Fire Protection in Refineries

API RECOMMENDED PRACTICE 2001
TENTH EDITION, JULY 2019

AMERICAN PETROLEUM INSTITUTE

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Introduction

API's *Fire Protection in Refineries*, First Edition, appeared in 1933 as the beginning of fire safety guidance series for the "downstream" segment. This 10th Edition recommended practice builds on experience gained over seven decades.

The term fire protection used in this publication includes measures taken to prevent fires, as well as those to minimize, control, or extinguish fires already burning. A thorough approach to fire protection starts with an understanding of the ignition and combustion processes, including control of potential fuel sources with an emphasis on containment. This publication gives some basic information on these subjects and identifies sources of more detailed information. While sections of this document discuss general design principles, it is not intended as a design manual. Rather, it presents guidance for those providing fire protection services to refineries and gives reference to sources of more detailed design related information.

The information presented is based primarily upon experience in many refineries. It is not intended to exclude or limit the use of other approaches of comparable merit.

Fire protection references comprise a very large body of literature. API 2001 highlights many of these references relevant to refineries while seeking not to duplicate them. Most of these references are not incorporated as "normative," and the user is advised to determine their relevance for specific applications.

Fire Protection in Refineries

1 Purpose and Scope

1.1 Purpose

The purpose of this recommended practice is to provide a better understanding of refinery fire protection and the steps needed to promote the safe storage, handling, and processing of petroleum and petroleum products in refineries. A basic premise of this standard is that fire prevention provides the fundamental foundation for fire protection.

1.2 Scope

This document covers basic concepts of refinery fire prevention and protection. It reviews the chemistry and physics of refinery fires; discusses how the design of refinery systems and infrastructure impact the probability and consequences of potential fires; describes fire control and extinguishing systems typically used in refineries; examines fire protection concepts that should be covered in operating and maintenance practices and procedures; and provides information on organization of and training for refinery emergency responders. Many of the concepts, systems, and equipment discussed in this document are covered in detail in referenced publications, standards, or governmental requirements.

1.3 Concept of Hazard vs Risk

Hazards are situations or properties of materials with the inherent ability to cause harm. Flammability, toxicity, corrosivity, and stored electrical, chemical, or mechanical energy all are hazards associated with various industrial materials or situations.

Risk requires exposure. A hot surface or material can cause thermal skin burns or a corrosive acid can cause chemical skin burns, but these can occur only if there is contact exposure to skin.

A person working at an elevated height has "stored energy" and a fall from a height can cause injury—but there is no risk unless a person is indeed working at heights and thus exposed to the hazard. There is no risk when there is no potential for exposure.

Determining the level of risk for any activity involves understanding and recognizing hazards, then estimating the probability and severity of exposure events that could lead to harm or damage, and the resulting consequences. Principles relating hazards to the risk for people are valid for evaluating property or environmental risk. For instance, hydrocarbon vapors in a flammable mixture with air can ignite if exposed to a source of ignition resulting in a fire that could cause property damage as well as injure people. Hydrocarbons that will burn are hazardous materials—but one element of risk includes a flammable fuel-air mixture being exposed to an ignition source.

2 Normative References

The following referenced documents are indispensable for the application of this document and are normative in those geographic areas under U.S. Federal OSHA jurisdiction. For dated references, only the edition cited applies. For undated references, the latest edition of the referenced document (including any amendments) applies. The bibliography organizes other references and sources of additional information by primary subject area. Additional information may be available from the Internet sites cited therein.

NFPA 30 [1], *Flammable and Combustible Liquids Code*

1 National Fire Protection Association, 1 Batterymarch Park, Quincy, Massachusetts 02169, www.nfpa.org.

OSHA 29 CFR 1910.119 [2], *Process Safety Management of Highly Hazardous Chemicals*

3 Terms, Definitions, Abbreviations, and Acronyms

For the purposes of this document, the following terms and definitions apply. Additional definitions and an expanded discussion of fire-related hydrocarbon properties and phenomena are included in Section 4 and Annex A.

3.1 Terms and Definitions

3.1.1
clean agent
Electrically nonconducting volatile or gaseous fire suppression agent approved by the U.S. Environmental Protection Agency (EPA) as substitutes for chemicals judged by EPA to be ozone depleting and are being phased out under provisions of the Clean Air Act (CAA); clean agents do not leave a residue upon evaporation.

3.1.2
combustible
As defined by NFPA and used in this document, refers to any solid that can burn or to any liquid that has a flash point of 100 °F (37.8 °C) or greater. See NFPA 30 for subclassification of combustible liquids.

3.1.3
combustion (burning)
The rapid reaction of oxidizable material with an oxidizer, usually oxygen from the air, followed by the development of heat. This reaction usually produces flames.

3.1.4
dry chemical agent
A powder of very small particles (usually sodium bicarbonate, potassium bicarbonate, or ammonium phosphate) treated for proper flow capabilities and tailored for class A (combustible), class B (flammable), or class C (electrical) fires (see NFPA 10 for specifics).

3.1.5
fire hazard analysis
FHA
A study used to evaluate fire hazards in a specific potential fire area and evaluate consequences of fire-related events.

3.1.6
flammable
As defined by NFPA and used in this document, refers to any gas that can burn or to any liquid that has a flash point below 100 °F (37.8 °C). The archaic term inflammable is obsolete. See NFPA 30 for subclassification of flammable liquids.

3.1.7
foam
For fire protection purposes is an aggregate of air-filled bubbles that will float on the surface of a flammable liquid. They are aerated solutions of water and a proper proportion of foam concentrate that may include a film forming agent.

3.1.8
fuel
Material capable of undergoing combustion. It is the material that burns to feed a fire.

2 U.S. Department of Labor, Occupational Safety and Health Administration, 200 Constitution Avenue, NW, Washington, DC 20210, www.osha.gov.

3.1.9
furnace “stuffing”
A furnace or heater running in a fuel-rich condition.

3.1.10
hazard
A situation or inherent chemical or physical property with the potential to do harm (flammability, oxygen deficiency, toxicity, corrosivity, and stored electrical, chemical, or mechanical energy).

3.1.11
management of change
MOC
A process to identify, evaluate, and address needs associated with changes in process technology, equipment. materials, or procedures other than “replacement in kind.” Some facilities apply MOC principles to personnel and organizations. MOC applied to personnel and organizations is often referred to as Management of Organizational Change (MOOC).

3.1.12
process
The refinery equipment, vessels, and piping in which refining takes place to “process” crude oil to manufacture petroleum products.

3.1.13
pyrophoric
The property of a material to self-heat and ignite in the presence of atmospheric oxygen.

3.1.14
risk
The probability and consequences of exposure to a hazard, hazardous environment or situation that could result in harm.

3.1.15
risk assessment
The identification and analysis, either qualitative or quantitative, of the likelihood and outcome of specific hazard exposure events or scenarios with judgments of probability and consequences.

3.1.16
risk-based analysis
A review of potential needs based on a risk assessment.

3.1.17
switch loading
Loading of low vapor pressure (high flash point) materials into containers where flammable vapors may be present from previous use, such as when diesel fuel is loaded into a tank truck or tank car that last carried a cargo of gasoline. (API 2003 provides additional information on the static ignition fire hazards associated with switch loading.)

3.1.18
water mist
Defined by NFPA 750 as a water spray for which average water droplets are less than 1000 microns at the minimum design operating pressure of the water mist nozzle.

3.2 Acronyms and Abbreviations

ASME	American Society of Mechanical Engineers
BLEVE	boiling liquid expanding vapor explosion

CCPS	Center for Chemical Process Safety
CFD	computational fluid dynamics
EIV	emergency isolation valves
EOC	emergency operations center
EPA	Environmental Protection Agency
FMEA	Failure Mode and Effects Analysis
FHA	fire hazard analysis
HAZOP	Hazard and Operability Studies
ICS	incident command system
LDH	large diameter hose
LPG	liquefied petroleum gas
MCC	motor control centers
MOC	management of change
OCIMF	Oil Companies International Marine Forum
OSHA	Occupational Safety and Health Administration
NACE	National Association of Corrosion Engineers
PASS	personal alert safety systems
PFOA	perfluorooctanoic acid
PHA	hazard analysis
PMI	positive material identification
NFPA	National Fire Protection Association
RIMS	Remote Instrumentation Modules
ROSOV	remotely operated shutoff valves
SCBA	self-contained breathing apparatus
SOP	Standard Operating Procedures
UL	Underwriters' Laboratories, Inc.
VCE	vapor cloud explosion

4 Chemistry and Physics of Fire—Special Considerations

4.1 Chemistry and Physics of Fire

The inherent hazards associated with processing, handling and/or storage of petroleum products are partly due to the volatility of many of these products. If proper precautions are not followed to prevent the concurrent presence of the components of combustion (fuel, air and an ignition source), there is the possibility of a fire or explosion. This could result in risk of harm to exposed personnel, damage to equipment, and adverse effects on the environment.

Personnel involved in refinery fire protection should be familiar with the general combustion principles. Annex A provides more in-depth information on the properties and hazards of petroleum products and the chemistry and physics of fire. This resource can be useful for review or training. Fire prevention and protection measures available to deal with these hazards can be found in other sections of this publication and in cited references.

4.2 Special Situations, Considerations, and Hazards

Certain inherent properties of hydrocarbon materials processed and produced in refineries present unique hazards related to hydrocarbon storage. Some of these phenomena (discussed in Annex A) have the potential to cause substantial damage. Some examples are: boilover, slopover, frothover, and boiling liquid expanding vapor explosion (BLEVE).

Hazards such as these should be recognized and addressed while designing for fire prevention and planning for emergency response. Operational precautions, such as outlined in this recommended practice, and well-planned emergency response can reduce the likelihood of occurrence and help prevent escalation in the event of an incident.

5 Fire Considerations in Refinery Design

5.1 General

This section discusses general design principles for refineries, with emphasis on fire prevention and fire mitigation. This recommended practice is not a design manual. Many of the references cited can provide specific design information. The principles outlined are intended as guides to good engineering practice.

The principles described identify certain areas to consider during refinery design for new construction or upgrades and expansions (see 1.3) to help reduce the possibility of a fire and to mitigate fire damage. Variance from the principles described does not necessarily imply that a refinery is inadequately protected against fire. Safety and fire protection practices should be evaluated within the design philosophy of the specific project involved, based on experience, accepted process safety management practices, normal industry practice, and regulatory requirements.

5.2 Hazard Analysis

Preventing and mitigating loss of containment of flammable and combustible materials is an important element of refinery fire protection. Systematic hazard analysis with implementation of the recommendations that adequately address/mitigate any findings can help a refinery avoid major releases of process materials and reduce the risk of potential fires. These activities can also help the facility implement corporate Management of Process Hazards programs and satisfy regulatory requirements. Regulatory examples in the United States are OSHA 1910.119, *Process Safety Management of Highly Hazardous Chemicals* (OSHA PSM) and the U.S. Environmental Protection Agency (EPA) Risk Management Program (RMP) Rule.

NOTE In-depth FHA discussions relevant to refineries can be found in some bibliography references such as the AIChE-CCPS (Center for Chemical Process Safety) *Guidelines for Fire Protection in Chemical, Petrochemical and Hydrocarbon Processing Facilities*. However, many published FHA protocols focus on structural fires and are less relevant to process facilities.

The use of hazard analysis (PHA) during process design, site selection, refinery layout, equipment selection, and civil and structural design will aid in the identification of potential hazards that might result in fires. Preventive and mitigative safety elements can then be considered early in the conceptual stages and continue throughout all stages of process design for new construction, upgrades, and expansions. The hazard analysis should include input from research and development personnel, designers, and refinery management. The purpose of the hazards analysis is to identify early in the design process any potential hazards inherent in a process design and to integrate protective measures to address these potential hazards.

The analysis should include an evaluation of the fire, internal explosion, and reactivity potential of process equipment and contents and the consequences associated with such events. An FHA then helps define "what to do" to prevent the event from occurring or to mitigate its consequences.

There are several types of PHA hazard analysis methodologies currently in use. Some of the more prevalent types are What If, Hazard and Operability Studies, Failure Mode and Effects Analysis, and Fault Tree Analysis. The AIChE-CCPS publishes *Guidelines for Hazard Evaluation Procedures* and now has more than 100 process safety resources listed in its catalog. In the United States, OSHA PSM and EPA RMP provide additional information on these methodologies and provide technical guidance resources on their respective websites. Similar regulatory resources are available in other jurisdictions.

Those concerned with fire prevention and protection should recognize that (although related) a process hazards analysis is not a fire protection analysis. A properly executed process hazards analysis can identify potential fire-related events that require further review. One method for further defining the appropriate level of protection for facilities and equipment is an FHA. An FHA is a study used to evaluate the significance of fire hazards in a specific potential fire area and evaluate consequences of fire-related events. The results of the FHA are integrated into an overall assessment process to assess risk and cost benefit trade-offs for mitigating hazards.

An FHA should document the inventory of hazardous material, calculate the size and magnitude of various fire scenarios, and determine the potential impact of those scenarios on personnel, equipment, the community, and the environment. The FHA should provide a clear understanding of the fire hazards so that performance-based fire protection solutions can be provided. The FHA should also consider available firefighting asset such as fire water supply, local fire response capabilities, and the availability of required firefighting foam and equipment.

5.3 Process Design

Process design includes evaluation of the properties of process materials, process conditions, and inventories. Process design should emphasize the principles of "inherent safety." For example, minimization of hazardous material inventories in the process design phase can be effective in decreasing the consequences of a release due to leaks or explosions.

It is important to have a basic understanding of the materials used in a process, including:

a) general properties such as reactivity, flammability, toxicity, and stability; and

b) procedures for safe handling of these materials, including when in storage.

In reviewing process conditions, it is important to understand the operating parameters intended by the design (such as pressure and temperature) along with their associated margins of safety. Potential hazards are introduced if abnormal operating conditions exceed process design conditions. Extremes in these conditions can increase stress, decrease strength, and may cause undesired chemical reactions or equipment failure.

5.4 Equipment Design

5.4.1 General

Proper design and arrangement of equipment in processing units, storage areas, and loading/unloading areas can prevent potential hazards from resulting in fires. Designs should be consistent with accepted industry codes or standards and supplemented with good engineering practices by personnel having knowledge of equipment service and its potential hazards. Key aspects of the design should include materials of construction, mechanical design and equipment construction, and the process control system. The following lists are examples (but not exclusive of other conditions or mechanisms).

The following conditions can lead to fires or explosions:

a) vapor clouds resulting from release of flammable liquids or gases;

b) spill releases of flammable liquids (including tank or vessel overfill);

c) pressure increase in vessels beyond their design overstressing vessel shell;

d) loss of inerting, enriching, or diluting systems;

e) increase in temperatures due to unstable conditions;

f) formation of flammable mixtures inside equipment;

g) mixing of incompatible materials;

h) conditions resulting in dust explosions;

i) undue or excessive vibration and shock from process conditions;

j) product release due to freezing of water in process piping dead-legs.

Potential mechanisms for material release from process equipment include:

a) vessel rupture due to pressure/flow demand greater than relief capacity;

b) vessel rupture due to brittle fracture;

c) failures of flanges, gaskets, seals, or plugs;

d) weld or casting failures;

e) excess corrosion/erosion (internal or external);

f) failure due to external loading or impact;

g) internal explosion;

h) tube rupture from overheating.

5.4.2 Materials of Construction

The "suitability for intended use" of materials at a refinery has a bearing on fire loss risk. The standards, specifications, and recommendations of nationally recognized authorities should be consulted and applied where relevant. In many instances, specifications have been promulgated by API to meet the particular needs and requirements of oil refineries. Additional information is available in the bibliography from organizations such as the American Society for Testing and Materials (ASTM); the American Society of Mechanical Engineers (ASME); NFPA; the American Society for Metals (ASM); the National Association of Corrosion Engineers (NACE); and Underwriters' Laboratories, Inc. (UL).

A careful review and selection of materials by qualified personnel decreases the potential for materials failure. Proper selection of the materials of construction requires a thorough knowledge of the internal process, the exterior environment, failure modes, correct material application and fabrication techniques, maintenance philosophy, and inspection intervals. Positive material identification (PMI) programs provide a quality-control method for preventing the unintended use of inappropriate materials, helping to avert one potential cause of material failures. For example, PMI programs can include training for awareness and identification of suspect and potentially counterfeit bolts.

Corrosion is a recurring cause of loss of containment of flammable and combustible materials leading to fires. The potential for unexpected corrosion is therefore one of the most important factors in selecting the materials of construction and maintaining surveillance programs. Refer to API publications for internal and external inspection of refinery equipment (some are listed in the bibliography).

The basis for selection of materials is the performance of the materials under process design conditions and the interaction of the materials with the external environment. Operating conditions include start-up, shutdown, and upset conditions. Any potential problem anticipated with a particular material should be discussed during hazard analysis sessions. It is important that personnel with relevant expertise be consulted during material selection.

5.4.3 Mechanical Design and Equipment Construction

5.4.3.1 General

Refinery processes frequently operate at high pressures and temperatures that put stress on equipment. Equipment used in the process must be designed to withstand the stresses of the operating conditions to which it will be subjected.

In addition to a quality control program for materials, a sound quality control program for equipment construction is important and should be in place for construction activities to verify that "as-built" construction is in conformance with design specifications.

5.4.3.2 Pressure Vessels

5.4.3.2.1 General

Design and construction specifications for vessels subject to pressures of 15 psi gage or more are given in ASME *Boiler and Pressure Code, Section VIII: Unfired Pressure Vessels*.

Suitable provisions must be made for cleaning and ventilating a vessel when it is inspected internally. It should be isolated from other equipment and from flammable, toxic, or inert materials. Appropriate precautions (such as water washing) should be used if inerted to address potential pyrophoric residue concerns.

Reactors, columns, exchangers, and boilers are typical pressure vessels found in a refinery that require special design considerations for structural supports, instrumentation, and protective systems.

5.4.3.2.2 Internal Design

Internal design of vessels should avoid pockets where the lack of drainage would allow water (or hydrocarbons) to accumulate, particularly during start-up. Proper placement of vent piping can avoid bypassing and allow effective purging of otherwise trapped condensable gases, which could leave water or light hydrocarbons in equipment. The sudden generation of steam caused by the contact of hot-oil charge stocks with water can result in dangerous overpressure of equipment. Hydrocarbons retained in equipment can create future fire (or industrial hygiene) concerns.

