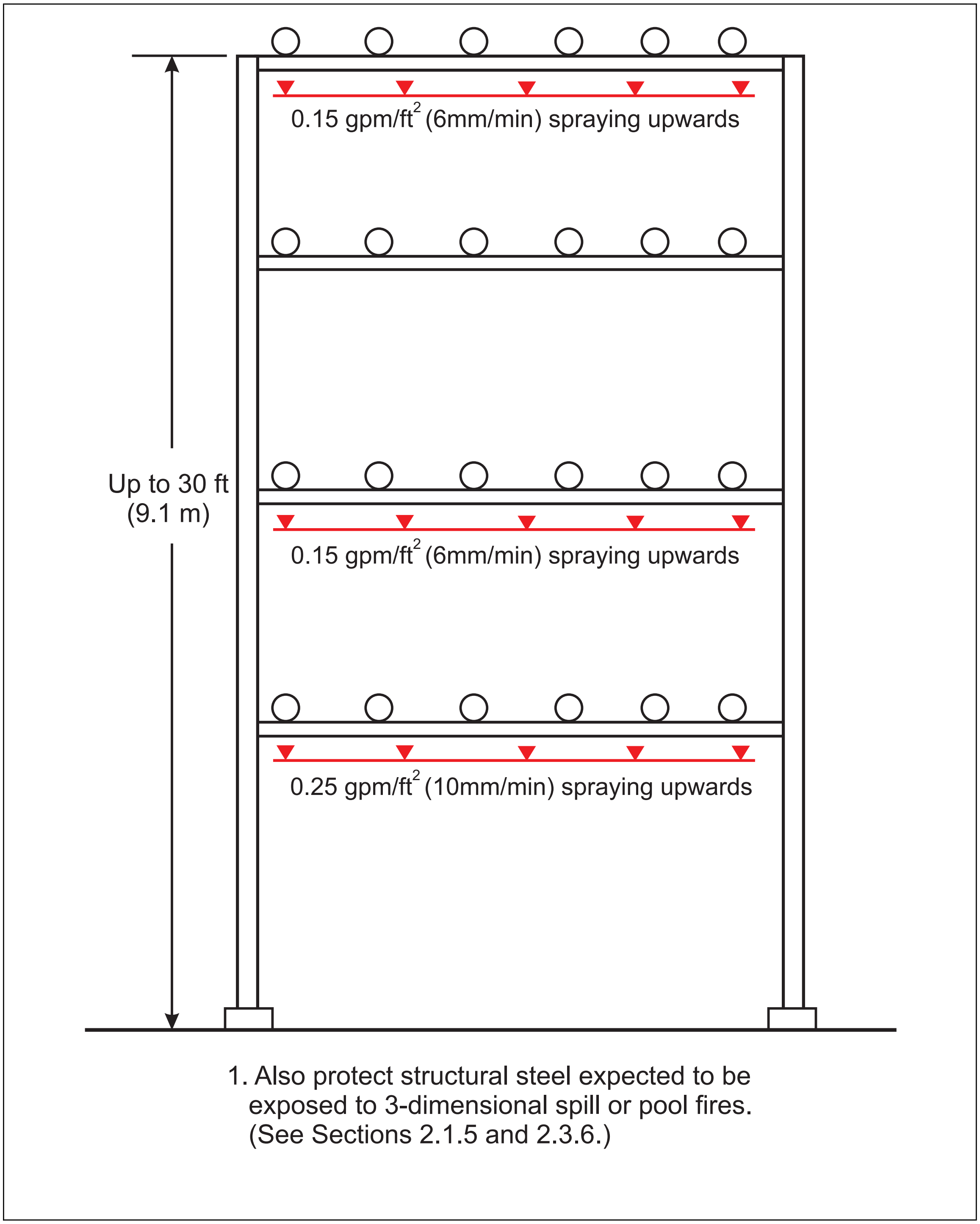



*Fig. 8. Fire protection of pipe racks*

### 2.3.7.3 Fin-Fan Coolers

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

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.

2.3.7.3.2 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 9).

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 2.1.5).

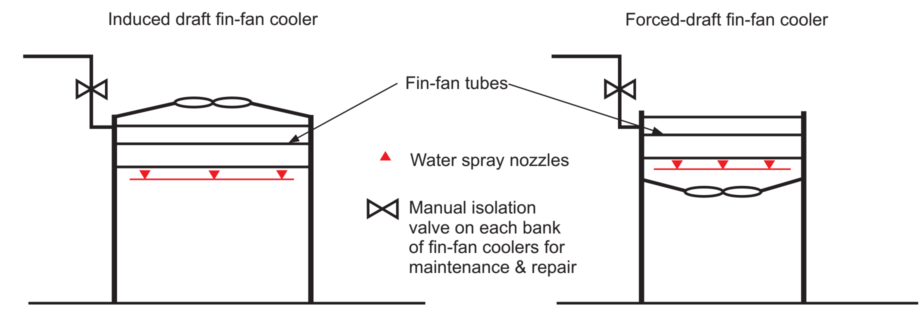



*Fig. 9. Fire protection of fin-fan coolers*

### 2.3.7.4 Loading/Unloading Stations

2.3.7.4.1 Provide deluge or water spray protection for loading and unloading stations that expose high-value facilities (i.e., are not located in accordance with Section 2.1.8), or if the loading station is vital to production.

2.3.7.4.2 Design the deluge or water spray system per Section 2.3.3.

### 2.3.8 Foam-Water Sprinkler Systems

Automatic sprinkler or deluge protection may be supplemented with an FM Approved foam-water or compressed air foam (CAF) system to limit fire damage or as an alternative to an emergency drainage system. Design the system as follows:

A. Use a foam concentrate that is compatible with the materials being handled. For polar solvents, use alcohol resistant (AR) foam.

B. Install the system in accordance with Data Sheet 4-12, *Foam-Water Sprinkler Systems.*

C. 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 density is larger, over the full demand area.

D. If a CAF system is used, hydraulically design the system in accordance with the manufacturer's recommendations and its listing in the Approval Guide.

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

1. 10 minutes in areas provided with fully adequate emergency drainage.

2. 20 minutes in areas with limited or no emergency drainage.

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

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

G. Where only a pool fire hazard exists, AFFF and AFFF-AR combination foam may be provided only at the bottom level above where ignitable liquids can accumulate (e.g., ground level or intermediate solid mezzanines). This does not apply to AR foam.

### 2.3.9 Protection of Piping, Valves and Fittings Against Damage from Explosion Hazards

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

2.3.9.2 Locate risers in areas cut off by pressure-resistant walls or shielded by structural columns.

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

2.3.9.4 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).

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

2.3.9.6 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.

2.3.9.7 Piping 2 in. (51 mm) or smaller may be welded. Alternatively, use malleable iron-on-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.

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

## 2.4 Equipment and Processes

### 2.4.1 Process Controls

2.4.1.1 Establish safe limits of temperature, pressure, chemical composition, liquid levels, flow rates, and other critical parameters for each process. Provide process instrumentation and control systems to ensure safe operation. See Data Sheet 7-43/17-2, *Process Safety,* and Data Sheet 7-45, *Instrumentation and Control in Safety Applications.*

2.4.1.2 Where process operations require or might result in operation in or through the flammable range of a flammable vapor, protect against the consequences of an unintended ignition and explosion with limits and controls or inerting to prevent entering the explosive range. Alternatively, provide mitigation features in the form of explosion venting or explosion suppression, or design the equipment to contain the pressure of the explosion without damage (i.e., explosion-resistant or shock-resistant design). See Data Sheet 7-59, *Inerting and Purging Vessels and Equipment.*

### 2.4.2 Process Equipment

2.4.2.1 Provide alarms and safety interlocks for critical upsets that are independent of the process control system and designed to ensure the process is maintained within the specified safe operating limits at all times, including during shutdowns, startups, clean-in-place operations, and foreseeable service interruptions or malfunctions of equipment and control devices (see Data Sheet 7-45).

2.4.2.2 Design and construct pressure vessels in accordance with applicable local codes, standards, laws, and regulations, such as the ASME Boiler and Pressure Vessel Code or international equivalent. Guidelines are provided in Data Sheet 12-0, *Applicable Pressure Equipment Codes and Standards.*

2.4.2.3 Protect pressure vessels from unexpected overpressure caused by fire exposure, unexpected pressure sources, uncontrolled (runaway) chemical reactions or other events using appropriate pressure relief devices designed for the hazard. See Data Sheet 7-49, *Emergency Venting of Vessels.*

### 2.4.3 Accidental Release Control Systems

2.4.3.1 Provide controls to shut off the flow of ignitable liquids and flammable gases in the event of a release, to achieve the following objectives:

A. Confine the liquid and vapor within the equipment

B. Limit escaping material to a minimum and prevent its spread

C. Stop the transfer of material

D. Quickly drain escaping liquid or vent equipment and systems handling gas to a safe location.

E. Limit the expected release and associated fire duration to less than the duration of the fire protection water supply.

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

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

#### 2.4.3.4 Isolation Design

Provide process equipment with block or isolation valves, 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 accident. The exact type, extent, and arrangement of such protective equipment will depend on the process involved and are often developed through a process safety review. See Figure 10 for a typical arrangement. Additional information is located in Data Sheet 7-43/17-2, *Process Safety.*

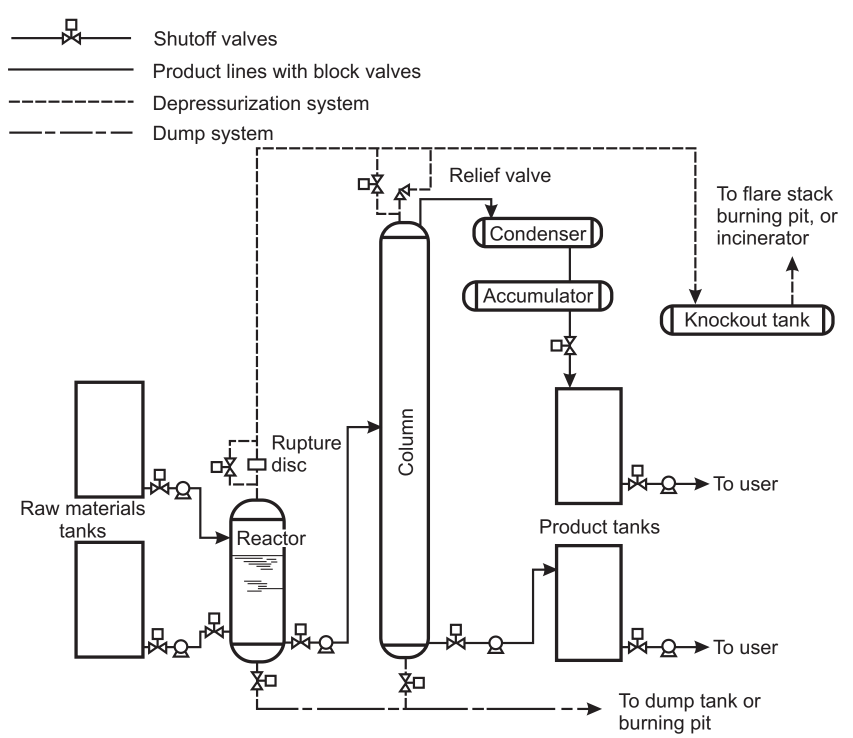



*Fig. 10. Accidental release control systems and valves*

### 2.4.3.5 Flammable Gas

2.4.3.5.1 Provide an FM Approved combustible gas detection system in areas where flammable gases are present. Design the system to sound an alarm to a constantly attended location (e.g., the process control room) upon detection of a gas concentration of 25% of the lower explosive limit (LEL). If appropriate, interlock detection with emergency safety/block valves to shut off incoming LPG or flammable gas to vessels, process units, and other applicable equipment or building areas at 50% of the LEL. For indoor locations, interlock detection to any installed emergency ventilation systems.

2.4.3.5.2 Where isolation measures are needed, refer to Figure 10 for a typical arrangement.

2.4.3.5.3 Arrange vents to discharge to a point where ignition of escaping vapors or liquids will not seriously expose equipment or structures.