5.4.3.2.3 Protection of Vessels

Vessels with internal refractory or insulation, or vessels that handle materials entirely in the vapor phase, may be subject to rapid overheating and rupture when exposed to fire if passive fireproofing, active fire protection cooling and/or a vessel depressuring system is not provided. Other vessels (including those with two phases or tanks containing flammable liquids) may also be subject to overheating if fire protection cooling or adequate distance separation is not provided.

5.4.3.2.4 Flanges

Vessel connections should be flanged as close to the vessel as practical to permit isolation. During the design and installation stages, consideration should be given to access to the flanges for blinding. Valves should be strategically located to allow opening of flanges for the purpose of installing and removing isolation blinds.

5.4.3.3 Block Valves

Where large volumes of flammable liquid are contained in process vessels, where feasible, block valves should be installed on connections below the liquid level. This will permit shutoff of fuel flow if downstream piping or equipment become involved in a fire. These manual or remote valves should be considered a prudent "second line of protection" with the first being prevention through design and operations.

5.4.3.4 Isolation Valves

5.4.3.4.1 General

A key consideration for isolation valves is being able to isolate sections of process to minimize the quantity of hydrocarbons released and prevent influx of additional material from other areas. Isolation valves should be provided at unit boundaries or within process unit areas to isolate equipment during fire situations. Consideration should be given to safe access and the ability to physically operate manually operated valves during fire conditions or in emergency situations. Where possible, battery limit valves should be spaced sufficiently far from process equipment fire hazardous areas to allow safe manual actuation. If located inside fire hazard areas, valves may need to be capable of remote operation.

Isolation valves can also permit blinding for maintenance and inspection. During blinding operations, blinds suitable for equipment-rated pressure should be installed. Isolation valves and drains should be provided for equipment that may be opened or removed during repair operations. See API 553.

5.4.3.4.2 Remotely Operated Valves

Where a review establishes a need, remotely operated shutoff valves (ROSOV) [sometimes used as and called emergency isolation valves (EIV)] should be considered during the PHA and FHA processes. Use of these and other isolation valves should be included in emergency procedures. However, use of automatic (fire or heat actuated) self- closing valves should be used only after a hazard analysis or MOC review to determine whether inadvertent activation may cause undesired consequences. This review should confirm the automatic valve system is inherently safe by a rigorous process safety review since closure of the valve in a non-fire situation or at the wrong time in a fire event may have undesirable consequences, such as causing excessive pressure in a process system or preventing the orderly shutdown sequence of equipment or transfer of product from tanks or vessels during an emergency. The review should include a determination of the safest alternative ("open" or "closed") on loss of power if ROSOV are used. Discussion of emergency valves (ROEIV, EIV, EBV, ROSOV) can be found in API 553 and UK HSE *Health and Safety Guidance 244*.

5.4.3.5 Oil and Gas Piping

Specifications for the construction of oil and gas piping at refineries are contained in ANSI B31.3. The piping layout should be designed with battery limit valves (API 553) so any major processing area within the refinery can be blocked off in case of fire. This can help prevent the flow of fuel into the fire area and reduce disruption of operations in other areas. Battery limit valves should be installed (5.4.3.4) with provision for good access without personnel exposure and with clearly understood labeling accompanied by relevant emergency response training. Manually operated valves should be evaluated to address the physical effort required to operate them under emergency situations.

During the design stages of a refinery project the process information, such as type of fluids, temperatures, pressures, and flow conditions, must be detailed so that compatible gaskets, materials of pipe construction, line flange classes, and pipe wall thicknesses can be provided for the piping system. Special piping and valving may be needed to address two-phase flow, high-pressure drops, corrosive or erosive fluid properties, or high-velocity flow conditions.

Other special design features of piping that may be of concern and need additional owner/operator review, discussion, and detail include:

a) thermoplastic or plastic lined pipe;

b) double-walled pipe;

c) piping in below-ground service;

d) cathodic protection and grounding features;

e) jacketed or heated piping;

f) preventive maintenance and inspection of piping systems to detect corrosion: under insulation or fireproofing, of plugs, nipples, of supports on piping, and internal;

g) special velocity effects (corrosion, erosion, vibration, noise, water hammer, mechanical, flow-induced vibration, acoustic induced vibration (Refer to API 521) and static electricity:

h) special coatings and insulation;

i) dead-leg potential for water accumulation and freezing or corrosion (see Section 8 and Annex B);

j) piping specification "breaks."

Consideration should be given to minimization or elimination of unshielded flangeless fittings, gasket-type couplings, or long bolt flanges. When exposed to fire, long bolts can expand and allow flange connections to loosen. Because of historical incidents, many facilities require alternative fasteners on new and revised installations and provide metallic flame impingement shields or insulate long bolts on existing equipment as temporary protection and target them for elimination.

Failure of small piping connections to mechanical equipment has caused numerous refinery fires. However, adequate bleeders and vents must be provided to permit removal of water from the system during start-up to provide adequate purging of air from the system and to allow verification that out-of-service equipment has been drained and depressured (see 5.4.3.2.2 and 5.4.3.6 regarding purging).

Valves on these small connections should be located as close as possible to the takeoff points and sized to provide resistance to vibration and accidental breakage. Where vibration is a concern, suitable bracing should be provided, and all-welded construction should be considered. Where screwed connections are used, backwelding should be incorporated up to the first block valve unless a specific case-by-case review determines that backwelding would be detrimental. Small diameter drain piping associated with valves should incorporate threaded plugs as a safeguard against leaks. If threaded pipe in hydrocarbon service is less than 1 in. diameter, some facilities require the pipe to the first block valve to be bridge welded.

5.4.3.6 Purging Systems

In the design of processing equipment, an inert purging system may be desirable. This system prevents flammable mixtures from being present by excluding air from equipment during unit start-ups and by purging equipment of hydrocarbons prior to maintenance and repair work. Steam, nitrogen, carbon dioxide (CO_2), and flue gas are common materials used for purging. Work practice procedures should address the inherent oxygen deficiency hazards to personnel of inert gases (see API 2217A). Long-term inerting of equipment can promote the formation of pyrophoric iron sulfides when the product contains sulfur.

Purging facilities should be installed on fired heaters and other fired equipment to ensure removal of flammable vapors from the firebox before lightoff. Proper purging procedures should be developed and followed, since lack of sufficient purging can be a contributing cause of fired heater and boiler explosions. Verification of adequate purge flow provides a safeguard of key importance.

5.4.3.7 Pumps and Compressors

Proper design of pumps and compressors, along with proper installation in conformance to design, can minimize the chance of process area fires. Refer to API 610, API 617, and API 618.

An operating compressor can be seriously damaged by liquid carryover. To prevent such carryover, suction and interstage knockout drums should be provided. High-level alarms and shutdown devices may also be needed.

The design of compressor systems should provide for the removal of air. Vents should be provided on the distance pieces of reciprocating compressors to avoid blowing gas into the compressor crankcase in the event of packing leakage. Vents should be located to eliminate the potential for pockets, which would not allow all air to be expelled from the system. The flammability and toxicity of the released gases will determine the safest location for the discharge point of such vents.

Drainage from suction and discharge bottles, suction knockout drums, distance piece drains, and gas engine fuel gas knockout drums should be routed to safe disposal points. Process bypasses on compressor systems require special design considerations, such as high-temperature alarms, shutdowns, and recycle coolers for over temperature conditions resulting from recycling. Vibration should be monitored for major pumps and compressors. For critical equipment, consideration should also be given to providing automatic and/or remote shutdown ability.

Small screwed connections to pumps and compressors are prone to fatigue and should be eliminated, where possible, or seal welded if elimination is not possible.

5.4.3.8 Gas Fueled Engines

Generally, gas fueled internal combustion reciprocating engines are provided with automatic shutdown controls based on low lube oil pressure, high jacket water temperatures, and engine overspeed. In some instances, shutdown controls are provided in case of vibration or of a high liquid level in the suction knockout drum.

The location of the air intake to gas engines should be configured to minimize the possibility of pulling in hydrocarbon vapors. There have been recorded incidents in which starting air system explosions resulted from accumulation of lubricating oil in the air piping receiver and from the backup of fuel gas from the engine.

5.4.3.9 Fired Equipment

API 560 and NFPA 85 should be used as references in the design of fired heaters and boilers.

Fired equipment (such as process heaters and boilers) has potential for mechanical failure resulting from harsh operating conditions. The following should be considered in the design of this equipment.

a) Fired equipment provides ignition sources and should be located on the periphery of the unit (preferably upwind of the prevailing wind direction) with additional spacing from process equipment.

b) Fuel systems should be designed for positive isolation when the equipment is shut down, to prevent fuel accumulation in the firebox and a possible explosion on start-up.

c) An excess of fuel in a furnace firebox can cause an “over-rich” condition (sometimes referred to as “stuffing,” “flooding,” or “bogging”) where subsequent introduction of air results in an explosive mixture. Furnaces should be equipped with analyzers that accurately monitor oxygen and CO inside the firebox to allow operators to balance fuel gas combustion.

d) The firebox should be designed with air, nitrogen, or steam purging so that any accumulated hydrocarbon vapors can be purged from the firebox before start-up.

e) The fuel system should be designed to prevent flameout from temporary loss of fuel through the use of pilots, minimum flow bypasses, or automatic shutdowns.

f) There should be instrumentation to detect hazardous situations (i.e. loss of process flow, low fuel pressure, loss of combustion air, etc.) and to shut down fuel to the furnace as required. A shutdown system should be separate from the control system.

g) Surface drainage should be designed to prevent flow of liquid from the furnace toward other process equipment and from other process equipment to the furnace.

h) Remote isolation should be considered for process streams being heated in fired heaters.

i) Fuel gas emergency shutdown systems should be upstream of the minimum flow bypass.

5.4.3.10 Utility Systems

The contamination of utility systems, such as steam, air, water, fuel gas, and inert gas with hydrocarbon, could result in serious safety problems. The most probable sources of contamination are utility connections joined to process equipment. Permanent connections should be avoided. Water lines coming from cooling light hydrocarbon service should have vent headers installed for surge protection and to allow venting of light hydrocarbon contamination prior to entry of the water stream into cooling water towers; other means of surge protection may also be used.

If the utility is used in processing, at least one check valve and a block valve (preferably "double block and bleed") should be installed at the connection. This arrangement can reduce the likelihood of a backflow intrusion of hydrocarbon if utility pressure is lost. To prevent possible hydrocarbon contamination, there should be no permanent cross- connection of fire water and process water utility systems (see NFPA 30). Temporary connections should not be routine and shall be subject to a change review process (such as MOC).

If the utility is required only when the equipment is out of service, such as for flushing, purging, or regeneration of catalyst, the utility connections should be blinded or disconnected. Should the utility be provided for intermittent or emergency use, double block valves with open bleeders and a check valve should be installed. All utility connections should be adequately identified. Check valves should be used at multiservice utility "hose station" headers.

Plant air systems have experienced fires from the accumulation of lube oil. Air systems should be designed to permit periodic cleaning to remove accumulated lube oil. The use of fire-resistant lubricants in air compressor crankcases should be considered. In new designs it may be possible to use oil-free compressors. Proper design and maintenance can eliminate excessive discharge temperatures caused by the air compressor and by fouling of the air-cooling system. Instrument and plant air systems might become contaminated with hydrocarbon if the compressor air intakes are located too close to potential sources of hydrocarbon releases; the location of air intakes can be addressed in process safety reviews.

If fuel gas is burned in fired heaters, suitable knockout facilities (and line heat tracing where climate dictates) should be provided to prevent the carryover of liquid condensate into burners. Fuel line block valves should be located at a sufficient distance from fired heaters to permit remote shutdown in case of fire without personnel exposure. Two options are:

— install manually operated valves sufficiently far from the furnace to allow safe operation, or

— install fire safe remotely operable valves with the actuation point outside the fire hazardous area for the furnace.

5.4.3.11 Loading Racks

Historically, a leading cause of loading rack fires has been overfilling. Procedures, training, and flow control equipment provide the first line of defense. In the event of a spill, drainage (with traps) to carry away and contain spills can reduce the probability of a fire. In the event of a fire, an important aspect of controlling loading rack fires is to stop product flow to the rack. Because valves at the loading manifold may be inaccessible under certain fire conditions, there should be facilities that can block off the product lines to the rack from a remote location. These facilities may include remote pump shutdown; remotely operated block valves in the product lines; block valves in the lines at a short distance from the rack that can be readily reached by the operator; and alarms or other communications that can notify other personnel to expeditiously block out the rack. API 2610 provides information for both truck and rail loading facilities. Guidance for rail facilities is provided in AAR Pamphlet 34. Loading racks are often equipped with foam or dry chemical fixed extinguishing systems.

In addition, static electricity may be an ignition source when materials are loaded at temperatures above their flash points or when "switch loading" occurs. Normal precautions include electrical bonding to facilitate relaxation of static charges, procedural control of fill rates and techniques (such as use of, bottom loading to avoid splash filling, and continuity of fill lines), and review of facilities (such as filtration) to minimize static charge buildup. Refer to API 2003 for a discussion of static electricity phenomena.

5.4.3.12 Storage Tanks

Design and management of storage tank facilities has been addressed by API and other industry bodies in many standards. Detailed information on mechanical design, fabrication, and nondestructive examination of storage tanks, and on protective systems can be found in API 620 and API 650. API 2610 discusses design and operation of tank facilities.

Along with environmental concerns, a major consideration in the design of storage tank installations is reducing fire risk. Risk reduction methods include: storing volatile materials in floating roof or inert gas blanketed tanks, control and containment of spills (NFPA 30 or jurisdiction fire codes) and protecting against overfill (API 2350); maintenance of tank integrity (API 653); proper arrangement and spacing of tanks (NFPA 30); and providing fire control and extinguishment equipment and systems (API 2021).

Typical storage areas may contain atmospheric, pressurized, refrigerated, or heated tankage. Additional API and NFPA standards listed in the references or bibliography address these more specialized storage facilities. Typically, large scale bulk storage is located in adjacent tank farms with smaller process tanks distributed throughout various areas associated with process batteries. It is not within the scope of this document to discuss issues that are covered in detail by referenced standards.

5.4.3.13 Process Tanks

Tanks closely associated with refining or petrochemical processes may have concerns beyond those associated with hydrocarbon storage tanks. Storage inventory in process tanks should be limited to the minimum required for stable and reliable process operation.

These concerns should be addressed in the design phase and covered in initial and periodic PHAs and included in operating procedures.

Examples of some potential concerns are:

— lack of frangible roofs (because these are often small diameter tanks);

— the corrosive nature of some process materials (such as “spent” acids);

— corrosion of tank bottom seams, vapor space or auxiliary appurtenances (see NACE RP 0205);

— unexpected overpressure and/or overheating (e.g. overpressure generated by heating caused by water-into-acid instead of acid-into-water);

— close proximity of large volumes of hazardous materials to process equipment;

— adding hot process streams to cold tanks.

5.4.4 Process Control Systems

The design and methods used to provide control, as well as the accuracy and reliability of the instrumentation, affect the safe operation of the refinery. Reliable measurement of pressure, temperature, flow, and level are important in preventing fires resulting from loss of containment. Instrumentation should be designed to facilitate routine testing. A review should be made of the desired action of each controller in case of air or electrical failure to determine whether the valve should fail open or closed or should remain in its existing position. Guidelines for installation of alarms, recorders, and shutdown systems must consider employee safety and equipment protection. The suitable positioning of such instruments can minimize risk when emergencies arise.

Consideration should be given to the use of an alarm prioritization system, since the number of alarms that may be activated under upset conditions can be high. The need for independent control signals on critical instruments also should be considered.

Plain glass or other types of rotameter and gage glasses that are vulnerable to mechanical or fire damage should be avoided in hydrocarbon or hazardous chemical services.

Guides to the installation and design of process measuring equipment are provided by the Instrument Society of America; NFPA *Furnace and Boiler Codes*; and ASME *Boiler and Pressure Vessel Codes*.

5.5 Location

5.5.1 General

The location of a refinery ideally will provide usable area ample for safe spacing of all facilities, with an allowance for buffer zones and future expansion. Consideration should be given to the nature of adjacent property and its relative location to the refinery, since refineries may expose these properties to a variety of potential hazards. Conversely, since adjacent properties can also expose the refinery to different types of hazards, those potential hazards should be taken into consideration in locating the refinery or evaluating hazards. For example, the location of neighboring airports and the prescribed landing patterns of aircraft could present collision hazards. Location should be considered in conjunction with proposed layout of facilities (5.6).

5.5.2 Climate and Geography

Natural perils such as windstorms, floods, and earthquakes can create fire hazards. The frequency and severity of these events should be taken into consideration when designing refinery systems. For example, certain areas subject to potential earthquakes require special bracing of equipment. Areas subject to extreme cold and heavy snow may require special designs to prevent equipment failure due to freezing or excessive snow or ice loading, along with the resultant fire hazards associated with those conditions. See 8.4 and Annex B.

Prevailing wind direction is generally unreliable. However, design of facilities with the potential for release of flammable or toxic materials should include awareness of prevailing wind conditions in siting and emergency response planning. This may reduce the probability of ignition or exposure by taking note of the seasonal variance of prevailing wind direction. Wind socks can help evaluate conditions if there should be a release; these need to be maintained to be functional and may not help if frozen or unlit at night.

5.5.3 Availability of Water

Availability of sufficient fire water and process water from internal, industrial, municipal or natural resources is an important requirement when considering the refinery operation and emergency response. Further details on water supply are discussed in 6.2 and 5.10.4.

5.5.4 Supplementary Local Fire Protection

The availability and resources available from local public or private fire departments should be investigated. Well- equipped public fire departments can be of valuable assistance. However, these departments generally do not train in fighting large petroleum fires so sharing of training facilities and experience can be mutually beneficial. Mutual-aid organizations, including other refineries or allied plants located in the same area, should be investigated. Members of such mutual-aid organizations frequently have specialized equipment designed for industrial use and have proven beneficial at locations where they have been put into effective operation. The availability of these organizations can influence the amount of private fire protection equipment and staffing required. In at least one area a nonprofit industrial firefighting group is jointly owned through industry membership.

5.6 Layout and Spacing

5.6.1 General

The layout of process units, utilities and equipment will vary widely, depending on topography, types of units and equipment to be installed and, to some extent, site operating conditions. However, in developing the overall layout of a refinery from a fire protection standpoint, it is important to consider the potential of fire escalation.

Consideration should be given to potential impact/effect on (or from) neighboring installations (such as community, adjacent industry, public roads, heaters, tankage, etc.). Facilities for future expansions should be included in the planning broad overview.