2.4.3.5.4 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.

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

## 2.5 Operation and Maintenance

2.5.1 Implement operator training and operator refresher training programs in accordance with the recommendations in Data Sheet 7-43/17-2, *Process Safety.*

2.5.2 Establish mechanical integrity programs in accordance with the recommendations in Data Sheet 7-43/17-2, *Process Safety.*

2.5.3 Refer to API 583,
Corrosion under Insulation and Fireproofing, for recommended practices to mitigate corrosion under fireproofing materials.

## 2.6 Human Factor

2.6.1 Establish a robust safety culture. Implement systems to manage process safety and take a lifecycle approach to inherently safer design. Refer to Data Sheet 7-43/17-2, *Process Safety* for additional information.

2.6.2 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. See Data Sheet 10-1, *Pre-Incident Planning.*

2.6.3 Establish a safe work permit program that includes, but is not limited to, the following:

- Hot work permitting
- Line breaking
- Lock-out tag-out
- Vehicle entry control
- Crane permitting
- Excavation permitting
- Hot tap permitting
- Temporary structure control

## 2.7 Utilities

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

2.7.2 Include utilities in Process Hazard Reviews. See Data Sheet 7-43/17-2, *Process Safety,* for further information.

2.7.3 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.

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

### 2.8 Contingency Planning

2.8.1 Ensure the tightness of deluge fire protection pilot systems by performing air leakage testing in accordance with Data Sheet 2-81, *Fire Protection System Inspection, Testing and Maintenance.*

2.8.2 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, *Installation/Maintenance of Private Service Mains and their Appurtenances.*

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

### 2.9 Ignition Source Control

2.9.1 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.

2.9.2 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.

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

2.9.4 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.*

2.9.5 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

### 3.1 General

Processing facilities where ignitable liquid, flammable gas, and liquefied flammable gas are used in quantity present significant protection challenges. Fire damage can be minimized by using fireproofing and fixed protection such as automatic sprinklers, water spray, and monitor nozzles. Explosion damage can be minimized by using open construction or damage-limiting construction (DLC) and by providing adequate spacing or separation.

Fires within chemical processing facilities may be open tank fires, pool fires from released liquids, spray fires from liquids under pressure, jet fires from escaping gases or vaporizing liquefied flammable gases, or combinations of these. Liquids escaping from elevated equipment will gravitate to lower levels, exposing other equipment in the structure; multilevel, three dimensional spill fires are possible. Equipment failure may also result in an ensuing fire.

Explosions within chemical processing facilities may occur due to handling of unstable materials, runaway chemical reactions, or from escaping gas or vapor, particularly within an enclosed area. Vapor cloud explosions are possible in congested open process facilities where large quantities of ignitable liquid are handled at elevated temperatures and pressures. For more detailed information on vapor cloud explosions, see Data Sheet 7-42, *Evaluating Vapor Cloud Explosions Using a Flame Acceleration Method.*

### 3.2 Protection Objectives

Processing facilities, particularly within chemical plants, involve structures that vary widely in shape and size. Some have neither walls nor roofs, but often have high elevations and small floor areas. Work floors of solid construction or open-grating construction may be located at various levels. Such floors may be incomplete or penetrated by stairs, piping, and equipment. Tanks, reactors, condensers, stills, and pipe racks may be arranged irregularly throughout or adjoining the structures.

The installation of fire protection at chemical plants is not a straightforward process, and designs will vary. The intent of this data sheet is to provide fire protection for equipment and structures that may be exposed to a long duration ignitable liquid or flammable gas fire. Passive and active protection features may include one or more of the following:

- Space separation
- Fireproofing
- Containment and Emergency Drainage
- Area-type automatic sprinkler or deluge protection
- Fixed directional deluge water spray protection

### 3.3 Construction and Location

#### 3.3.1 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 and importance of facilities.

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

##### 3.3.1.1 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 cause a build up of pressure. Ultimately, the failure pressure of the vessel will be reached and it 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 a detonation, with vessel parts becoming missiles that may cause damage some distance from the event. A fireball is also likely and can ignite other fires in the affected area. Data Sheet 7-0, *Causes and Effects of Fires and Explosions* provides guidance. In existing plants it is usually impractical to provide additional separation required to reduce the loss to adjoining process units.

##### 3.3.1.2 Other Vessel Failures

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 with consequence due to the sudden pressure release but not directly creating a fireball. See Data Sheet 7-0, *Causes and Effects of Fire and Explosions.*

##### 3.3.1.3 Detonations

Sometimes detonable materials such as acetylides or organic peroxides are accidently produced or accumulated in a process. If these can be anticipated and predicted, it may be possible to provide safe isolation for such hazardous processes. See Data Sheet 7-0.

### 3.3.2 Spacing and Layout of Facilities

#### 3.3.2.1 General

Chemical plants are typically laid out in blocks over the site area (see Figures 11 and 12; these figures represent very broad, general concepts. The outer boundary of Figure 11 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 process 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 while within blocks there may be smaller unit blocks with smaller access ways and clear space.

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 utilities, 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. Spacing tables and suggestions for equipment arrangement in this data sheet may be used as starting points for site layout, but site-specific analyses should be conducted.

Within process units, spacing should be arranged in blocks with access for operation, maintenance and fire fighting considered. These access ways should 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 can be involved in a projected incident). The hazard of the occupancy/process and physical barriers that limit fire spread should be considered.

Within the unit, operations such as reactors, distillation towers, large pumps and compressors and fired process heaters should preferably be located on the perimeter. Equipment stacking (one piece of equipment supported directly on a lower one) is common for space economy and other reasons; however, this can increase fire involvement.

Equipment stacking outside of process structures should not exceed three high. 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. 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.

The control room should be situated beyond battery limits and may need to be structurally reinforced or provided with blast resistance.

Again, site-specific analyses should be conducted in the initial design phase. Modifications to existing facilities are rarely practical except during major upgrade projects.

A. The following facilities may present an unacceptable exposure to nearby operations:

1. Large quantities of ignitable liquids or flammable gases in tanks, tank farms, process areas, processing buildings, ignitable liquid spill containment from process areas or tanks or flare stacks.