The refinery layout should provide accessibility for firefighting and spacing to limit the potential for fire escalation within a unit or to neighboring unit/equipment. Consideration should be given to accessibility of unit isolation block valves firewater monitors, deluge, and water spray activation valves. Remote shutoff or actuation valves may be warranted for emergency response, especially if access to manual valves may require personnel exposure to hazardous conditions.

The typical rectangular or block layout for process units provides many advantages. It can provide off-site locations for process piping, service lines, and fire main systems. In addition, future expansions can be completed with a minimum of disruption to existing operations. Roadways that separate the blocks provide excellent fire breaks and facilitate the movement and operation of firefighting equipment.

5.6.2 Occupied Buildings and Other Structures

Wherever possible, buildings not directly involved with hydrocarbon processing should be well separated from process areas, storage areas, loading facilities and other hydrocarbon handling equipment. For several reasons, including the need for unit surveillance, maintenance and process control during emergencies, some process plant buildings control centers and operator shelters are in or located near hydrocarbon processing or handling areas. For information on managing risks associated to buildings, see API 752, API 753, and API 756 which provide guidance for locating permanent and portable buildings.

5.6.3 Roads

The design of adequate roads for transportation and communication is important in fire protection. Access to all refinery areas should be assured by roads wide enough to allow personnel egress and emergency vehicle access and positioning. Depending on roadway uses, vehicle traffic will vary on roadways. Because it may be necessary to block certain roads in emergencies, two or more approaches to each refinery area are desirable. Turning radii should allow adequate maneuvering for mobile emergency equipment to clear pipe supports and equipment. Pipe racks and other crossings should be designed to provide adequate overhead clearance for emergency and other vehicles.

Major and secondary roadways typically allow movement without restriction. Additionally, major roadways, e.g. site entry gates, need to be wide enough with clearance on each side to reduce risk of collision.

Secondary roadways are used primarily to support maintenance and turnaround activities with reduced traffic and reduced width as compared with major roadways.

Certain process and tank field area roads closer than 25 ft to process equipment used only for emergency access infrequent maintenance activity are typically designated as “restricted,” access and can only be used after authorization by operations, after completion of hot work permitting procedures.

5.6.4 Egress

5.6.4.1 Site Egress

For personnel egress should be provided from all buildings, process areas, and elevated structures taking into consideration the nature and location of hazards. The basic concepts for all areas include:

a) provision of a sufficient number of exits;

b) arrangement of exits to permit safe egress during emergencies;

c) provision for unobstructed egress paths;

d) provision of adequate lighting;

e) provision of a fire alarm where fires may not be obvious to the occupants;

f) ensure compliance with applicable codes and regulations;

g) provision of a designated assembly/muster areas.

5.6.4.2 Egress from Process Structures

When reviewing egress from elevated process structures, the following concepts should be considered:

a) provide a sufficient number of exits;

b) arrange exits to permit safe egress during emergencies;

c) provide unobstructed egress paths;

d) provide adequate lighting;

e) provide fire alarm where fires may not be obvious to the occupants;

f) ensure compliance with applicable codes and regulations.

A review of the need for a second means of egress from elevated structures should take into consideration the following:

a) frequency and number of personnel on the elevated structures;

b) type, volume, and pressure of the hydrocarbon sources that could restrict egress in the event of a fire;

c) availability of fire suppression equipment to immediately quench a fire and safeguard the exit routes;

d) height of the structures and the ability of personnel to move laterally away from the fire hazard.

5.6.5 Layout of Process Units

In planning the layout of process units and supporting facilities, consideration must be given to safety, environmental impact, constructability, economy, operability, and efficiency of process and maintenance operations.

Decisions on layout should take into account several factors including:

a) Minimizing involvement of adjacent facilities in a fire and hence prevent the escalation of an incident.

b) Ensure that critical emergency facilities are not subject to fire damage.

c) Exposure to radiation during fires and overpressure from explosions.

d) Access for firefighting, fire trucks and other types of emergency equipment.

e) Access for operators to perform emergency isolation and shutdown actions in a fire or other emergency.

f) Prevailing wind and continuous ignition sources.

g) Access for normal operation and maintenance.

h) Access for turnaround maintenance activities.

i) Enhance site security.

j) Meet local code requirements.

Decisions on distance between storage of flammable and combustible liquids and process areas require consideration of many of the same factors as the decision on distances between process units. Tank dikes provide primary protection against liquid spills reaching process units. Where possible, consideration should be given to locating process areas on ground higher than tankage so that in the event of an incident the topography would prevent major tankage spills, frothovers, or boilovers from gravitating into the process area. See Section 3 for definitions, 5.6.8 for further discussion of spacing of equipment outside of process units, and NFPA 30 for minimum storage tank spacing (from one another, public fence lines, or important facility structures).

Typically locating process areas on ground higher than tankage so that in the event of an incident the topography would prevent major tankage spills, frothovers, or boilovers from gravitating into the process area. See 5.6.8 for further discussion of spacing of equipment inside process units, and NFPA 30 for minimum storage tank spacing (from one another, public fence lines, or important facility structures).

Decisions on the separation distances between the areas handling liquefied petroleum gas (LPG) and other areas require careful consideration. A release and explosion at one of these storage areas can produce an overpressure causing damage several hundred feet away. See API 2510 and NFPA 58 for further spacing information.

As outlined above, process units should be broken up into rectangular areas with firefighting access ways that have a minimum width to allow access by fire-fighting equipment. In addition to perimeter roadways, intermediate firefighting access ways may be necessary to permit firefighting attack from two sides. The maximum dimensions of the areas should take into account the ability of perimeter fire-fighting equipment reaching process equipment.

Areas containing hydrocarbon processing equipment should preferably be located outdoors, allowing open ventilation to dissipate leaked or spilled products. Experience has shown that fires and explosions have been prevented or minimized when only a roof and partial wall are used to protect equipment from wind, rain, and snow. Processing equipment should be located as far from ignition sources as possible.

When process equipment is located indoors, suitable ventilation should be provided to prevent the accumulation of vapors in the event of a leak. NFPA 30 provides additional guidance on ventilation design. Installation of fire and gas detection and suppression systems should be considered

5.6.6 Process Unit Spacing

Spacing is a key component of a fire protection system combined with drainage, fireproofing, fire water protection, process isolation and other features to limit fire escalation. When sufficient spacing is provided between process units, the likelihood of a fire spreading from one process unit to another is reduced without the need for extensive fire protection facilities. Spacing between equipment within a process unit (intra-unit spacing) limits damage from small, localized fires (i.e. involving pump seals or piping leaks) during the initial stages of a fire but supplemental fire protection facilities coupled with action by operations and emergency response personnel many times is required to isolate and extinguish the fire.

Spacing of process equipment and between units is a fundamental aspect of risk management for the refining and petrochemical industries. Siting and layout are a key risk reduction measure to separate potential sources of fires, explosions, or toxic incidents from neighboring facilities and site boundaries to limit such events from impacting people and assets.

Equipment within a refinery process unit can be arranged in many ways, each having its own advantages and disadvantages. Safety, operability, and ease of maintenance are to be considered in process hazard analyses when locating each item within a unit. The relative importance of these considerations varies with each item, process unit, and refinery, and must be evaluated for each case with equipment located accordingly. In the event of a vapor cloud explosion (VCE) congested equipment spacing can lead to a more severe blast overpressure exposure due to higher flame speeds Less congested spacing between equipment should also minimize the spread of fire.

Consideration should be given to access for fire suppression.

Many companies have developed spacing tables based on experience and engineering judgment where spacing allows time for personnel to respond and contain fire damage. Many of the spacing tables used today have a similar form that follows earlier guidance that was developed by the Oil Insurance Association (OIA) in 1963. Spacing tables have evolved over time based on learnings and experience from fire incidents.

Spacing tables, similar to that found in CCPS's *Guidelines for Facility Siting and Layout*, provide a good basis for most new and existing process units when new equipment is added. There are cases where smaller inventories of hydrocarbons, process conditions and operations and/or where additional fire protection facilities are provided, distances from spacing tables can be reduced based on risk.

When situations arise where the company's spacing tables may not address specific attributes, e.g. fired heater closely coupled to a reactor where feed to the reactor is heated above autoignition temperature, decreases in spacing does not increase risk. But in most cases, where spacing cannot be met for technical reasons, additional fire protection facilities and/or other mitigations can be provided to achieve risk equivalency.

When evaluating spacing and fire protection facilities that conduct a qualitative risk assessment that identifies risk equivalency, a risk-based approach can be considered. Below is an example of a work process (also see Figure 1) that can be followed when making a risk-based decision regarding spacing. This process can focus on spacing between specific equipment or a broader table can be developed for the entire process unit.

1. Equipment and Process Information—The fire risk assessment process begins by collecting equipment and process information including inventories of material, operating pressure and temperature.

2. Fire Hazard and Scenario Development—Identifying and analyzing fire hazards and scenarios is the next step in a fire risk assessment. The hazard identification should be structured, systematic, and address all fire hazards. The result of the hazard identification is a list of potential fire hazards that may occur in the process unit, for example, jet, pool, flash, or BLEVE. The scenario should also identify equipment involved in the release. Each identified hazard will have a range of possible scenarios; it may not be reasonable to evaluate every scenario. Therefore, representative fire scenarios can be applied to cover a range of scenarios. The scenarios to evaluate are those where the initial release and ignition characteristics are likely to cause the most extensive damage.

3. Fire analysis—The process to determine the size, severity, and duration of a scenario and its impact on personnel, equipment, operations, and the environment. It is important to look beyond the initiating event to determine the potential for fire to spread to adjacent areas. If the fire is not detected early and quickly controlled, then the fire can escalate and involve other equipment and units. For escalation to occur, the fire must impact adjacent equipment by either radiant heat or flame impingement. Guidance regarding escalation should be developed so its consistently applied throughout the study(s) i.e. heat flux that impacts equipment.

   Fire analysis should incorporate a method for estimating fire impact to personnel, structures, and equipment. Computerized fire models are available to complete the analysis ranging from spreadsheets to computational fluid dynamics (CFD) modeling.

4. Likelihood—The likelihood of a scenario is the prediction on an annualized basis that a scenario occurs. The likelihood of the fire scenario should consider:

   a) The frequency of the initiating event (loss of containment)

   b) Probability of ignition

   c) Post release events (escalation) and their related probabilities that can occur after the flammable material is released

Measures to reduce the impact of fire include active and passive fire protection systems. Active and passive fire protection need to be evaluated in the likelihood of escalation.

5. Estimate Risk—Risk is defined as the likelihood of events that lead to the consequences e.g. human injury, economic loss, or environmental damage. It is important to recognize that there are assumptions and uncertainty related to risk such that it's not an exact measure, and risk tolerance will vary between companies.

6. Risk Reduction Strategies—Additional fire protection facilities or adjusted spacing should be considered to reduce risk. Additionally, preventive measures can be considered to reduce the likelihood of the scenario(s).

7. Document spacing requirement —Update and document the spacing tables for the process unit being evaluated.

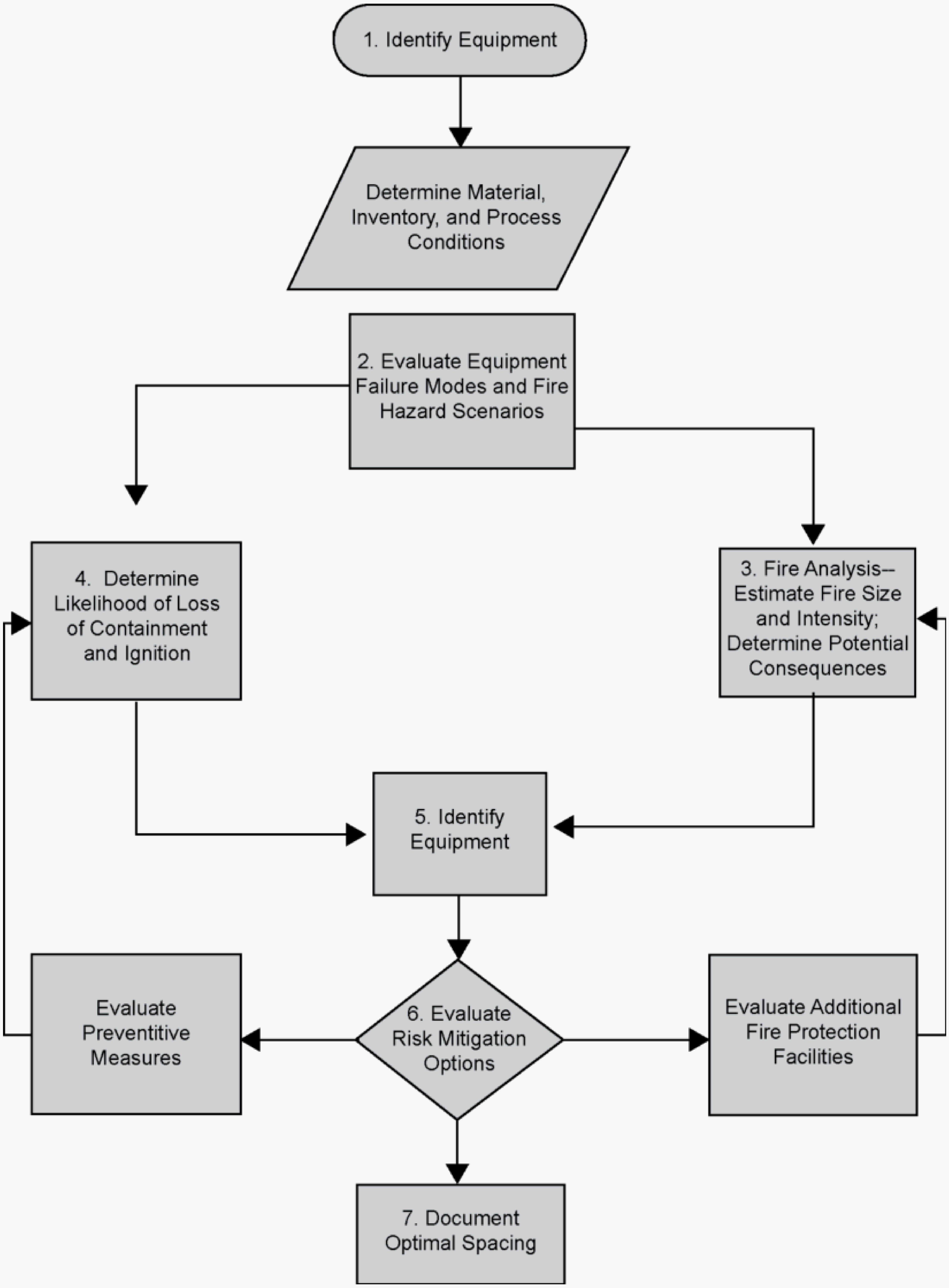


Figure 1—Risk Assessment Work Process Example

5.6.6.1 Fired Heaters

Since fired heaters are a constant source of ignition, their location must be carefully selected. Where practical they should be located on the upwind side of a unit, near battery limits, with consideration given to the effects of adjacent units as well as the equipment in the same unit. The top of a fired heater stack should be located above any equipment and working platforms within a short horizontal distance. Incinerators and vapor destruction units should be spaced as fired heaters.

5.6.6.2 Equipment Operating Above AIT

Equipment handling flammables above auto-ignition or 600 °F, whichever is lower, have an increased probability of fire because ignition is likely when leakage of fluid occurs. As a result, increased spacing between equipment, (such as towers, drums, or pipe bands) is required to avoid escalation.

5.6.6.3 Pumps and Compressors

Rotating equipment, such as pumps and compressors, is more susceptible to accidental releases than most other equipment. Therefore, from a fire protection standpoint, it is preferable to locate this type of equipment away from ignition sources. Pumps handling hydrocarbons should be carefully located, avoiding areas below pipe alleys, major vessels, air coolers, and other critical equipment. Where this cannot be avoided, consideration of fixed fire protection systems is appropriate (see API 2030). Additional spacing should be given to mechanical equipment handling flammable liquids near or above their autoignition temperature and fixed protection considered.

5.6.6.4 Instrumentation

When possible, instrument control cables for critical instrumentation should be routed underground or above ground through low-risk areas. This will reduce the chance of a minor fire causing an emergency shutdown and will allow for an orderly shutdown in the event of a major fire. Fireproofing of cable trays or conduit, or the use of fire-resistant cable should be considered when they pass through a fire scenario envelope as defined in API 2218.

5.6.6.5 Vulnerability to Fire Damage

The vulnerability of certain types of equipment to fire damage is an important layout consideration. For example, the thin metal that improves efficiency of air fin coolers increases their vulnerability to external flame exposure compared with thick-shelled tubular water exchangers. Where possible, vulnerable equipment should be located away from low point drains and pumps handling materials at temperatures above their autoignition temperature.

5.6.7 Spacing of Storage Tanks and Vessels

5.6.7.1 Atmospheric Tank Storage

Generally, atmospheric tankage is intended only for storage of stocks that, at storage temperature, have a true vapor pressure less than atmospheric pressure. The location and arrangement of tanks will generally be governed by topography, character of nearby structures, type of stocks to be stored, shipping facilities, process flow, routing to tankage, and refinery operating conditions.

From a fire protection standpoint, decisions on the layout and spacing of tanks within a tank farm should take into account several factors. These include:

a) characteristics of the stored product;

b) size of the tanks;

c) spill control, impounding or secondary containment consistent with NFPA 30;

d) maximum potential fire radiation;

e) boilover potential for crude oil and other viscous oil storage;

f) fixed fire protection available and to be added;

g) access for firefighting and emergency response equipment;

h) business interruption consequences;

i) prevailing wind direction;

j) distances from adjoining properties where buildings may later be constructed;

k) proximity to areas of high congestion, including large areas of dense vegetation.

Hydrocarbon pumps and main control valves should be located outside of the diked area.

Spacing between major tankage and process units should be maximized. For additional information and minimum spacing requirements see NFPA 30.

5.6.7.2 Pressurized Tank Storage

Major releases or fires impacting aboveground storage of LPG materials in vessels have the potential for significant impact, including BLEVEs, if tankage has fire impingement. Decisions on separation distances between LPG storage and areas such as process units and buildings require careful consideration of the explosion potential of these storage vessels; explosions can cause damage several hundred feet from the storage area. Therefore, it is advisable that these installations be located as far as practical from major process areas. Refer to API 2510 for minimum spacing requirements, API 2510A for additional LPG fire protection considerations, API 752 for issues dealing with structures, and NFPA 58 for general LPG guidance. Refer to API 2510 for more information on water draw requirements.

Valves for manual activation of water deluge or spray systems that provide fire protection cooling for LPG storage should be accessible without placing personnel at risk. Where this is a concern, remote operated valves should be considered.

Pumps, piping manifolds, and extraneous aboveground piping should be located outside the dike or spill wall area surrounding the pressure vessels. Potentially vulnerable product piping should be protected from exposure to traffic impact.

5.6.8 Spacing for Offsite Facilities

5.6.8.1 Electrical Substations and Motor Control Centers

Utility equipment provided for safe reliable operations must be carefully considered with respect to spacing. Potentially, a loss of any one of these critical utilities could lead to a major unplanned outage or loss of capacity.

All switch racks must meet the applicable electrical area classification requirements. Critical electrical switch racks which consist of electrical supply or control equipment for an individual piece of equipment or small group of equipment which would interfere with the function of an emergency system or would result in downtime exceeding duration of one week. Reduced spacing may be considered for non-critical switch racks based on a case-by-case evaluation.

5.6.8.2 Remote Instrumentation Modules

Similar to electrical substations, remote instrumentation modules (RIMs) should be located where damage from fires and explosion involving operations is limited. Potentially, a loss of any one of these critical instrumentation modules could lead to a major unplanned outage or loss of capacity. RIMs that support multiple process units should be provided additional spacing to limit the impact of an incident to multiple units.

Note Remote instrumentation modules (RIMs) are similar to motor control centers (MCCs).

5.6.8.3 Cooling Towers

Cooling towers can be vital to the operation of several process units. Since they are potentially susceptible to fire, some of the same considerations that are used in determining spacing between process areas should be used in determining the location of cooling towers. NFPA 214 provides guidance on fire protection.

When determining the location of cooling towers, wind drift should be considered. This is because water vapor from cooling towers can cause equipment corrosion and poor visibility. Water mist “drift” also has the potential for freezing on roads and other areas in cold climate locations. Preferably, when there are predictable prevailing winds, the cooling towers will be located downwind of process areas, control rooms, and instrument air dryers.

5.6.8.4 Pipelines

Areas of potential fire exposure should be avoided when routing main refinery pipelines. Hydrocarbon piping from an off-site facility (such as storage) or from a unit that will remain in operation should not be routed through a unit that can be independently shut down for overall maintenance.

Piping on sleepers should not be exposed at drainage ditches or trenches where oil may exist. Where pipelines cross drainage ditches, flanged or threaded joints should be avoided.

5.6.8.5 Loading Racks

As with other process operations, loading racks should be separated from other refinery equipment so that fires associated with either the rack or the adjacent unit will not spread to the other from their point of origin. See API 2610.

5.6.8.6 Marine Terminal Facilities

Marine terminals are vitally important to the continued operation of some refineries. The location of marine terminal facilities is dependent on the condition of the waterway. However, since these terminals are potentially subject to large petroleum spills, consideration should be given to providing clear space between docks for firefighting access. Refer to the OCIMF *International Safety Guide for Oil Tankers and Terminals* for further information on layout and design of marine terminals and NFPA 307.

5.7 Fireproofing

While location and spacing are of substantial importance in minimizing the degree of equipment involvement in a fire, additional protective measures still may be necessary. One of the key protective measures is the ability of equipment and its support structure to maintain integrity during a fire. The purpose of fireproofing is to permit the emergency shutdown of a unit, restrict the addition of fuel to a fire, and protect personnel and equipment from the effects of equipment or support failure during a fire. See API 2218 for details on the design and application of fireproofing in hydrocarbon processing and storage areas. One concern is that fireproofing adds weight and may conceal corrosion (see API 583). This varies with the type of fireproofing system. Some jurisdictions have specific specification requirements for fireproofing of LPG vessels.

5.8 Pressure Relief and Flare Systems

5.8.1 General

For the design of pressure-relieving systems, refer to API 520, API 521, and API 2000. The design of flare facilities is discussed in API 520, API 521, API 537, and in 5.8.3. For requirements on safety valve installation, set pressures, and valve arrangement, refer to ASME *Boiler and Pressure Vessel Code*, *Section VIII: Unfired Pressure Vessels*. Subsequent discussions of design will be limited to problems associated with fire and explosion risks involving pressure-relief or flare facilities.

5.8.2 Relief Valves

Safety-relief valves are provided to prevent overpressure of refinery equipment in emergencies created by operational errors, equipment failures, and fire and to ensure the safe disposal of released materials. When block valves are installed on either side of relief valves, those block valves must be locked or secured in the open position while the relief valve is in service. Relief valves that release liquid hydrocarbons should discharge into a closed disposal system. Where only hydrocarbon vapor is vented, relief valves may discharge directly to the atmosphere if certain conditions are met. These include the following:

a) proper distances between point of release and personnel areas;

b) conformance with relevant environmental regulations for emergency releases;

c) low toxicity;

d) temperature below autoignition;

e) dispersion of released material based on discharge velocity, molecular weight, condensing temperature, and other physical properties of the material.

Safety relief valves should be tested at scheduled intervals to determine whether they will function at the designated pressure. The test interval will vary from several months to several years, depending upon the cleanliness of the service, the severity of operating conditions, the results of previous inspections, and the existence of legal requirements. The frequency of the test should be established for each valve based on operating experience, engineering judgment, and industry practice. See API 576 if a valve beneath is closed so a PRV can be removed for testing or service, equivalent overpressure protection is required while the unit is in operation. Often a replacement valve is installed, and the valve reopened.

Where relief valve discharges are routed to a closed system, headers should be sized to handle the maximum flow resulting from any single contingency without developing excessive back pressures on the relief valves connected to the system. Where safety relief valves are connected into closed emergency relief systems, the grouping of equipment within one fire risk area may influence the size of the relief facility piping required. By providing reasonable separations between groups of equipment, the quantity of materials released into the flare systems under fire conditions can be reduced. Fire-related electric power failure should be included in flare system contingency analysis.

Conditions under which the system can become plugged, blocked, or frozen should be avoided, and piping should be designed without “pockets” and sloped toward liquid knockout drums to avoid the accumulation of liquid that may cause surging, plugging, or freezing.

If a closed emergency relief system serves more than one unit, it may be necessary to isolate sections of the system when individual units are shut down. Therefore, the location of adequate facilities for blinding or isolating the unit should be examined. When isolating a unit, the integrity of overpressure protection for other units should be in accordance with relevant API or ASME standards.

When safety-relief valves discharge to the atmosphere, vent stacks should terminate above adjacent equipment. Otherwise, localized overheating of nearby process vessels might result from radiation or convective heating if the valve should open and vapors ignite during a fire or other abnormal condition.

Drainage on the discharge risers of atmospheric safety valves should be designed to reduce the likelihood of problems. If drains become clogged, condensed hydrocarbons from leaking safety valves can accumulate and subsequently be blown over the unit if the valves release. If the material reaches an ignition source, a fire could result. If water accumulates in the vent stack, freezing may occur, either as a result of low ambient temperatures or from the refrigeration process caused by rapid evaporation of leaking low boiling point hydrocarbons.

Drains should be installed at the bottom of the riser. Care should be taken with regard to drain orientation so that, under fire conditions, any burning vapor discharged from the valve opening will not impinge on equipment. Installation of elbows in the drain to direct any released vapor away from nearby vessels or piping can reduce this possibility.

Vent stacks that discharge at elevated locations are sometimes equipped with snuffing steam to extinguish fires caused by lightning ignition of relief valve leakage. See API 521 for additional information.

5.8.3 Flare Systems

Flare systems provided for the safe disposal of gaseous refinery wastes are the subject of API 521 and API 537. Depending on local environmental constraints, these systems can be used for:

a) venting during start-up or shutdown;

b) venting of excess refinery gas;

c) handling emergency releases from safety valves, blowdown, and depressuring systems.

Designs vary considerably, depending upon the type of connected equipment and the complexity of the overall system. Though specific design details are not discussed in this publication, some potential problem areas are reviewed.

Because flare systems are open to the atmosphere and a continuous ignition source exists at the end of the line, internal system explosions are possible if appropriate safeguards are not in place. The most positive approach to eliminating this hazard is to adequately purge the system to remove trapped air before the pilots are ignited. Provisions should be made for the safe lighting of these pilots, either by electrical ignitors or by ignition pipes where flammable mixtures can propagate the flame to the pilots.

Vent connections or bleeders that could allow air to be released into the flare system should be avoided. However, the total elimination of air from flare systems may not always be practical. To minimize the risk, it is common practice to either continually inject a fuel-gas purge or to install liquid seals as flashback devices to limit flame propagation through the system. For this purpose, liquid seals are preferable, and the use of flame arrestors is discouraged because the small passages in flame arrestors are subject to fouling that may cause excessive pressure drops during periods of high flow. The design of purging systems should consider the possibility of air ingress into the flare system from the flare stack when using lighter-than-air purge gases. Dry molecular seals can be used to minimize purge gas rates.

Another area of concern is the possibility of liquid carryover from the flare stacks that may spray burning liquid over a widespread area and start fires at grade level. The size of knockout drums must be based upon the equipment that discharges to the drum, the rates of liquid entry, the duration of a release, and whether blowdown or liquid pumpout streams are routed to the flare stacks. Creation of an exclusion zone beneath flares is normal practice for protection of personnel and facilities (primarily based on thermal radiation).

Consideration should be given to the provision of a high-level alarm and liquid pump-out on the flare knockout drum. Maximum allowable liquid levels must be established to ensure adequate vapor space to avoid entrainment of liquid when safety valves operate. System safety reviews should consider the effect on downstream storage of potentially high-temperature effluent from the knockout drum.

The location and height of flare stacks should be based upon the heat release potential of a flare, the possibility of personnel exposure during flaring, and the exposure of surrounding plant equipment. Where personnel are expected to work in the vicinity of a flare without restriction on the length of exposure, 500 BTU/hr/ft^2 (1.58 kW/m^2) radiant heat exposure level has been established by some companies as an acceptable limit. The U.S. EPA specifies radiant heat of 5 kw/m^2 (1580 BTU/hr/ft^2) for 40 sec as the "end point" exposure level of concern for RMP offsite consequence analysis. However, published sources suggest that radiant heat levels up to 2500 BTU/hr-ft^2 (7.9 kW/m^2) may be tolerated for 5 sec to 15 sec if the only concern is short-time exposure of personnel to permit escape from the area under emergency release conditions. It should be noted that these criteria are for risk assessment. Other radiant heat reference resources are noted in the bibliography.

The location of flares in the vicinity of tall refinery equipment should be examined. Flames or hot combustion products can be carried by the wind, which could cause problems and create hazards to personnel working on these elevated structures at the time of a flare release. More information on flares is provided in API 537.

Another important consideration in the design of flare systems is the adequacy of drum seals that might have open sewer connections. Liquid levels are frequently maintained in drums by a loop-style seal. The highest pressure that may exist in these drums under maximum flare release conditions should be determined. The seal leg should be of adequate depth to prevent displacement of seals under the highest pressure to avoid release of hydrocarbons at grade level or to the sewer. Liquid seals should be included in a facility freeze precaution procedure.

5.9 Drainage, Containment, and Waste Disposal

5.9.1 General

The design of drainage and the determination of the means and capacity required to control refinery wastes are of prime importance in minimizing the size of liquid hydrocarbon fires. Maximum fire water runoff, rain runoff, and spill size requirements should be considered in designing drainage and containment systems.

5.9.2 Spill and Waste Disposal for Process Areas

When a new refinery layout or expansion is planned, preventing the spread of fire is an essential consideration. Suitable drainage is required to prevent the spread of major spills from one area to another and to adequately control surface drainage and refinery waste and fire water. The natural slope of the land can often be used effectively in the development of an adequate drainage system. Ideally, storage facilities should be downgrade from process areas. Windstorm and flood data must be used along with potential fire water usage in determining proper drainage system capacity requirements. Drainage system capacities should also be considered when making upgrades to firewater systems.

From a fire protection standpoint, the purpose of drainage and containment systems in process areas is to minimize the area subject to hydrocarbon spills and to direct those spills away from critical equipment. Process areas are generally paved with a hard-surfacing material. The pavement should slope toward catch basins located in open areas so that spills will flow away from the equipment rather than under it. All spill and waste disposal systems must consider social and regulatory environmental constraints during their design.

Fire stops or water seals should be provided throughout industrial sewer or drainage ditch systems to prevent vapors from material released into the sewer system from spreading to other areas. Sealed sections of sewer systems should be vented at suitable points to prevent pressure buildup and the blowing of seals if light materials should enter the system. The sealing and venting of such systems are of importance where drains from a building are connected to an industrial sewer system.

Below-grade trenches, compressor or pump pits, and building basements within process areas should be avoided where practical. These areas present corrosion and housekeeping problems and provide a place for trapping flammable vapors.

Open refinery separators are generally located away from process and storage equipment. However, this may not always be feasible, so care should be taken to minimize locating ignition sources near these open separators because, under some conditions, flammable vapors could be released from their surfaces.

Discharges to the sewer from process equipment handling volatile hydrocarbons can be a mechanism for vapor release. If a level controller were to fail in an open position, it could be a source of vapor in the immediate process area, as well as throughout the sewer system. Vapor accumulation can pressurize sewers, resulting in blown seals and vapor release at other points. Where such potential exists, suitable instrumentation or a disengaging drum should be provided.

5.9.3 Diking and Waste Disposal for Storage Areas

For low flash point refined oil and crude oil storage tanks, dikes are usually provided to prevent oil spills from involving other facilities. The usable volumetric capacity of the diked area should not be less than the greatest amount of liquid that can be released from the largest tank within the diked area, assuming a full tank. See NFPA 30 for requirements of dike design and arrangement.

Dikes are used primarily to contain tank overflows, bottom leaks, and line failures, as well as to limit the uncontrolled off-site flow of water applied during a fire. Accumulations of liquid will either be limited in quantity or be removable before the retention capacity is reached. Experience has shown that, under normal conditions, it is unlikely that the full dike capacity would be needed.

Catastrophic tank failures are extremely unlikely. However, should a total tank failure occur, the oil wave may not be contained, and oil could surge over the dikes. This could also be true where boilover or slopover conditions prevail.

To permit ready movement of firefighting equipment across the dike, most companies restrict dike heights to ~6 ft (1.8 m), although higher dikes may be permissible. Facility policy, codes, or regulations may require multiple stairs or ladders for access and egress from diked areas.

It is advisable to develop a means of controlling drainage from the dike area in the event of a fire. Pipe connections through the dikes, with valves on the exterior of the dike and discharging into drainage ditches, should be an adequate means of control. These valves should be kept closed except when necessary to drain accumulated water. Some facilities use locks on dike drain valves to reinforce proper drain usage.

Multiple tanks within one diked enclosure are acceptable depending on tank capacity vs dike capacity. Intermediate dikes (curbs) may be necessary to separate tanks or groups of tanks. NFPA 30 provides additional details and presents impounding alternatives to diking.

5.10 Power and Utilities

5.10.1 General

Refinery service and utility lines, such as water, steam, instrument, air, electric light, and power, should be designed for maximum reliability. A reliable communications system also is necessary. An alternate communications system for use during an emergency may be desirable. The possibility and impact for service interruption of modern computerized digital telephone systems that rely on electric line power should be considered during utility reliability studies. (Traditional analog telephones do not rely on external power sources.)

5.10.2 Electric Power

5.10.2.1 Electric Installations as Ignition Sources

API 500, NFPA 30, and NFPA 497 should be used as guides in determining the proper electrical area classification. Local electrical codes or the National Electric Code should be used for design and installation within the specific classified areas.

The use of outdoor substations in nonhazardous areas reduces the possibility of flammable vapor concentrations that might occur in substation buildings from ground seepage and poorly sealed drains.

5.10.2.2 Electric Power Affected by Fires

In the event of fire, circuits may be subject to interference from exposure to high temperature or water drainage. This should be considered when locating overhead lines or when establishing a safe location for a substation in process areas.

5.10.2.3 Electric Power Continuity Impact

A total power loss at a refinery can be expected to cause unit upsets with the potential for fires. Access to two power sources reduces the probability of outage caused incidents regardless of whether power is purchased or generated on site. Electric power may be purchased from a utility company or generated in the refinery. If power is purchased, it is preferable to have at least two main feeders to bring power into the refinery via two different routes. Where the possibility of electric power outages exists, small engine-driven emergency generators may be provided for critical electrical circuits.

Electrical emergency backup equipment may either be manually operated or arranged for automatic switchover upon failure of the main supply. Dependable AC power for critical electrical control circuits may be provided by battery sets equipped with chargers and static inverters.

5.10.3 Steam

If steam is used to generate electrical power, steam-generating facilities should be located where they will have minimal exposure to external fire. The facilities should be designed to allow automatic shutdown of noncritical steam users following the loss of electric power, thereby reducing the steam load during power failure.

Steam boilers may be weather protected and installed outdoors. When the boilers are housed, the building should be constructed of fire-resistant or noncombustible material. Area drainage should be designed to prevent an inflow of flammable hydrocarbons.

The boiler fuel system should be designed to reduce the possibility of explosion in the event of burner flame failure. The modern, high-heat release, fast-steaming boilers that use a forced draft do not allow sufficient time for the operator to determine the corrective action required in an emergency. Therefore, fully automatic boiler supervisory controls with continuous burner flame scanning should be considered.

It is preferable that main steam lines be installed in areas of low fire exposure, such as along roadways. A looped system designed with division valves to permit shutoff of sections and to permit steam to be supplied from two directions is desirable. Steam lines are usually installed overhead to simplify condensate drainage and insulation requirements and to provide for pipeline expansion. Refer to API 583 for more guidance.

5.10.4 Water

Water pumps for process, fire, and service requirements should be located as close as possible to the water supply source. This will permit the use of short suction mains for effective and reliable pump operation. Steam, electric motor, or internal combustion engine pump drives may be used, depending upon the reliability of the power source. Multiple pumps, each using a different type of drive, often provide optimum reliability. Total capacity should be sized based on normal needs and emergency scenario analysis. Emergency needs should identify what reduced utility water usage could impact process stability and potentially result in product releases.

Spare engine-driven water pumps are desirable where the possibility of electric power outages exists and generation of refinery steam to operate water pumps can be subject to interruption. Planning should include provision for replenishing engine fuel supplies.

Hydrocarbon vapor release is another consideration with process water cooling towers. This may be caused by hydrocarbon leakage from coolers and condensers into the cooling water return system. Provision for vapor disengaging and venting from the return system may be considered. Detection of hydrocarbon leakage, location of cooling towers, and adequacy of vapor dispersion should all be considered in the design of process water cooling towers.