2. Centralized, multi vehicle railcar or truck stations for shipping or receiving of large volume liquids.

3. Large quantities of ordinary combustibles in a building or in yard storage.

B. The following facilities may be sources of blast or missile damage:

1. Processes or storage containing unstable or explosive materials.

2. Process with exothermic chemical reactions where multiple controls are needed to prevent a runaway reaction

3. Processes using equipment with a volume exceeding 5000 gal (35 $m^3$) whose vapor space must be taken through the explosive range at periodic intervals for operation or maintenance purposes.

4. Processes at pressures over 500 psig (35 barg).

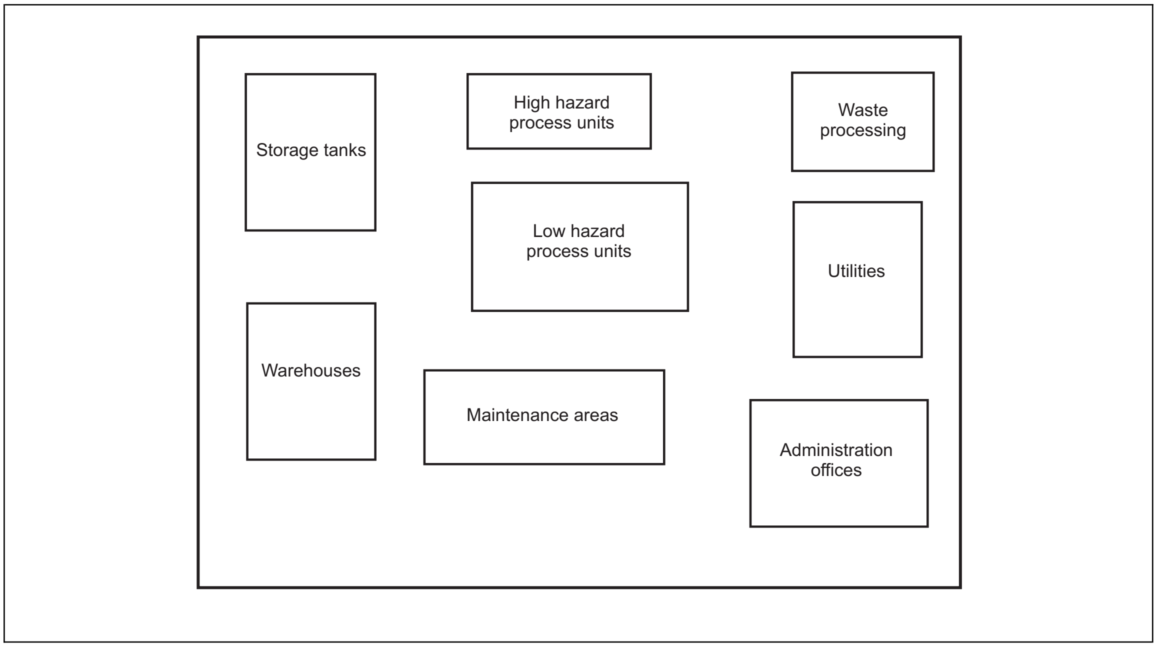



*Fig. 11. Typical site layout*

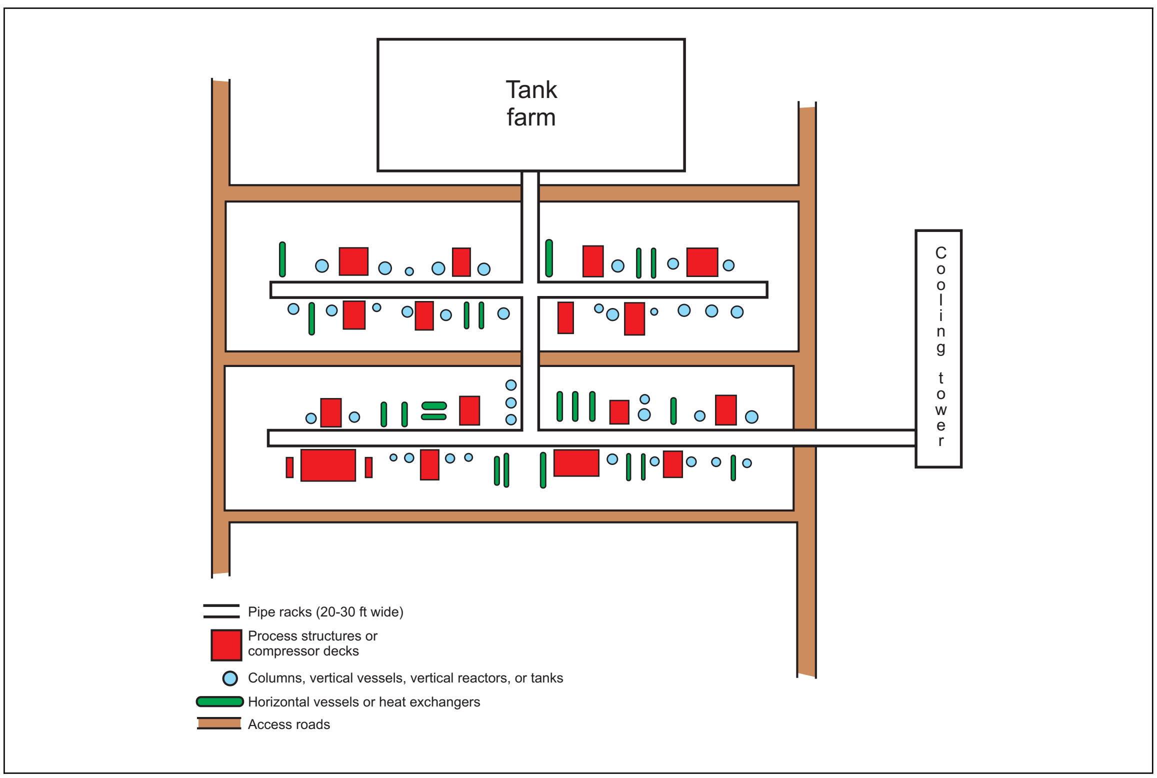



*Fig. 12. Typical layout of process structures, tanks, and vessels*

### 3.3.2.2 Specific Considerations

3.3.2.2.1 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 loss potential.