Measures should be taken to prevent freezing of water mains that provide the necessary fire, process, and service requirements. Interconnecting or looping of lines in vital services is desirable.

Process and fire water systems should be separate. Permanent connections between the fire water system and any process system shall be prohibited, to prevent contamination of fire water with process fluids. If extraordinary circumstances require the systems to be temporarily connected the design should ensure the minimum fire water flow rates and total volume demands (see 6.2.2) are always available regardless of the process water demands. A change review process (such as an MOC—see 3.11 and NFPA 30) should be conducted to guard against contamination of fire water by process water that may contain hydrocarbons or additives that might cause foam breakdown. A schedule to resume removal of the temporary connection should be part of the plans for the initial connection. Isolation of process water from fire water should use double block and bleed valves, removable spool pieces, or other means to assure no contamination can occur. Check valves alone are not sufficient.

Refinery fire water systems are discussed in Section 6.2.

6 Fire Control and Extinguishing Equipment

6.1 General

This section discusses the general approach for fire control and extinguishment that has been successfully adopted for use by both large and small facilities throughout the petroleum industry. The goal of effective fire control is to extinguish a fire in the shortest possible time, with no loss of life and minimum loss of property. The exception to aggressively seeking rapid extinguishment is where the fuel for the fire is a pressurized gas or liquid release that should be allowed to burn until the source of fuel can be shut off.

The primary objective of firefighting is to extinguish a small fire before it expands to become large or to control a large fire and protect adjacent exposures until emergency response resources and staffing are sufficient to safely mount an aggressive suppression effort.

Most facilities have the following three basic types of firefighting equipment ready for immediate use.

a) Fixed System—A fire protection system that is permanently installed and connected to a supply of extinguishing agent(s). These systems may be automatically or manually activated. A water spray system supplied directly by the plant fire water system or a gaseous clean agent system in a control room or computer room are examples of fixed systems found in refineries.

b) Semifixed System—A fire protection system that is permanently installed but not connected to a supply of extinguishing agent. These systems generally require personnel to manually connect an extinguishing agent supply to the system prior to use. One example is a tank foam system that terminates at a connection located outside of the dikewall.

c) Portable Equipment—Fire suppression equipment that must be moved to the site of the fire, then assembled or positioned before being put into service. It is generally stored until needed at a location accessible to its intended users. Examples include fire trucks, portable pumps, fire hose, foam monitors, foam supplies, fire extinguishers, and most fire department equipment.

Fire protection equipment should be kept in fully functional condition and inspected and tested periodically in accordance with facility policy and accepted procedures. In some instances, equipment may be regularly inspected and tested by an outside service or agency. Proper records should be kept of each inspection (for an example, see NFPA 25).

6.2 Water for Fire Suppression

6.2.1 General

Water is used universally as a firefighting agent. It serves as a cooling, quenching, smothering, emulsifying, diluting, and displacing agent. The high latent heat of vaporization of water (its high absorption of heat when converted to steam) makes it particularly valuable in fighting oil, gas, and class A combustible fires. It is usually available, easily handled, and when applied as a fog (finely divided spray) is effective and safe to use on most petroleum fires where it inhibits combustion by both cooling and smothering (excluding oxygen).

Water is the primary agent for cooling equipment, structures, and tank shells that are exposed to a fire. This prevents or reduces both heat damage to equipment and overpressure that results from overheating vessel contents.

When used as a coarse high-velocity spray stream, water can sweep pools of burning fluid out from under elevated equipment. Extinguishment will result if the fuel surface can be cooled below the temperature at which it will give off sufficient vapor to support combustion (fire point). The proper way of applying water for extinguishment is in the form of a spray. If a water spray is properly applied to the surface of a burning liquid hydrocarbon with a flash point above 200 °F (93 °C), it can produce a layer of froth on the liquid surface, which will act similar to foam and smother the fire. One example is fighting a hot asphalt tank. However, care must be used to prevent slopover.

Spills of flammable liquid that are soluble in water may, in some instances, be extinguished by dilution. The quantity of water required to extinguish a fire by dilution varies with the solubility of the products and is generally quite large. For example, a solution of 75 % water and 25 % ethyl alcohol will support combustion. As a result, for soluble materials it is generally impractical to extinguish fires involving deep liquid spills and those within tanks by dilution with water because fire spread, and tank overfilling may occur before sufficient dilution is achieved.

Water is used as a displacement medium in leaking hydrocarbon lines. It may also be used to float liquid hydrocarbons above a leak in a tank to replace product leakage with water leakage. To be effective in pressurized pipes and tanks, the water pressure must be greater than product pressure. Care should be taken to avoid flow of a higher-pressure product into a lower pressure water system and to avoid overpressure of the vessel and piping. Water cannot be used to displace refrigerated LPG or liquefied natural gas from a leaking pipeline if the product temperature is colder than 32 °F (0 °C), or for liquids that have a temperature above 200 °F (93 °C).

By cooling exposures and controlling fire intensity, water can be used effectively to control pressurized gas or liquid fires and spill fires involving low flash point fuels. Water cannot be used effectively to extinguish such fires and extinguishment may be undesirable because of potential vapor cloud hazards. However, experienced firefighting personnel can use water spray as very effective personal protection from radiant heat and flame contact to gain access to equipment so that valves can be closed, shutting off the fuel source for fire suppression. Also, in some conditions, firefighters can disperse moderate quantities of escaping gas or vapor using water spray.

Water is the principal ingredient in firefighting foam; mixed with foam concentrate this is the most effective agent for extinguishing large flammable liquid spill fires or tank fires.

6.2.2 Water Supply

6.2.2.1 General

The required water supply for firefighting may be obtained from a combination of dedicated higher-pressure fire water mains, and other available and reliable sources. The fire water system should be designed such that the fire main sizing meets fire flow requirements throughout the refinery. Each important fire risk area should be looped with fire mains sized to supply the critical areas with water at the appropriate fire flow rate and pressure.

The design demand should be based on hydraulic calculations for current and future scenarios. The fire main size should be calculated to deliver the minimum pressure and flow requirements for monitor nozzles, fixed suppression systems, and fire apparatus intakes [typically 75 psig to 125 psig (520 kpa to 940 kpa]) hydrant pressure at full rated demand). Refer to Table 1 and Table 2 for guidance on establishing minimum flow and pressure requirements.

Gate valves should be installed to sectionalize the water main grid so that only part of the system will be out of service during failures or repairs. Gate valves and buried system post indicator valves should be used and marked for easy identification.

Fire water should be supplied by a system that is independent of all other uses and be from a reliable source. If the normal source is not reliable, an emergency supply should be provided from a storage tank or reservoir. If a storage tank or reservoir is used for emergency water, it should normally be kept full. The storage tank capacity should be adequate to meet the high-pressure water requirements for a period of at least four to six hours (or longer as determined by the FHA). It is desirable to have an adequate supply of makeup water available in addition to storage requirements.

Water sources should be of high quality and free of water treatment chemicals that will be detrimental to firefighting foam generation. Pump inlets must be adequately protected from debris entering the system. The use of all possible water sources for firefighting may provide large economies in construction and operating costs. Sources for consideration are the public water supply, and natural water sources. Also, other available sources of water, such as storm water drainage sewers and environmental ponds, should be considered. Under emergency conditions, the use of cooling water tower basins can be considered. Review and testing before a time of need is prudent to determine whether cooling water additive treatments include antifoaming agents that might affect the quality of firefighting foams. Consultation with the manufacturers of the additives and foam concentrate may be necessary. Regardless of the source, the water supply should equal the minimum requirement under adverse conditions.

Fire lines, valves, hydrants, monitors, pumps, storage tanks, and portable water-type extinguishers should be protected from freezing. Lines should be designed and installed to avoid overstressing caused by earthquakes, settlement, severe shock from mechanical impact, and damage by fire exposure. Possible damage to fire water lines should be considered in the original design and the potential minimized by measures such as putting lines underground near process areas or pressurized storage (e.g. LPG) and installing barricades when lines are aboveground but near roadways (particularly at intersections). Diagrams of lines and valves should be posted at key points throughout the plant, and any or alteration to the system should be subject to an MOC review and documented concurrent with the change.

Connections to firefighting systems that permit the diversion of water for other purposes should be avoided. Where such connections are in place, procedures should be established to ensure that adequate volumes of fire water are available when needed (see 5.10.4).

For more information, refer to NFPA 24.

6.2.2.2 Flow Rate Ranges for Manual Firefighting

The minimum fire protection water supply should be capable of providing the flow rates, pressures, and duration determined from a pre-incident scenario analysis. The following discussion provides broad general guidance.

The flow rate of water required for fire protection should be calculated separately for each considered fire area within the refinery. The fire protection water supply is normally sized to be capable of providing the largest calculated flow rate required for any single fire area within the facility.

Specific design criteria for fire water flow rates depend on plant design, configuration, and process hazards. The actual design can be determined by:

1) providing 0.1 gpm/ft^2 to 0.5 gpm/ft^2 (4.1 Lpm/m^2 to 20.4 Lpm/m^2) of water to the fire area based on congestion and unit structures while considering the appropriate fire response based on pre-incident plans and experience, or

2) historical experience with similar facilities.

Where the fire protection water system is intended to supply only monitors and hose streams in support of manual firefighting and suppression, sample flow rate ranges may be estimated using values suggested in Table 1.

Table 1—Example Water Flow Rates for Manual Firefighting [a]

Scenario Area of Interest	Fire Water Flow Ranges, per Minute in Thousands of Gallons (thousands of liters)	Example Flow Rate Ranges Based on Protected Area (gpm/ft² or Lpm/m²)
Radiant heat protection		0.1 gpm/ft² (4.1 Lpm/m²)
Process Areas—Handling flammable liquids or high-pressure flammable gases	4000 gpm to 10,000 gpm (15,000 Lpm to 38,000 Lpm)	Cooling: 0.2 gpm/ft² to 0.3 gpm/ft² (8.2 Lpm/m² to 12.3 Lpm/m²) Suppression: 0.3 gpm/ft² to 0.5 gpm/ft² (12.3 Lpm/m² to 20.4 Lpm/m²)
Process Areas—Handling gases or combustible liquids	3000 gpm to 5000 gpm (11,000 Lpm to 19,000 Lpm)	0.20 gpm/ft² to 0.30 gpm/ft² (8.2 Lpm/m² to 12.3 Lpm/m²)
Tank Storage—Flammable and combustible liquids in atmospheric tanks	0.16 gpm/ft² to 0.3 gpm/ft² (6.5 Lpm/m² to 13 Lpm/m²) (application rate increases with tank diameter)	See API 2021 and NFPA 11
LPG Storage—Tanks and vessels [b]		See API 2510, API 2510A, and NFPA 58 (250 gpm to 500 gpm at point of impingement by a high-velocity jet flame—API 2510A)
Warehouses		See applicable *Building and Fire Codes*
Buildings—Offices, laboratories, and similar structures		See applicable *Building and Fire Codes*

[a] The total (gpm or Lpm) flow required will depend on size, congestion and the needs of the exposed facilities being protected. The specific flow rate (gpm/ft² or Lpm/m²) chosen will depend on the definition of the fire area and the fuel loading in the area. Flow rates required for full surface jumbo tank fires often exceed 10,000 gpm (see 6.2.2.6 and API 2021).

[b] Do not extinguish gas fires until the source of gas can be isolated.

6.2.2.3 Determining Water Flow Rates for Process Areas

Where the considered fire area is totally or partially protected by fixed water spray, sprinkler, or foam systems, the flow rate should be the sum of the flow rates required for proper operation of the fixed systems, plus an allowance for simultaneous operation of monitors and hose streams. Where there are multiple fixed systems within the fire area, the calculated flow rate should consider whether adjacent systems may need to operate concurrently (see API 2030 and NFPA 15 for more detail).

6.2.2.4 Suggested Residual Pressure

The residual pressure required for fire protection should be determined separately for each considered fire area within the refinery. The required pressure should be the highest pressure required by any system or piece of equipment at the delivery point where it would be operated during the fire scenario. Suggested residual pressures for common fire protection systems and equipment items are shown in Table 2.

The fire protection water supply and the distribution piping should be sized such that the required pressure is met at each considered fire area when flowing the required flow rate for that fire area.

Table 2—Suggested Residual Pressures

System or Equipment Item	Desired Residual Pressure	Measured at
Calculated sprinkler, water spray, or foam system	As determined in the system calculations, generally between 75 psi and 125 psi (520 kpa to 940 kpa)	As specified in the calculations, usually at the base of the system riser or the connection to the main
Fixed monitor	100 psi (690 kPa)	At the monitor base
Hydrant directly feeding hose streams	100 psi (690 kPa)	At the hydrant
Hydrant feeding a fire truck if no fixed equipment is operating	20 psi (138 kPa)	At the hydrant

6.2.2.5 Fire Water Flow Duration

The total water supply within the refinery should be capable of supplying the maximum flow for a period of not less than four to six hours, consistent with projected fire scenario needs. Where the water system is supplied from a tank or reservoirs, the quantity of water required for fire protection should be reserved exclusively for fire protection. However, where the tank or reservoir is automatically filled by a line from a reliable, separate supply, such as from a public water system or wells, the total quantity in storage may be reduced by the incoming fill rate.

6.2.2.6 Water Requirements for Tank Fires

Full surface tank fires represent large water demands for fire suppression. Pre-incident planning should consider water sources and delivery to the fire. This may involve high-capacity foam monitors, large diameter hose (LDH) and high-capacity mobile pumps. API 2021 discusses tank fire suppression with water-foam solution needs indicated in Figure 5 from that standard (see Figure 2).

Recent testing of new foam formulations (see 6.3.1) has revealed there may be a need to increase the application rate from historical values, particularly when fluorine free foam concentrates are used. Consult your foam supplier and/or NFPA 11, for additional guidance specific to the foam concentrate being used.

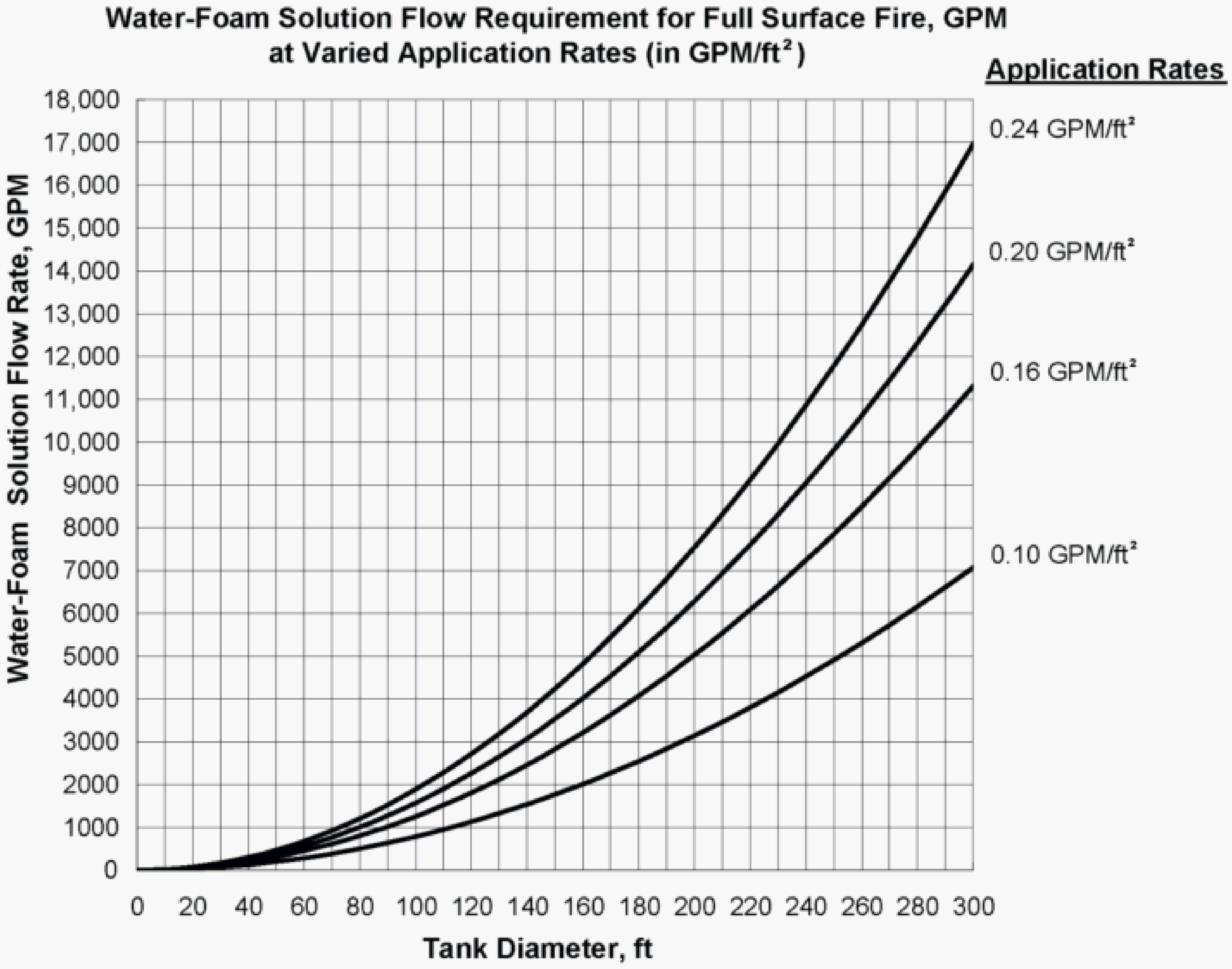


Figure 2—Water-foam Solution Flow Requirement for Full Surface Fire, gallons per minute at Varied gpm/ft² Application Rates (Figure 5 from API 2021, Fourth Edition)

6.2.3 Pumping Equipment

It is desirable to provide fire water pumps with different power sources for drivers to decrease the vulnerability of the system. Most locations divide drivers between electric motors and diesel engines. Steam turbine drivers are also used. If electric power is generated on site from the same steam system that supplies steam driven fire water pumps, then the electric and steam pumps are vulnerable to a “common cause” failure. Gasoline engine drivers normally are not used for fixed installations because of relatively high maintenance and lower reliability. Spare firewater pumping capacity is normally provided such that loss of any one pump will not impact the ability to still meet the maximum firewater demand.

Centrifugal pumps, including horizontal split case and vertical turbine pumps, preferably with a relatively flat characteristic curve, are generally used for supplying fire water systems. Centrifugal pumps with these characteristics provide a steady, non-pulsating flow of water at uniform pressure and can also idle against closed valves for a length of time without damage to the pump or connected equipment. In some instances, relief valves or governors are provided to prevent overpressuring the fire water system. Ideally, pumps are located in areas not likely to be impacted by a fire or explosion. Larger installations with multiple pumps typically place pumps in separate areas of the facility to reduce their vulnerability.

New fire pump installations should meet the requirements of NFPA 20. Fire system pumps are usually divided into three categories:

a) jockey pumps that maintain sufficient pressure and have the capacity to supply first-aid hose streams that might be required during emergencies or during the early stages of a fire;

b) main fire pumps that are operated, either manually or automatically, to provide the basic capacity;

c) pumps in standby service to provide water in the event of failure or demand exceeding the capacity of other pumps.

6.2.4 Fire Hydrants

The type of fire hydrant used will depend upon climatic conditions. Standard self-draining fire hydrants meeting the American Water Works Association standards are generally used in freezing climates.

Fire water supply manifolds can be used instead of fire hydrants in nonfreezing climates. Fire hydrants or headers can include a variety of outlets, including large "steamer" or hose connections. Hose connections should be compatible with those used on the hoses of the local fire department and mutual-aid organization, or adequate adapters should be provided.

The number of hydrants in an area is usually determined by the design and type of process. The normal distance between fire hydrants ranges from 150 ft to 300 ft (45 m to 90 m), depending on the fire hazard, layout of the area, water requirements, and the number of outlets on the hydrants. The distance between a fire hydrant and a building or structure that is to be protected should be at least 50 ft (15 m), if possible.

6.2.5 Fire Hose and Reels

Fire hose may be categorized as attack hose or supply hose. Traditionally most refineries have used 2 $^1/_2$ in., 1 $^3/_4$ in., and 1 $^1/_2$ in. hose as their standard for attack hose. LDHs (from 4 in., 5 in., and 6 in. in diameter up to 10+ in.) have growing acceptance and application as supply hoses. Coordination of hose fittings and connections with local mutual-aid or public resources is appropriate irrespective of the sizes of hose used.

The 2 $^1/_2$ in. attack hose is used primarily for heavy cooling streams. Three or more people are required to handle 2 $^1/_2$ in. hose lines, depending upon the system pressure. Two $^1/_2$ in. hose lines are suitable to supply water for small portable ground monitors. It is general practice to carry this hose on mobile equipment to reduce plant hose requirements. Some 1 $^3/_4$ in. or 1 $^1/_2$ in. hose is usually carried on the mobile equipment for use in tank farms or other outlying areas.

LDH is used to supply high-flow mobile monitors such as used for tank fire suppression or for water supply to areas where a system is too small, compromised or nonexistent.

In some cases, LDH provides advantages because:

a) its lower friction loss reduces pumping resource requirements,

b) it minimizes personnel staffing requirements by reducing the need for multiple hose lays (one 5 in. LDH may carry as much water as six 2 $^1/_2$ in. hoses),

c) it facilitates the use of high flow rate monitors used for tank firefighting.

For rapid availability of water in process areas, permanently connected hose reels and hose stations have been used extensively. These reels are usually provided with a 1 $^1/_4$ in. or 1 $^1/_2$ in. hard rubber or comparably sized fabric hose for incipient firefighting. The hard rubber hose on a "continuous flow" reel has the advantage that it can be charged and used by one person without unreeling it entirely. However, its use is limited because hydraulic pressure loss limits the length of hose to ~100 ft (30 m) to assure adequate nozzle pressures. Fixed fire monitors are often used in conjunction with hose reels in many new facilities. Hose reels stations may be configured to provide foam for rapid response to leaks or spills.

6.2.6 Nozzles

Combination fire hose nozzles providing water patterns continuously variable from straight streams to water spray (or water fog) are widely used. Straight water streams are used primarily for cooling equipment, although they have been used effectively for sweeping burning hydrocarbon spills away from exposed equipment. Straight water streams are reasonably good at nozzle pressures as low as 45 psig to 50 psig (310 kPa to 345 kPa) and provide a longer range than water spray nozzles. Care must be taken to avoid damage to insulated facilities or equipment from high-pressure, high-flow straight-stream hose streams.

Straight stream patterns are generally used when:

a) extended reach is required, particularly in high wind situations;

b) deep penetration of the fire area is required;

c) water quality is such that fog nozzles cannot be operated due to plugging;

d) low water pressure prohibits the use of fog nozzles.

It is general practice to use shutoff-type nozzles so that the hose line may be controlled by the person at the nozzle. Most water fog combination-nozzle manufacturers recommend nozzle pressures at 100 psig (690 kPa) with functional operation in a range from 70 psig (485 kPa) minimum to 125+ psig (860+ kPa).

When used by experienced personnel, water spray can be effective for:

a) extinguishing fires involving high-flash products;

b) chilling hot vapors and preventing ignition;

c) cooling low flash point (gasoline and LPG) oil and gas fires to reduce their intensity;

d) cooling exposed equipment and preventing or reducing fire damage or involvement of other fuels as a result of equipment heat stress (such as blown gaskets or opened flanges);

e) dispersing vapors and preventing their ignition from nearby ignition sources;

f) cooling fires in light hydrocarbons service (such as gasoline) so that they may be more readily extinguished by dry chemical agents used in combination with the water supply;

g) frothing out fires involving heavy viscous oils;

h) providing a protective cooling curtain for personnel who are operating valves or other shutoff devices.

Reference should be made to manufacturers' literature, NFPA 1964, and NFPA's Fire Protection Handbook for a thorough discussion of nozzle types and water spray patterns, as well as water capacities, range, and related information.

6.2.7 Monitors and Master Stream Delivery Devices

Monitors may be equipped with various delivery devices. They can be mounted on trailers or pickup trucks to provide high-volume mobile master streams. Fixed monitors may be desirable for use at spot locations. Because their area of coverage is limited, fixed monitors should be carefully placed to provide optimum coverage. These locations should be reviewed during both the design and the final construction stages of a job to avoid unnecessary obstructions like piping and support columns. In some cases, fixed monitors are provided with shields to protect the operator from radiant heat. Monitors (fixed and truck/trailer mounted) can be configured to provide foam for rapid response to leaks or spills.

The installation of fixed monitors in an area does not necessarily eliminate the need for portable monitors and/or hydrants for hand line use, because fixed monitors may not provide complete coverage of the entire area and may possibly be inaccessible during an emergency. Portable monitors can be used in place of handheld lines to reduce stress on firefighters if mobility is not required.

Special installations may require elevated monitors, remote control monitors, or oscillating monitors. Elevated monitors can be used to protect areas inaccessible from grade because of congestion or at docks.

6.2.8 Water Spray Systems

Water spray cooling systems can be used to reduce fire exposure damage by keeping a water film on exposed surfaces to absorb radiant heat. They can also be designed to reduce fire intensity at the source. Water spray systems are not designed to protect against direct impingement by pressure fires due to the inability to penetrate the flames and low flow rate densities (see 5.6.8.2, API 2030, and NFPA 15). Manually operated valves should be located away from areas of potential exposure so they can be activated in time of need without putting personnel at risk.

6.3 Foam

6.3.1 General

Firefighting foam forms a cohesive floating blanket on the liquid surface that extinguishes fire by smothering and cooling the fuel. Foam also prevents reignition by inhibiting vapor release, thus preventing formation of combustible mixtures of vapor and air. Applying a foam blanket to fuel spills before ignition can prevent spills from becoming fires.

Foams are particularly suited for extinguishing two-dimensional flammable liquid spill fires or in storage tanks where the foam forms a vapor-sealing blanket that secures the area after extinguishment. In fires involving jetting or falling fuel, such as an overflowing tank or line flange leak, foam is effective only on the fire that arises from fuel spills and on pools that form flat surfaces. Foam is not suitable for extinguishing fires that involve flammable gases or liquids containing large amounts of LPG.

To extinguish deep tank fires or spill fires, continuous foam application at no less than the required rate is critical. See NFPA 11 for minimum recommended application rates. Higher application rates may be needed on large tanks. The fire may not be extinguished unless the foam is applied and maintained on the liquid surface until it is sealed by a cohesive blanket of foam. Cooling water applied to a flame-exposed tank shell above the level of fuel in the tank may assist in extinguishing a fire. When foam is applied by hand lines or monitors over the rim of a tank, wind and thermal updrafts frequently carry a portion of it away. As specified in NFPA 11, foam must be applied at a 60 % higher rate to compensate for this loss.

Foam is made by mechanical action or agitation achieved by the turbulent mixing of atmospheric air into the foam solution of water containing liquid foam concentrate. The variety of foam types typically used in a refinery are:

a) fluoroprotein (FP),

b) aqueous film-forming foam (AFFF),

c) film forming fluoroprotein (FFFP), and

d) alcohol resistant (or multipurpose) AR-AFFF or AR-FFFP.

Factors influencing the choice of a specific foam type for use at a facility include:

a) the type of product for which fire suppression may be required,

b) the type of foam concentrate stocked by potential mutual-aid participants,

c) sources and timing of supply from manufacturers for major incidents,

d) cost effectiveness of the candidate foam concentrates,

e) logistics—1 % vs 3 % vs 6 % concentrates (see API 2021).

f) use of foam for vapor-suppression to prevent ignition or post-suppression.

The manufacturer of the foam-making equipment should be consulted for the correct percentage of concentrate to be used in their system. Proportioners should be designed and set for the percentage of foam concentrate used to form the desired solution.

For detailed information on foam application methods and equipment, see technical information provided by the foam concentrate and apparatus suppliers. For additional information on foam types see API 2021 and NFPA 11. In application, finished foam applied to a fire can be mixed, but mixing foam concentrates of different varieties is not recommended.

6.3.2 Foam Environmental Concerns

In 2006, the Environmental Protection Agency launched the PFOA Stewardship Program to address concerns of the impact of Perfluorooctanoic Acid (PFOA) and long-chain Per- and Polyfluorolkyl Substances (PFAS) on human health and the environment. One goal of the program was to eliminate the manufacture and use of PFOA in products by 2015. This material has been used for decades in the manufacture of synthetic firefighting foam concentrate, as well as many other products. In response, manufacturers have developed more environmentally friendly foams, including some that are fluorine free. Environmental and fire protection experts should be consulted prior to the use and/or disposal of existing foam concentrates, remediation of contaminated sites, as well as the conversion from existing to newer foam concentrates (including decontamination of equipment).

6.4 Dry Chemicals

6.4.1 General

Application of a dry chemical can be effective in controlling and extinguishing fires occurring during the processing and handling of flammable liquids and solids. The finely divided chemical produces free radical interceptors that break the oxidation chain reaction that inhibits the combustion process within the flame itself.

These agents are effective on small spill fires and on fires involving jetting or falling fuels. However, caution should be exercised when extinguishing pressure fires to ensure that the remaining hazard is not greater than the original fire. Dry chemicals are nonconductive agents suitable for fires involving energized electrical equipment with recognition that the particulate residue may be corrosive and certainly requires cleanup.

Rapid fire control and flame reduction may also be achieved by using multipurpose (ABC) dry chemical on combustible materials such as wood and paper; however, an additional quenching agent such as water must often be used to extinguish the remaining embers.

Dry chemical extinguishing agents have proven to be effective when used simultaneously with water fog without interfering with the effectiveness of the chemical. The water fog will quench embers, cool hot surfaces, and reduce flame size making the fire easier to extinguish with the dry chemical. This cooling effect is particularly important if a fire has been burning for a significant period, since there is a high chance of “reflash” if fuels contact heated metal. For further information, see NFPA 10 and NFPA 17. Dual agent foam systems (see 6.5) are available to apply both foam and dry chemical on hydrocarbon fires through combined nozzle systems. Ideally, the dry chemical “knocks down” the fire and the foam secures against reignition.

6.4.2 Dry Chemical Extinguishers and Equipment

Dry chemical extinguishers are available in hand-carried, wheeled, truck-mounted, and stationary units. They have capacities ranging from 1.5 lb (0.7 kg) to 3000 lb (1365 kg) of chemical per unit. Multiple units can provide higher capacities if required for special installations. Stationary units can be piped for manual, semiautomatic, or automatic control. NFPA 17 provides information concerning installation of dry chemical extinguishing systems.

Portable hand extinguishers containing 30 lb (13.65 kg) or less of dry chemical are recommended for use as incipient firefighting equipment for small fires. Several hand extinguishers may be used simultaneously for extinguishing larger fires. Reserve, or secondary, protection can be provided by wheeled or stationary extinguishers with capacities up to 350 lb (160 kg). Some operators prefer to use several hand units simultaneously from different angles to provide coverage of the fire and reduce the potential for reignition. This multiple application may be supplemented by properly- directed water fog streams.

Portable extinguishers should be placed in locations that are safely accessible in the event of a fire. Whenever an extinguisher is used, it should be replaced and removed for inspection and recharging. Some operators seal an extinguisher or cabinet so that it may be monitored more readily. Other operators place the extinguisher in an expendable plastic bag that serves the same purpose while keeping the extinguisher clean and preventing atmospheric corrosion. Reference should be made to the manufacturer's recommendations for inspection, servicing, and repair; NFPA 10; and any relevant regulatory requirements.

Large chemical quantities delivered by hose line discharge can be supplied by stationary or mobile extinguishers having capacities of 500 lb (225 kg), 1000 lb (455 kg), and 2000 lb (909 kg). Selected hose line stations may be equipped with these extinguishers to protect areas of special concern.

Extinguishers designed for stationary use may also be mounted on vehicles for the protection of larger subdivided areas. Manufacturers have made available specially designed fire trucks with dry chemical capacities to 3000 lb (1365 kg). The chemical may be discharged through hose lines, or through high-capacity turret nozzles that have a protection range of ~100 ft (30 m). These fire trucks may also be equipped with supplementary water extinguishing equipment. However, when using large wheeled units, fire visibility may be lost by the dust cloud.

6.5 Combined (Dual) Agents

Certain AFFF and FFFP foams are compatible with dry chemicals. Systems have been developed for simultaneous or alternate application of these foams with dry chemicals. In some designs, the dual agent system can substantially increase the dry chemical component range (using the foam stream to carry the dry chemical) and improve visibility because the water/foam stream inhibits dust cloud formation. Some very high capacity systems are commercially available. The foam supplier should be consulted to ensure compatibility of agents and equipment.

6.6 Clean Agent Fire Extinguishing

6.6.1 General

Clean agent systems are traditionally used in applications where water-based extinguishing systems are presumed to present a higher potential for equipment damage than the design basis fire scenario. Clean agents such as halocarbons and inert gases (e.g. CO_2, see 6.6.4) are normally used to protect enclosed spaces. The decision to use a clean agent should be based on an understanding of the fire hazards in the enclosure and the ability of the enclosure to contain the clean agent during a fire. The design of the clean agent system must account for leakage from the protected space, and the likelihood that the enclosure integrity will be compromised during the system discharge. It is also important to recognize that a particular enclosure may require a clean agent concentration that creates a safety hazard to personnel and this consideration should be included in choice of a clean extinguishing agent. Additional safeguards (such as prerelease alarms and post-release warning lights) may be needed to ensure prompt evacuation and prevent entry into a hazardous atmosphere.

Clean agent systems are most suitable for unoccupied enclosures containing mission critical equipment (e.g. remote I/O, critical machinery, computer rooms, etc.). Since these are unoccupied, an automatic detection system is a vital component of the clean agent system package. A clean agent system will offer little value in terms of equipment preservation if the detection system does not promptly initiate the release of the agent. NFPA 2001 provides additional information on clean agent systems. The U.S. EPA "Significant New Alternatives Policy (SNAP) Program" evaluates alternatives to ozone-depleting substances such as Halon. An EPA approval list and useful reference information for alternative fire suppression agents is posted on the SNAP Program section of the U.S. EPA website. The EPA's program evaluates and regulates substitutes for the ozone-depleting chemicals that are being phased out under the stratospheric ozone protection provisions of the U.S. CAA.

6.6.2 Halon Extinguishing Agents

Halon extinguishing agents such as 1211, 1301, and 2402 are no longer permitted for use in new installations in accordance with the Montreal Protocol, due to concerns regarding effects on the Earth's ozone layer. In some areas (including the United States), recycling to refill existing systems is permissible while other areas are more restrictive. For maintenance of existing Halon systems, refer to NFPA 12A for Halon 1301 systems and regulations relevant to the installation jurisdiction. *A Safety Guide for Decommissioning Halon Systems* is available from the Halon Recycling Corporation (HRC).

NOTE HRC is a voluntary, nonprofit trade association formed by concerned Halon users and the fire protection industry to support the goals of the environmental community and the U.S. EPA. Its function is to assist users of Halon firefighting chemicals to redeploy the existing bank of halons from applications where alternatives are feasible to those unique situations that still require Halons (www.halon.org).

6.6.3 Alternate Agents to Replace Halon

A variety of alternate halon replacement total flooding agents are available; see NFPA 2001 and the U.S. EPA listing at www.epa.gov/ozone/snap/fire. Significant system revision is typically required for a replacement agent storage or delivery (or both). A careful "total system" review should be undertaken when choosing any retrofit agent, including those represented as "drop in" halon replacements. Information on halon alternatives is available from the halon Alternatives Research Corporation website. The availability and use of halon alternates continue to be in flux.

6.6.4 Carbon Dioxide

An "inert" gas such as CO_2, discharged into a closed room or into enclosed spaces, can be effective in extinguishing fires in petroleum pump rooms, electrical installations, and for some special machinery or laboratory apparatus. However, CO_2 is not biologically inert and presents an asphyxiation hazard to personnel. Both concerns should be recognized and addressed in the use of a CO_2 inert gas system. Due to static electricity hazard, CO_2 systems should not be used to inert a flammable atmosphere to prevent ignition. See NFPA 12 and the U.S. EPA Review of the Use of Carbon Dioxide Total Flooding Fire Extinguishing Systems [Wickham] for additional information.

6.6.5 Steam Smothering

The general use of steam as an extinguishing agent can be ineffective. A substantial delay will occur before sufficient air is displaced or diluted to render the atmosphere incapable of supporting combustion. However, because steam is cooler than flame and the water vapor has a high thermal capacity, there are special situations where steam is effective, such as:

a) smothering steam in furnace fireboxes and header boxes,

b) steam rings on equipment flanges,

c) steam rings on hot-tap equipment,

d) blanketing on small hydrogen leaks,

e) steam lances for rapid unit response.