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

3.3.2.2.2 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.

3.3.2.2.3 Compressors

For process gas compressors, separation from operational facilities will reduce related fire exposures. Grouping of 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 should be located so as to minimize 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.

3.3.2.2.4 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 is particularly important for safety critical cables required for a safe shutdown, and relative to potential business interruption due to the loss of critical 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.

### 3.3.3 Containment and Emergency Drainage

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

Properly engineered containment and emergency drainage is vital to limiting the extent of damage that could result from ignitable liquid fires. The key objectives of spill containment and emergency drainage 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 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 13 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 14.

### 3.3.4 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 prevent a deflagration.

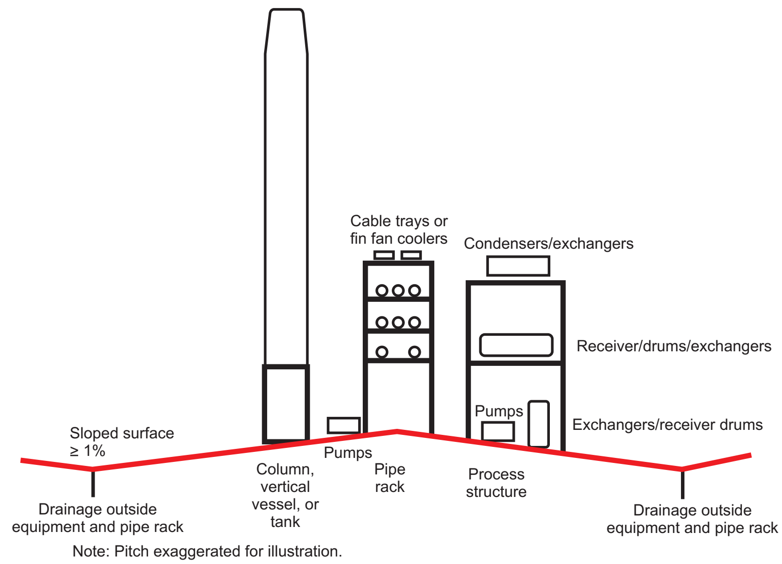



*Fig. 13. Example of suitably arranged emergency drainage*

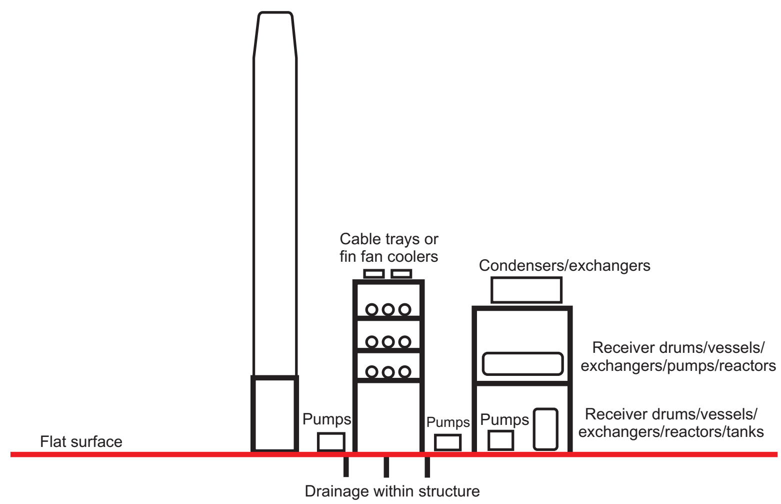



*Fig. 14. Example of less-desirable emergency drainage design*

B. Overpressure caused by a vapor-air deflagration inside ordinary industrial buildings can easily result in severe structural damage, loss of contents 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 to prevent much additional loss of equipment, as well as 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 in order to limit the extent of structural damage in case a 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 the majority of foreseeable events.

### 3.3.5 Fireproofing for Process Structures

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.

Alternatively, water spray protection may be used for protection of steel columns, but the design of the system is critical. It is important to have a continuous film of water over the protected area.

### 3.4 Active Fire 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 shut down the release of fuel. 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 sprinkler 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 supplied by a dedicated, adequate, reliable fire protection water supply, and

B. emergency drainage and containment 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, thereby preventing weakening of metal by overheating. The cooling and wetting also will prevent load displacement caused by thermal expansion of structural members and rupture of process tanks and piping.

### 3.4.1 FM Large-Scale Fire Tests

#### 3.4.1.1 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 using heptane as a fuel source were conducted: 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 rather than open steel grating beneath such equipment 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 exists. While the protection criteria listed in this data sheet will not extinguish a 3D spill fire, it will ensure adequate cooling and prevent collapse due to overheated steel until the fuel is removed (either by drainage or due to fuel consumption).

#### 3.4.1.2 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).

3.4.1.2.1 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 15). 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. 15. 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.

3.4.1.2.2 Three-Dimensional Spill Fire

An additional test was conducted using the same process structure as described above, but with an approximately 22 gpm (84 L/min) 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 16, 17). 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. 16. Ethanol spill in process structure prior to ignition*