Steam should not be injected into large vapor spaces such as cone roof tanks containing flammable mixtures; static electricity generation from such application is believed to be the source of ignition for fires in the past.

6.6.6 Water Mist—A Pseudo-gaseous Agent

Water is an excellent fire suppression agent due to its high specific heat and high latent heat of vaporization; there are no environmental concerns associated with its use. As a mist, water can act as a "pseudo-gas" making it attractive as a fire extinguishing agent because of the following.

a) The higher surface area of water mist "particles" makes it more effective (per unit applied) than more dense water application.

b) Because of this increased effectiveness, water mist can require very small quantities of water to achieve extinguishment (compared with conventional water application methods such as "traditional" sprinklers, water spray or hose streams). The after effect is more like gas than water thus minimizing collateral damage done by the water.

Water mist systems can be single fluid (water only) or twin fluid (water and a separate atomizing gas). Twin fluid can use compressed air as an atomizing agent or a gas that aids fire suppression, which is called a hybrid system. Because water mist acts much as a gas, it is most effective in enclosed spaces (such as turbine or compressor enclosures) where application density can be maintained, and the agent will not be affected by wind currents.

Water mist fire suppression system and hardware development is continuing. These systems are actively promoted by manufacturers and supported by insurance companies, who conduct research and testing. Water mist systems are being used in a growing number of offshore oil production facilities and in some commercial shipping. The manufacturer should be consulted for current application limitations, listings, and approvals.

NFPA 750 provides resource information.

7 Operating Practices

7.1 General

Standard operations procedures (SOPs) and emergency operating procedures (EOPs) should be developed appropriate to facility fire safety needs consistent with owner/operator internal standards and regulatory requirements. In the United States, this includes regulations such as 29 CFR 1910.110, 1910.119, 1910.120, and 1910.156, as well as regulations promulgated or adopted by local jurisdictions. Job and task procedures also should be developed. Supervisory and processing unit personnel should review SOPs and EOPs on a regular, facility-established basis to assure they are both accurate and up-to-date and that procedures are being adhered to as written and intended. Supervision should inform (educate and/or train) employees of their fire safety and emergency response roles and their responsibilities for safe unit operation, especially the potential process consequences or hazards associated with deviation from SOPs and EOPs.

All personnel should understand their responsibility and accountability for safe unit operation and how unsafe or abnormal conditions or circumstances should be handled. Employees should be able to take appropriate action in the event of abnormal circumstances, including, but not limited to the following:

a) leaks, odors, or unusual sound levels;

b) accumulations of flammable liquids or gases;

c) defective or damaged equipment;

d) excessively high or low temperatures or pressures;

e) unauthorized hotwork;

f) unauthorized vehicles or personnel in an area;

g) malfunction of instrumentation or control systems that may affect safe unit operations;

h) evidence of structural weaknesses caused by deterioration.

A clear set of expectations should be developed so that personnel know their role in all phases of the operation.

7.2 Normal Operations

7.2.1 The fire/loss prevention measures described in this section shall be considered for normal unit operation.

7.2.2 Operating procedures for furnaces, heaters, and other fired equipment should address purging, initial light off, reignition, draft controls, furnace "stuffing," burner management systems, safety interlock systems, and fuel shutoff systems.

7.2.3 Locomotives, other than the fireless steam type, should not be permitted to operate near low flash point oil loading racks while tank cars are being loaded or while the area may be contaminated with flammable vapors (such as when a spill or release of flammable liquid or gas occurs in the area).

7.2.4 Procedures for reducing static charge accumulation while loading tank trucks, tank cars, tankers, and barges should be prepared and followed. Refer to API 2003.

7.2.5 Grounding or electrical insulation of electrical equipment, lines, cargo hoses, and equipment shall follow API guidelines for dissipation of static charges (see API 2003) for loading installations at docks, wharves, piers, loading terminals, and railcar loading installations.

7.2.6 Grounding or electrical isolation of hydrocarbon processing equipment should meet API 540. An assurance program should be established and performed routinely by qualified personnel to verify proper electrical grounding or isolation.

7.2.7 Housekeeping procedures should be followed in all areas to prevent accumulations of oil, grease, or class A materials (rags, wood, cardboard).

7.2.8 Fire and safety systems should be easily identified (color coded and identified), inspected routinely for operability, maintained, and calibrated in accordance with manufacturers' recommendations to assure they will function as designed and intended. Personnel expected to operate this equipment as part of their job responsibility should be trained on the equipment, its capabilities, and limitations.

7.2.9 Storage of flammable or combustible liquids should be in accordance with NFPA 30.

7.2.10 SOPs for material transfers should be incorporated into daily operations. Examples include:

a) tank gauging,

b) tank sampling,

c) tank transfer line up,

d) tank filling—product movement,

e) water draws,

f) tank dike drain valve position.

Employees should be aware of the procedures to be followed in the event of high-level or overfill alarms, spills, releases, or other emergencies that may occur during material transfer operations.

7.2.11 A clear understanding of utility system capabilities, capacities, and limitations is needed by operating personnel to ensure safe operation.

7.2.12 Important lines, valves, tanks, vessels, and other equipment should be identified in accordance with facility or regulatory requirements.

7.2.13 Safe work permits issued and authorized by qualified, assigned persons are typically needed for the following type jobs:

a) hot work (including vehicle access),

b) cold work,

c) confined space entry,

d) lifting and rigging

e) equipment isolation,

f) excavation,

g) bypassing critical protections, (e.g. shutdown devices/systems, fire and gas detection, safety instrumented systems)

7.2.14 Control and maintenance of purge and pressurization systems for equipment that does not meet the electrical classification for the area is essential for control and suppression of ignition source

7.2.15 Precautions should be taken to exclude air, water, inert gases, and other noncompatible, contaminated, or undesirable materials from processes for which they were neither designed nor intended. The use of incompatible fittings can provide one safeguard against inadvertent connections.

7.2.16 The addition or deletion of process chemicals such as demulsifiers and corrosion inhibitors should be done with the thorough understanding of metallurgical implications. Likewise, changes to operating parameters (e.g. transition temperatures), feedstocks (particularly those containing sulfur), and equipment repairs involving hot work (normalizing, annealing, heat treatment, and weld repair) typically involve detailed job procedures that address metallurgical concerns. Process chemical changes should be reviewed and entered into the facility hazard communication system.

7.2.17 Electrical junction boxes, receptacles, or other service devices should not be used in a classified area unless all bolts, covers, screws, and seals are maintained according to the manufacturers' recommendations and NFPA 70. Appropriate permits should be issued for repair, maintenance, and replacement of such equipment located within classified areas

7.2.18 Temporary repairs for the control of hydrocarbon leaks, such as epoxy injections, containment boxes (clamps), etc., should be engineered in accordance with appropriate engineering practices and have proper management review and approval via MOC or an equivalent system prior to implementation. All such repairs should be considered temporary until such time as they are safely and permanently repaired (see API 570).

7.3 Emergency Operations

7.3.1 The potential for fires, explosions, or gas releases increase during times of abnormal or emergency operation. Properly executed pre-incident plans for responding to unusual circumstances are needed to address these conditions.

7.3.2 SOPs and EOPs should address job responsibilities and duties for unit personnel who will participate in start- up and planned or emergency shutdowns of the process. These responsibilities should address the requirements described in facility policies and OSHA 1910.119.

7.3.3 Operating personnel should be informed of relief system and flare system capabilities and limitations to support safe operation under abnormal or adverse operations.

7.3.4 Operating personnel should be trained to develop awareness and understanding of the consequences of potential abnormal operations.

7.3.5 Management systems should be instituted to quickly notify potentially affected parties (nearby process units, adjacent facilities, and community neighbors). See 7.4.

7.3.6 EOPs should address abnormal events such as loss of various utilities (power, steam, air, cooling water, etc.) floods, hurricanes, tornadoes, earthquakes, high winds, lightning, heavy snows and ice storms, freezing temperatures, civil unrest, and terrorism, where applicable. See Section 9 on emergency response organization.

7.3.7 Unit personnel shall be informed of their emergency response (E/R) roles in the facility emergency management program. Personnel responses shall be consistent with OSHA 1910.120(q) and OSHA 1910.156. Personnel assigned E/R roles should have appropriate levels of training and emergency equipment, including personal protective equipment (PPE) needed to safely carry out those roles and responsibilities. E/R drills should be a routine part of unit SOPs and EOPs. See 10.2.4 on simulated fire drills.

7.4 Loss of Containment

7.4.1 General

Leaks and releases represent significant concerns. Containment of hydrocarbons is the primary and most effective fire prevention principle. Containment of hazardous chemicals, such as Hydrofluoric and sulfuric acid, chlorine, etc., is also important to protect personnel responding to a potential fire emergency. Considerations for response to control a leak should include but not be limited to the following:

a) protection of personnel against exposure,

b) utilization of emergency response personnel and resources,

c) isolation of the fuel release or leak at the upstream source,

d) isolation of transfer medium,

e) isolation of ignition sources,

f) containment of product,

g) downwind and off-site impact,

h) displacement and/or removal of liquids still at risk,

i) reduction of hazard zone via application of firefighting foam for vapor suppression,

j) development of mitigation cleanup strategies.

7.4.2 Liquid Leaks

If a break or serious leak occurs in a line, the pumps should be shut down and all appropriate block valves closed. If possible, suction can be applied to the affected portion of the line unless the resultant entrance of air creates a hazard. In that case, water or inert gas displacement may be desirable. If the leak involves a tank or any large vessel, available lines should be used to pump out the liquid to a level below where the leak or release has occurred. Trenches, dikes, or diversion walls should be used either to confine the spill or to divert it to sewers or separators. If the leak is otherwise unstoppable, water may be used to displace the liquid provided this does not create a greater hazard.

If a large spill occurs, portable pumps or vacuum trucks may be required to supplement permanent equipment in recovering the hydrocarbon. If flammable vapors are present, safe (hot) work permits shall be issued and caution used in positioning the pumps because the pump drivers may be sources of ignition and personnel exposure may be a concern. Traffic should be controlled, and vehicles should be excluded from the affected area. Proper bonding and grounding should be used. Vent hoses from vacuum trucks must be placed with caution, to prevent ignition of the vapors (see API 2219).

Water spray or steam applied at the emission point of a small leak may aid in dispersing vapors and preventing ignition. Foam may be applied to cover hydrocarbon spills to reduce vaporization.

7.4.3 Gas Leaks

In the event of a break or failure of a hydrocarbon vapor or LPG line or vessel, all nearby or downwind sources of ignition should be immediately eliminated. The vapors from leaks may roll along the ground and accumulate in low-lying areas before diluting and dispersing. Large leaks have the potential to travel great distances and still be within the flammable limits for hydrocarbon. Some gas leaks may be toxic to humans, as well as being flammable; emergency responders should use appropriate personal protective equipment and people down wind may need to shelter-in-place. It may be possible to disperse vapor leaks by using air, steam, water or other chemical agents to mitigate the potential flammable toxic hazards. If ignition occurs, a pressure fire should never be extinguished until the source of the leak can be identified and isolated.

8 Maintenance Procedures

8.1 General

Fire prevention during construction, turnaround, repair, demolition and both routine and emergency maintenance activities depends upon careful planning and preparation with isolation or the removal of flammable and combustible liquids, vapors, sludges, or other hazardous chemicals and materials before any work is begun. Major activities such as demolition or the removal of process equipment and associated appurtenances pose unique hazards. Lines and equipment must be identified and marked. Hydrocarbon-freeing procedures must be followed, such as blinding, purging, gas freeing, steaming, water washing, liquid evacuation, or inerting.

In normal or emergency repair and maintenance activities and during demolition it is sometimes impossible to verify the complete removal of flammable material or elimination of harmful substances and chemicals such as, but not limited to acids and oxidizers. Therefore, precautions must be taken when conducting hot work and to prevent ignition sources from contacting flammable mixtures. Examples include:

a) isolation or control of drainage in the work area;

b) inerting container piping, etc.;

c) enriching containers piping, etc.;

d) using spark containment enclosures around the work area;

e) use of alternatives to hot work (cold cutting, hydraulic scissors cuts, pneumatic tools) while recognizing that some of these can also produce sparks as metal is cut;

f) application of water, lubricating oil, etc. to provide coolant to the area being worked upon to reduce heat below the ignition point.

Good housekeeping is an important prerequisite in preventing fires associated with maintenance procedures. Refuse that is combustible should be removed from the area and stored in appropriate containers. Leaks and spills should be addressed promptly.

8.2 Hot Work

Prior to approving hot work, verify whether the work can be done without performing hot work inside live process units or on equipment containing hydrocarbons. Hot work should be prohibited on the roof of tanks containing hydrocarbons until the hydrocarbons have been removed. Alternatives to the use of hot work in process areas should be considered when work must be conducted away from designated shop or hot work areas. However, hot work activities, such as electric or gas welding, cutting, brazing, or similar flame or spark-producing operations are necessary for certain equipment maintenance, repair, construction, and demolition activities at refineries. Hot work maintenance activities normally require a hot work permit or authorization provided by trained and designated qualified individuals. Hot work activities may be subject to several regulations, for instance, OSHA 1910.119, OSHA 1910.147, and OSHA 1910.252. Historically, U.S. Coast Guard permit requirements have been an additional consideration for hot work at marine docks associated with refineries. See API 2009.

Certain maintenance and repair activities may require welding or hot tapping on equipment in service if it is infeasible or impractical to take the equipment out of service. Such activities require careful planning, supervision, and execution by competent individuals. For additional information on hot work, refer to the bibliography.

In special circumstances inerting of a tank, line or vessel vapor space may be appropriate as a hot work safety precaution. Inerting is the subject of API 2009, Appendix B. For inerting to be effective, qualified knowledgeable persons experienced in inerting should be involved with planning, supervising, and executing the inerting operations. Inerting does not reduce the need for flammability monitoring in the hot work area.

8.3 Planned Maintenance Activities

The following elements related to fire safety should be considered for inclusion in planned maintenance activities:

a) written maintenance procedures;

b) up-to-date engineering drawings, inspection procedures and reports, manufacturers' information, and historical information on repairs;

c) PMI programs;

d) written safe work authorization procedures;

e) established rigging and lifting procedures;

f) use of tools and equipment (see NFPA 30);

g) adherence to grounding and bonding procedures;

h) static discharge awareness (see API 2003);

i) control of hazardous energy and material sources (lockout/tagout, see OSHA 1910.147 and ANSI Z244.1);

j) procedures for bypassing critical shutdown and safety equipment and their subsequent return to service;

k) maintenance inspection of pressure vessels (see API 510 and API 572);

l) piping Inspection and repair (see API 570);

m) tank inspection and repair (see API 353, API 575, API 653, and API 2610);

n) MOC procedures (see CCPS publications and OSHA 1910.119).

8.4 Winterizing and Freeze Protection

Freezing conditions challenge normal operations. Preparation, planning and protection programs in areas with freeze potential should verify that out-of-service piping is "freeze proofed" and provide winterizing to reduce potential for ice formation and fracture of vulnerable equipment. Items of potential concern include (but are not limited to) instrumentation, aboveground fire water lines, tankage and application equipment (sprinklers, deluges, and monitors), safety showers and eyewashes, and dead-leg pockets in which water can accumulate (such as bottom gauge glasses, low spots in pipe runs, draw connections, bleeders, and valve manifolds).

Dead-legs are a special concern. Attention should be directed to identification and elimination of dead-legs in process piping where freeze-related fracture could cause release of flammable product. Annex B provides information to assist facility planning to recognize and avoid problems. It includes additional dead-leg guidance.

9 Emergency Response Organization

9.1 General

This section reviews the basic principles of emergency response and fire protection organization with the recognition that many different types of organization function effectively. While this section primarily addresses site personnel the comparable needs exist for mutual-aid, industrial cooperatives, or contract organizations.

9.2 Incident Command System (ICS)

The ICS is an integrated management system for emergencies such as fires, hazardous material spills, multi-casualty incidents, earthquakes, floods, etc. [The term incident management system (IMS) is also used.] ICS provides a management structure with defined modular roles for coordination of facility personnel and operations, local fire departments, mutual-aid organizations, and equipment responding to an emergency. For ICS to function effectively, training and education of all personnel (including management) who will assume ICS roles is important.

Use of ICS is mandated by OSHA 1910.120(q) and has been adopted into the U.S. federal government's Homeland Security National Incident Management System. The U.S. Fire Administration (part of FEMA and the U.S. Department of Homeland Security) provides free self-study courses for ICS in the training section on their website www.fema.gov. Additional information on ICS (directed primarily toward public fire departments) is available in NFPA 1561 and in publications from Oklahoma State University's Fire Protection Publications (www.ifsta.org).

Many refineries designate facilities and staff to function as an emergency operations center (EOC). The EOC addresses incident related management needs not specific to the incident mitigation strategy or tactics. These include internal interface with noninvolved operational units and external relations with the community, regulatory agencies, and the media. Incident command may operate from the same location as the EOC but frequently is situated in close proximity to the incident site while maintaining close communication with the EOC. This provides functional advantages for communication with emergency response and process operations personnel as well as providing useful isolation from distraction.

Firefighting is only one aspect of handling fire incidents. An ICS incorporating an EOC can be used to manage a wide range of related emergency response activities that must be coordinated with firefighting, which can include:

a) activating fire alarms;

b) implementing emergency action and evacuation plans;

c) providing rescue and first aid for the injured;

d) accounting for personnel from the area affected by the incident;

e) shutting down equipment and rerouting fuel from the fire area;

f) performing special emergency maintenance work;

g) shutting off nonessential water usage from the fire main;

h) controlling utilities;

i) dispatching firefighting equipment;

j) providing auxiliary traffic control and security;

k) transporting and staging reserve personnel and equipment;

l) maintaining a system to account for personnel working in the "hot zone;"

m) providing rehabilitation areas for response personnel;

n) ensuring liaison among all the emergency activities;

o) providing for media communications and good public relations;

p) providing for backup operating personnel;

q) making mandatory timely notifications of federal, state, or local agencies.

Normally the person responsible for the unit where the fire has occurred should take the lead role for emergency shutdown operations. An alternate should be assigned in case the responsible person is not available. Supervision of the actual firefighting is the responsibility of the incident commander (IC) or a designated alternate. Coordination between the persons in these two roles is a key to safe and effective fire control.