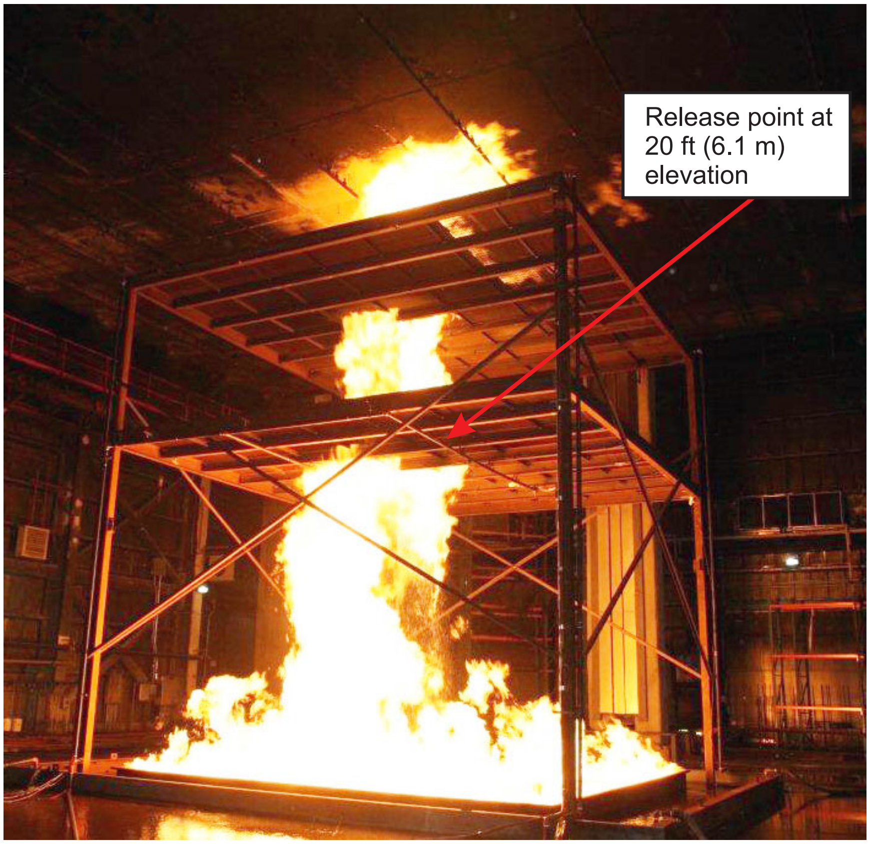



*Fig. 17. Three-dimensional spill fire before sprinkler activation (22 gpm [83 L/min] ethanol flow rate)*

### 3.4.2 Area Protection

The design of area protection will vary depending on whether the facility is located indoors or outdoors. For indoor locations, automatic wet sprinkler, 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.

The design will also depend on the presence of intermediate floors or mezzanines. For indoor locations, a design density of 0.3 gpm/ft$^2$ (12 mm/min) is recommended below solid levels, such as under roofs and solid mezzanines. A density of 0.3 gpm/ft$^2$ (12 mm/min) is also recommended above areas where the potential exists for holdup of ignitable liquids, such as solid intermediate mezzanines. Above open-grated mezzanine levels, where the potential for ignitable liquid holdup does not exist, the design density can be reduced to 0.15 gpm/ft$^2$ (6 mm/min).

For outdoor process structures, a design density of 0.3 gpm/ft$^2$ (12 mm/min) per protection level is necessary, regardless of the configuration of intermediate levels (i.e., solid or open-grated). The increased density process is due to the potential negative impact of the outdoor environment, including the effects of wind.

### 3.4.3 Water Supply for Deluge Systems

Sections 2.3.2.3.2 and 2.3.3.3.1 recommend 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. For example, 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 the 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 to actuate the deluge system.

### 3.4.4 Local 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 conduit, piping, and other obstructions. If these items serve to obstruct roof or mezzanine level sprinklers, supplemental protection is necessary. This 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 water spray for exposed equipment and structures will be necessary. 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 more practical.

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

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

#### 3.4.4.1 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 the manufacturer of the system. Nozzle orifice sizes, spray profiles, spray angles, and the axial distance from the nozzle to protected surface, among other factors, will all impact the performance of the protection system. To determine 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.

### 3.4.5 Pipe Racks

Pipe racks, as with other process structures or equipment containing ignitable liquids, require some form of active fire protection to cool the piping and the 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 increase 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, with 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 a number of tall distillation columns or vertical vessels in a row.

### 3.4.6 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 by fire from nearby equipment or if the gas is being condensed to a liquid within the tubes.

#### 3.4.7 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 include complex configurations, including tall structures, a large number of potential obstructions to sprinkler discharge, and a typical lack of 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 of these facilities, contractors must often undergo specialized safety training and background checks, and complete their work using specialized safety clothing and equipment.

### 3.5 Accidental Release Control Systems

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. However, it remains good practice to implement controls to limit potential releases as much as possible. Industry standards, as well as individual companies, maintain various best practices for minimizing ignitable liquid and flammable gas releases.

### 3.6 Chemical Plant Utilities

#### 3.6.1 Typical Utilities

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

- 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)
- Waste water (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)

#### 3.6.2 Load Shedding

At chemical processing sites that can lose a major portion of a utility suddenly, load shed priority plans are critical to 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). First shut down units that can drop offline and be restarted quickly with little to no production or physical damage implications.

## 3.7 Loss History

### 3.7.1 FM Loss History

Between 2003 and 2014, FM clients reported losses at chemical plants and similar occupancies due to a variety of perils and involving a diverse range of equipment. These losses included both processing and non-processing area incidents.

Table 2 presents a summary of these losses by peril. As shown in the table, a large percentage of these losses, relative to both the frequency and dollar amount of the events, are attributed to natural hazards. Fire and explosion losses, when combined, resulted in 20 percent of reported losses by number and nearly one-third by dollar loss. Mechanical and electrical breakdown events, although not specifically covered in this data sheet, also accounted for a large percentage of these losses.

Table 3 presents a break down of mechanical and electrical losses. Many of these specific types of equipment are covered by other FM Property Loss Prevention Data Sheets. Table 2 does, however, provide an indication of critical pieces of equipment and key loss drivers at chemical plants. The majority of mechanical and electrical breakdown events involved compressors, turbines, generators, and switchgear.

Table 4 presents a further breakdown of both fire and explosion losses by type of involved equipment. Although the frequency of fire and explosion losses is distributed throughout a variety of plant areas and equipment, the dollar losses are driven by typical equipment such as reactors, reformers, cracking furnaces, and regenerative thermal oxidizers. These pieces of equipment account for only 15 percent of recorded losses by number but nearly 50 percent by dollar amount.

This loss experience clearly indicates the greater explosion loss potential for chemical plants or occupancies, which can be primarily attributed to uncontrolled or runaway reactions and occasional unconfined vapor cloud explosions. The primary causes of these fire and explosion incidents were equipment failure due to inadequate design or maintenance, and operator error (i.e., human factor failures).

Table 4 also includes a line item that documents “fire/explosion losses falling under the scope of DS 7-32.” This demonstrates that chemical plants may incur losses that are not strictly limited to these specialized chemical occupancies. A combination of Data Sheet 7-14 and other data sheets such as Data Sheet 7-32 may be appropriate where hazards vary throughout the plant.

Tables 5 and 6 present the fire and explosion loss data separately.

### 3.7.2 Contingent Time Element

As shown in Table 2, a significant loss driver at chemical plants is “contingent time element.” A loss occurring at a third party supplier may significantly impact the ability to continue production. Similarly, a loss occurring at a customer’s facility may impact sales to that customer. In either case, without a contingency plan in place, such as alternative suppliers, the time element loss may be severe.

For example, Hurricane Ike, which made landfall in Galveston, Texas in September 2008, had a significant impact on numerous chemical facilities. In some instances, individual plants suffered direct damage due to flooding that totaled tens of millions of dollars. Additionally, even more facilities experienced contingent time element losses during this event due to damage at supplier locations. Many plants experienced losses associated with multiple suppliers and customers.

### 3.7.3 External Loss Data

A survey by another property insurer of 110 losses in excess of US$750,000 at chemical and petrochemical plants attributed over 60 percent of the losses to equipment design problems and operator error. Explosions accounted for 66 percent of the number of losses and 71 percent of the dollar loss. Areas cited as receiving inadequate attention and contributing factors in these losses were material hazard evaluation, chemical process design review, equipment design review, maintenance policies, and operator training programs. Another survey of 465 large losses in the chemical and allied industries attributed 21 percent of the losses to operational failures (mainly human element) and 29 percent to equipment failure.

*Table 2. Losses by Peril, 2003-2014*

| *Peril* | *Percentage of Losses* | *Percentage of Loss Cost* |
|---|---|---|
| Natural hazards | 30% | 17% |
| Mechanical / Electrical Breakdown | 15% | 18% |
| Fire | 12% | 15% |
| Contingent Time Element | 10% | 13% |
| Explosions | 8% | 16% |
| Tube / Tray Damage | 5% | 7% |
| Service Interruption | 5% | 3% |
| Structural (e.g., collapse) | 3% | 7% |
| Liquid releases with no ensuing fire | 3% | 1% |
| Theft | 3% | 0% |
| Overpressure / Implosion | 2% | 1% |
| Sprinkler Leakage | 2% | 0% |
| Contamination | 0% | 2% |
| Total | 100% | 100% |

*Table 3. Mechanical and Electrical Breakdown Losses, 2003-2014*

| *Equipment* | *Percentage of Losses* | *Percentage of Loss Cost* |
|---|---|---|
| Compressors | 26% | 42% |
| Turbines, Generators, Engines | 22% | 14% |
| Transformers, Switchgear | 18% | 17% |
| Air Separation | 6% | 4% |
| Fans, Blowers | 6% | 1% |
| Pumps | 4% | 1% |
| Reactors | 2% | 10% |
| Heat Exchangers | 2% | 6% |
| Extruders | 2% | 1% |
| Dryers, Kilns, Ovens | 2% | 1% |
| Electrolyzers | 2% | 1% |
| Boilers, Furnaces | 2% | 1% |
| Other | 6% | 1% |
| Total | 100% | 100% |

*Table 4. Fire and Explosion Losses by Equipment, 2003-2014*

| *Equipment/Area of Plant* | *Percentage of Losses* | *Percentage of Loss Cost* |
|---|---|---|
| Dryers, Kilns, Ovens | 12% | 9% |
| Reactors | 8% | 31% |
| Fire/Explosion Losses falling under the scope of DS 7-32[1] | 8% | 5% |
| Tanks | 8% | 3% |
| Boilers, Furnaces | 7% | 6% |
| Regenerative Thermal Oxidizers | 5% | 3% |
| Conveyors, Elevators | 5% | 2% |
| Dust Collectors, Cyclones, Bag Houses | 5% | 1% |
| Recovery, Cleaning Systems | 4% | 9% |
| Transformers, Switchgear | 4% | 9% |
| Explosives | 3% | 1% |
| Compressors | 3% | 1% |
| Silos | 3% | 0% |
| Reformers, Cracking Furnaces | 2% | 9% |
| Heat Exchangers | 2% | 1% |
| Heat Transfer Fluid | 2% | 1% |
| Ducts | 2% | 1% |
| Turbines, Generators, Engines | 2% | 2% |
| Distillation Columns | 2% | 1% |
| Electrolyzers | 2% | 1% |
| Cables | 1% | 0% |
| Extruders | 1% | 0% |
| Solvent Extraction | 1% | 0% |
| Adjacent Properties | 1% | 0% |
| Filter Presses | 1% | 2% |
| Air Separation | 1% | 1% |
| Pulverizers | 1% | 1% |
| Unloading Areas | 1% | 0% |
| Pipelines | 1% | 0% |
| Stacks | 1% | 0% |
| Flammable Gas | 1% | 0% |
| Cooling Towers | 1% | 0% |
| Total | 100% | 100% |

[1] These fire and explosion losses occurred at chemical plants, but the area of fire origin fell under the scope of Data Sheet 7-32 (i.e., the scope of Data Sheet 7-14, including the potential for a long duration ignitable liquid release or high temperatures, pressures, and flow rates, was not met).

*Table 5. Fire Losses by Equipment, 2003-2014*

| *Equipment/Area of Plant* | *Percentage of Losses* | *Percentage of Loss Cost* |
|---|---|---|
| Fire Losses falling under the scope of DS 7-32[1] | 10% | 8% |
| Tanks | 9% | 4% |
| Dryers, Kilns, Ovens | 9% | 3% |
| Transformers, Switchgear | 7% | 18% |
| Conveyors, Elevators | 7% | 4% |
| Boilers, Furnaces | 6% | 7% |
| Reactors | 5% | 7% |
| Reformers, Cracking Furnaces | 4% | 20% |
| Compressors | 4% | 2% |
| Heat Transfer Fluids | 4% | 2% |
| Silos | 4% | 1% |
| Turbines, Generators, Engines | 3% | 5% |
| Recovery, Cleaning Systems | 3% | 7% |
| Ducts | 3% | 1% |
| Dust Collectors, Cyclones, Bag Houses | 3% | 0% |
| Distillation Columns | 2% | 1% |
| Cables | 2% | 0% |
| Solvent Extraction | 2% | 0% |
| Extruders | 2% | 0% |
| Filter Presses | 1% | 5% |
| Pulverizers | 1% | 1% |
| Explosives | 1% | 1% |
| Unloading Areas | 1% | 1% |
| Stacks | 1% | 0% |
| Flammable Gas | 1% | 0% |
| Adjacent Properties | 1% | 0% |
| Cooling Towers | 1% | 0% |
| Electrolyzers | 1% | 0% |
| Regenerative Thermal Oxidizers | 1% | 0% |
| Total | 100% | 100% |

[1] These fire losses occurred at chemical plants, but the area of fire origin fell under the scope of Data Sheet 7-32 (i.e., the scope of Data Sheet 7-14, including the potential for a long duration ignitable liquid release or high temperatures, pressures, and flow rates, was not met).

*Table 6. Explosion Losses by Equipment, 2003-2014*

| *Equipment/Area of Plant* | *Percentage of Losses* | *Percentage of Loss Cost* |
|---|---|---|
| Dryers, Kilns, Ovens | 16% | 13% |
| Reactors | 12% | 52% |
| Regenerative Thermal Oxidizers | 10% | 5% |
| Boilers, Furnaces | 9% | 5% |
| Dust Collectors, Cyclones, Bag Houses | 9% | 2% |
| Recovery, Cleaning Systems | 6% | 11% |
| Heat Exchangers | 6% | 3% |
| Explosives | 6% | 2% |
| Tanks | 6% | 2% |
| Air Separation | 1% | 1% |
| Compressors | 1% | 1% |
| Explosion losses falling under the scope of DS 7-32[1] | 4% | 2% |
| Electrolyzers | 3% | 1% |
| Pipelines | 1% | 0% |
| Distillation Columns | 1% | 0% |
| Silos | 1% | 0% |
| Ducts | 1% | 0% |
| Conveyors, Elevators | 1% | 0% |
| Adjacent Properties | 1% | 0% |
| Total | 100% | 100% |

[1] These explosion losses occurred at chemical plants, but the area of fire origin fell under the scope of Data Sheet 7-32 (i.e., the scope of Data Sheet 7-14, including the potential for a long duration ignitable liquid release or high temperatures, pressures, and flow rates, was not met).

## 4.0 REFERENCES

### 4.1 FM

Data Sheet 1-21, *Fire Resistance of Building Assemblies*
Data Sheet 1-44, *Damage-Limiting Construction*
Data Sheet 2-81, *Fire Protection System Inspection, Testing and Maintenance*
Data Sheet 3-10, *Installation/Maintenance of Private Service Mains and their Appurtenances*
Data Sheet 4-1N, *Fixed Water Spray Systems for Fire Protection*
Data Sheet 4-12, *Foam-Water Sprinkler 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 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 7-31, *Storage of Aerosol Products*
Data Sheet 7-32, *Ignitable Liquid Operations*
Data Sheet 7-42, *Evaluating Vapor Cloud Explosions Using a Flame Acceleration Method*
Data Sheet 7-43/17-2, *Process Safety*
Data Sheet 7-45, *Instrumentation and Control in Safety Applications*
Data Sheet 7-49, *Emergency Venting of Vessels*
Data Sheet 7-50, *Compressed Gases in Portable Cylinders and Bulk Storage*
Data Sheet 7-55, *Liquefied Petroleum Gas (LPG) in Stationary Installations*
Data Sheet 7-59, *Inerting and Purging Vessels and Equipment*
Data Sheet 7-74, *Distilleries*
Data Sheet 7-83, *Drainage and Containment Systems for Ignitable Liquids*
Data Sheet 7-88, *Ignitable Liquid Storage Tanks*
Data Sheet 7-91, *Hydrogen*
Data Sheet 10-0, *The Human Factor of Property Conservation*

Data Sheet 10-3, *Hot Work Management*
Data Sheet 12-0, *Applicable Pressure Equipment Codes and Standards*

### 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*

#### 4.2.3 Center for Chemical Process Safety (CCPS)

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

#### 4.2.4 US Department of Defense

UFC 3-340-02, *Unified Facilities Criteria, Structures to Resist the Effects of Accidental Explosions,* December 2008

#### 4.2.5 The Viking Corporation

F_042602, *Design of Water Spray Systems for Fire Protection,* April 18, 2003

## APPENDIX A GLOSSARY OF TERMS

*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.

*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 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″.

*Process unit, high-hazard:* Processes involving unstable chemicals, or operating pressures greater than 1000 psig (69 bar), or an explosion hazard which could result in wide spread damage. This could also include units with potential for the rapid release of more than about 5000 gals (20 cu m) of ignitable liquids by a single initial incident.

*Process unit, low-hazard:* Processes that are not high hazard.

*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, as well as large liquid holdup or high process flow rates at elevations above ground level 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.

*Total constructive loss:* A condition were the cost of the repair exceeds the actual value of the item damaged. In a normal loss scenario, the cost of labor, scaffolding, expedited crews, etc. can result in losses approaching the average per square foot (square meter) monetary value for the fire area. This does not mean that all of the equipment will be damaged beyond repair.

Unstable material: A material that, in the pure state or as commercially produced, will vigorously polymerize, decompose or condense, become self-reactive, or otherwise un*dergo 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).

There are only a small number of ignitable liquids that meet the definition of water miscible. These include alcohols (including methyl alcohol, ethyl alcohol, n-propyl alcohol, isopropyl alcohol, tert-butyl alcohol, and allyl alcohol), ethylene glycol, propylene glycol, acetic acid, and acetone. Acetone, however, creates a more severe fire than the other water-miscible liquids. Therefore, for the purposes of this data sheet, acetone should be treated the same as other non-water-miscible liquids. For additional information on water-miscible ignitable liquids, see Data Sheet 7-32, *Ignitable Liquid Operations.*

## APPENDIX B DOCUMENT REVISION HISTORY

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

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.