9.3 Duties of Fire Protection Staff

Because of variables among facilities—such as size, management structure, available personnel, throughput, nature of operations, philosophy of fire control, and resources used—each refinery may choose a unique type of fire-protection organization to meet its needs. In many refineries the emergency response fire-protection organization consists of a staff who may supervise firefighting activities, conduct fire training, inspect emergency response equipment, participate in rescue and emergency medical activities, maintain and issue fire-protection equipment, and investigate and report fires. This staff may also counsel operating and engineering groups on fire protection for new or rebuilt facilities, attend planning sessions for major shutdowns of operating equipment, work with fire insurance representatives, and confer with regulatory agencies on codes and ordinances. In some refineries, this staff is integrated with the safety or accident-prevention group. In many refineries a volunteer fire organization operates effectively to fulfill a portion of the above duties.

Periodic review of a refinery's fire-protection program is recommended so that the firefighting organization will function effectively. Written policy, procedures, and minimum training requirements are specified in the OSHA 1910.156 and OSHA 1910.120(q) regulations. NFPA 600 provides training guidance for advanced exterior fire brigades while NFPA 601 provides information that aids management in the selection and training of security personnel hired to protect property against fire loss. See NFPA 1081.

9.4 Notification Procedures

A callout notification system should be developed to contact off-site personnel with emergency response duties, including those with incident command or EOC roles.

When a fire is reported, the procedure should include prompt notification of the facility firefighting and emergency team personnel, outside community or regulatory authorities requiring notification, and any outside mutual-aid groups who may be called upon to provide equipment, supplies, or personnel. Procedures should be in place to establish sequence and priorities for notification depending upon incident needs.

In some refineries, arrangements are made for the fire or emergency calls to be received at constantly attended locations, such as a laboratory, powerhouse, or main gate. Special telephones are used only for incoming emergency calls. A dedicated phone number is selected, and decals showing this number are attached to all in- plant refinery phones.

The alarm procedure is initiated by the attendant receiving the emergency call. The attendant should be trained for the duty and be supplied in advance with the following:

a) an emergency callout list for key personnel, local public fire departments, ambulance services, and doctors—in some instances, an independent agency is used for handling this emergency callout;

b) a set of written notification scripts specific to incident type and personnel or agency being notified;

c) an emergency communication system between the main office, the main gate, and other key locations—the location and nature of the emergency will be announced over this system;

d) a method for recording all calls (e.g. logbook, tape recorder, etc.) and time of notification;

e) a checklist to ensure that all notifications appropriate to the type of incident have been completed.

Issuance of company identification to key people who may have to respond from off site (including members of the firefighting squads, incident command, and EOC personnel) is desirable to assist passage through roadblocks when proceeding to the refinery during an emergency. Firefighters should wear personal and organization identification on their clothing or headgear.

9.5 Firefighter Selection and Training

In developing a firefighting organization, the number of firefighters should be appropriate to the anticipated need. Specific types of personnel should be chosen for the firefighting organization. Selection should be based on the number of workers available, their job assignments, diversity of skills, their freedom to be relieved of duty to respond to emergencies, and the type of fire-protection equipment available. Care should be taken to verify that firefighting personnel are physically capable of performing the duties that are assigned.

A core group of firefighters should be selected from regular shift employees who can be relieved from regular duties for firefighting; they, in turn, should be supplemented by day staff or off-duty employees. Some locations select shift personnel for firefighting duties based on job assignment or classification. Other facilities use a voluntary basis, rather than assigning firefighting duties to specific individuals within the plant. Many plants use a combination of assigned and volunteer fire crews. Consideration should be given to shift changes, days off duty, and vacations to provide adequate coverage always. Where possible, emergency plans should use supplemental assistance from outside fire departments or mutual-aid groups for major incidents.

When working with volunteer or other supplemental firefighting groups, it is important to determine which personnel will oversee each aspect of the firefighting activity. Use of the ICS provides an excellent functional tool for this coordination and satisfies regulatory requirements.

Most fires have the potential for the emergency response action to include shutting down equipment, as well as fighting the fire. The division of responsibilities among emergency activities should be made through a pre-fire training program. Emergency simulations and unit specific drills help prepare for fire incidents. The training program in Section 10 outlines one approach. It should be tailored to apply to a refinery or to the needs of specific types of potential incidents. Training should be structured to develop an effective emergency response capability as well as provide regulatory compliance. See NFPA 1081.

9.6 Incident Commander

Operating under the ICS one individual should be designated as the IC. This individual should have received appropriate ICS training. The IC role is modular and can be passed to another individual as personnel availability changes. The ICS structure provides an expandable framework to address both small and large incidents. Many locations use ICS for all incidents to provide a consistent approach and maintain familiarity with the process and terminology.

The IC should have multiple reliable means of communication so that, during an emergency, he or she can promptly contact those involved in fire control operations. Portable radios, cellular phones, and plant phones are some options. Communication with potential mutual-aid or third-party responders should be reviewed in advance both for incident notification and for subsequent on-site incident management. A person who is fully conversant with radiotelephone equipment can be of great value to coordinate the fire emergency communications with the regular plant communications system. The type of communication used will be determined by the refinery's communications resources, as well as by the type and size of the fire.

9.7 Firefighter Personal Protective Clothing and Equipment

9.7.1 Protective Clothing

Proper protective clothing is required for fire brigade members and emergency responders based on their anticipated exposure and duties. Federal regulatory requirements are outlined in OSHA 1910.156 and OSHA 1910.120(q). NFPA 600 states that protective clothing shall be available in sufficient quantity and sizes to fit each brigade member expected to fight advanced exterior and/or interior structure fires. NFPA 600 states that all firefighters protective clothing (frequently called bunker gear or turnouts) must meet the requirements of the appropriate NFPA standard (see NPFA 1971). Nonfire brigade personnel working in a fire-exposed area should be similarly protected. OSHA 1910.132(d)(1) addresses *PPE—Hazard Assessment and Equipment Selection,* and states, "The employer shall assess the workplace to determine if HAZARDS are present, or likely to be present …"

9.7.2 Respiratory Protection and Other Equipment

Positive pressure self-contained breathing apparatus (SCBA) shall be used by potentially exposed fire brigade personnel when, in the judgment of the personnel in charge (i.e. IC, Safety Officer, Fire Chief, etc.) the atmosphere is hazardous, suspected of being hazardous, or could rapidly become hazardous. Use of other equipment such as personal alert safety systems (PASS) devices should be considered for use to determine if they are appropriate, such as when fighting interior structural fires.

10 Training for Firefighting

10.1 General

The primary goal for emergency response training is to develop and maintain an effective organization that functions safely during emergency situations without unduly putting individuals at risk. Written training policies and procedures for firefighting should be developed. All personnel should receive training commensurate with level of responsibility and which prepares them for the duties they will be assigned. This section discusses some of the various types of fire training currently in use. Refer to OSHA 1910.156 and OSHA 1910.120(q) for minimum U.S. regulatory training requirements and NFPA 600 and NFPA 1081 for guidance. Instructors should be familiar with the characteristics and limitations of the equipment used. Training should be conducted both in the classroom and on the drill grounds, using various types and sizes of live fires and simulations. A system for tracking individual training should be used; credit for training received through other venues (such as volunteer fire departments or individual study course work) can be considered for maintaining current status.

10.2 Drill Ground Training

10.2.1 General

When "hands-on" training is conducted on site, drill grounds may be built to provide adequate training for the facility involved. Training should not be limited solely to pit, tank, and other two-dimensional fires. Realistic props can be constructed from scrap equipment and can be used to simulate jet, spray, and other three-dimensional pressure fires potentially encountered on the job. Where possible, more than one type of fuel should be used for fire suppression training, reflecting the range of materials likely to be encountered in fires at the location. This will build experience and skills appropriate for the facility. Training plans should consider providing experience with hydrocarbon fires for personnel from public departments who may respond as mutual aid. On-site training can be supplemented using offsite training from fire training schools available throughout the country.

10.2.2 Instructors

Instructors and those expected to lead firefighters must be provided with training that is more comprehensive than that provided to the general membership of the fire crew. Qualified drill ground instructors may come from the plant fire brigade, plant staff, or outside personnel; they may also be plant personnel, trained by skilled instructors, who in turn train the staff working with them. The qualifications of all instructors should be documented.

10.2.3 Types of Training

Personnel expected to respond to fires should be provided with training consistent with those expectations. This should include primary education or training for whatever equipment they are expected to use.

For all responders, including those with incipient firefighting roles, this typically will include identifying the need for, and use of, personal protective equipment and facilities designed for use by one person (such as hand extinguishers, small water and foam hose lines) as well as activation of fixed water-spray systems, fixed monitors, and deluge sets.

Secondary training for brigade members may include handling of equipment such as large hose lines, fire mains and foam equipment, fire apparatus, SCBA, and related equipment. Training activities should strive to develop teamwork among the various groups assigned to respond to major fires.

Training of outside emergency responders is also important. If public or other outside fire departments respond to plant fire alarms, it may be advantageous for their personnel (especially officers) to participate in some of the training used for the refinery emergency responders.

10.2.4 Simulated Fire Drills

Simulated fire drills should be used in a facility's firefighting training program. In large facilities these may be related to unit specific pre-fire incident plans (see Section 11). On-the-job simulated emergency (hypothetical) fire drills relate the drill-ground training to potential emergency problems in operating areas. This can be achieved if an operating personnel and emergency response personnel jointly plan a simulated emergency. The drill should activate those portions of the ICS that would be incorporated in a "real" response.

For example, a stubborn fire from a blown packing gland may be simulated. If the unit is operating smoothly, appropriate personnel should be advised of the drill, notifications made, and the alarm should be sounded. The firefighters should then respond with the appropriate firefighting equipment and incident command should be established. Fire suppression setup should proceed while the operating personnel simulate emergency shutdown operations. These shutdown operations may be accomplished by placing tags or small fiber gaskets, marked "open" or "closed," on valves, pumps, and the like. This approach is sometimes called a "red tag" drill.

For observation purposes, one or more persons may be assigned to keep a record of the time required to activate fire-extinguishing equipment and to report on the overall efficiency of the fire drill. The lessons learned from the drill should then be discussed with the operators, and, if necessary, the drill may be repeated to improve performance. At the conclusion of the drill, a critique should be conducted to evaluate the effectiveness of the response and how it might be improved.

Strategies should be developed to direct the control and extinguishment of various types of refinery fires. Strategies may include evaluating the means to provide appropriate resources to resolve an overall problem, identifying specific needs such as lifesaving and rescue techniques, and covering exposures. Drills using these strategies should be conducted periodically in various sections of the refinery.

If feasible, drills should be expanded to include the activation of spray systems and fixed monitors and the use of large hose lays. The appropriate fire crews should be employed in these drills.

10.3 Classroom Instruction

Basic classroom instruction can include discussion of firefighter safety, tabletop demonstrations, fire tetrahedron theory including the burning characteristics of various fuels, and education regarding the function of the various types of firefighting agents used at the facility. This classroom instruction should include a review of:

a) safety procedures for emergency responders,

b) personal protective equipment for firefighters,

c) practice in the use of self-contained breathing apparatuses,

d) ICS operation and roles,

e) fire-related special hazards in the workplace,

f) review of any special hazardous materials showing quantities and location,

g) emergency action procedures,

h) pre-fire plan,

i) firefighting tactics,

j) fire water and foam systems.

Study of past fires is an important aspect of the fire training program and should be part of the committee agenda. When possible, reports of fires in other refineries should be studied to increase knowledge of firefighting problems specific to refineries.

10.4 Overcoming Personal Concerns

Many of the psychological reactions and concerns experienced by inexperienced individuals when they face a large fire may be overcome with proper drill ground training. Persons trained on large fires recognize the magnitude of their task and usually do not become overly confident. They also learn the capabilities and limitations of their equipment; or, situations such as use of SCBA or "smoke house" training may trigger claustrophobia.

10.5 Documentation

Training records should be maintained to ensure readiness of the emergency response personnel and document regulatory compliance. Written training requirements based on emergency responder duties and roles are specified in OSHA 1910.156 and OSHA 1910.120(q).

11 Pre-fire Incident Planning

11.1 General

Effective emergency response requires pre-incident planning. Many facilities use a written pre-fire plan that addresses coordination of activities and resources. The following plan elements originated with a major facility, but the basic principles apply to all facilities. Any plan should be tailored to the size, complexity, and special needs of the specific organization. Emergency response plans should be consistent with the existing facility organization structure to minimize disruption of normal operations.

11.2 Pre-fire Incident Planning

Pre-fire incident plans provide effective tools for reviewing response capability and for structuring training. They also assist in regulatory compliance. Pre-fire plans should provide guidance for addressing special concerns such as mentioned in 5.6 and Annex A (such as BLEVE, boilover, water reactive chemicals, etc.).

Candidate subject areas for inclusion in a pre-fire plan might include:

a) identified fire hazards, including review of hazardous material inventory;

b) potential weather concerns (including freeze conditions; see Annex B);

c) water requirements (extinguishing, cooling, etc.);

d) water supply availability;

e) foam delivery requirements and capability;

f) response requirements: personnel availability vs requirements; fire suppression “delivery” equipment; consumables such as foam, dry chemical, CO_2, etc.;

g) needs for major incidents with intensive resource requirements such as storage tank fires (see 6.2.2.6 and API 2021);

h) mutual-aid and third-party response organization capabilities, resources, and response time;

i) evacuation requirements and procedures (facility personnel, contractors, community);

j) communication needs (employees, emergency response personnel, community, law enforcement, regulatory);

k) scaled plot plan of the hazard and/or areas potentially involved;

l) scene security;

m) accessibility to scene (e.g. having an alternate route in case access to the scene is blocked by rail cars or other equipment);

n) decontamination facilities and procedures;

o) designation of staging areas;

p) major medical response for multiple injury situations;

q) industrial rescue capability;

r) areas with asbestos, benzene, polychlorinated biphenyls, etc.;

s) location of radioactive instrumentation elements.

Overall facility plans may consider adding information regarding business continuity, post incident traumatic stress potential, environmental follow-up, and reference to security guidance documents.

Annex A
(informative)

Chemistry and Physics of Fire

A.1 General

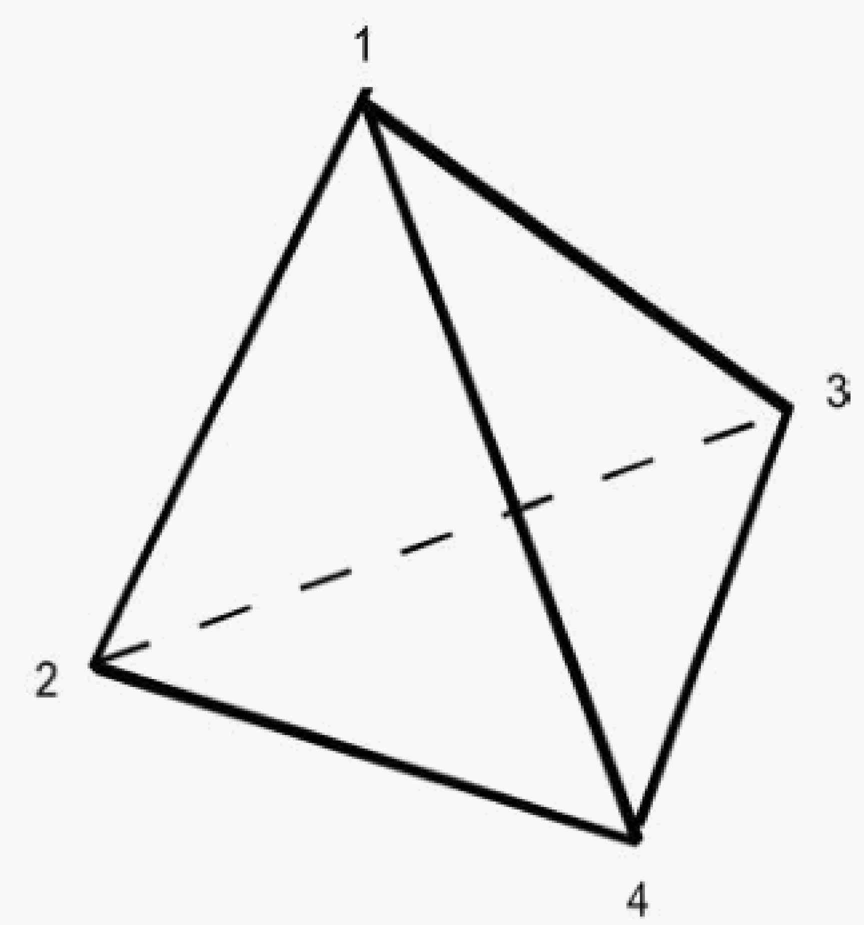
The same property that makes petroleum products useful has an inherent hazard: they support combustion. This hazard presents risks associated with processing, handling, or storage, or a combination thereof. The risk can increase in proportion to the volatility of the product. When proper precautions are followed to prevent the concurrent presence of the components needed for combustion the possibility of a fire or explosion will be reduced. This reduces risk of harm to exposed personnel, damage to equipment, and adverse effects on the environment.

A.2 The Combustion Process

Three components are necessary for a fire to begin—oxygen (usually from air) mixed in the proper proportions with fuel that has been exposed to sufficient heat to vaporize, with enough additional heat to initiate combustion and vaporize more fuel.

A fire starts and is sustained by a fourth essential component, a free-radical chemical chain reaction that enables the fire to continue as long as the three other components remain available. The four essential components are represented in the fire tetrahedron diagram as shown in Figure A.1.

A basic understanding of the components of a fire and an appreciation of the related fire prevention measures will help reduce the risk of fire and aid fire personnel in their suppression efforts should a fire occur.



Key

1 chemical reaction
2 oxygen
3 heat
4 fuel

Figure A.1—Fire Tetrahedron Diagram

A.3 Fuel Types and Classes

Fuels can be classified as three types: solids (coal, wood, plastic, etc.); liquids (gasoline, crude oil, alcohol, etc.); and gases (propane, hydrogen, acetylene, etc.). As only gases burn, the combustion of a liquid or solid fuel requires partial conversion of liquid or solid fuels into a gaseous state by heating. This process is called pyrolysis for solid fuels and vaporization for liquid fuels.

NFPA 10 classifies fires based on the fuel involved—either type A, B, C, D, or K. Fire extinguishing agents are often identified by this system based on the type of fire for which they are effective (i.e. a dry chemical fire extinguisher may carry a Class ABC rating where a pressurized water extinguisher carries only a Class A rating).

Class A fires are those involving ordinary combustible solid materials such as wood, coal, paper, rubber, and many plastics.

Class B fires are those involving flammable and combustible liquids and gases such as gasoline, crude oil, alcohols, LPG, and hydrogen.

Class C fires are those involving energized electrical equipment. While electricity is not a fuel, it represents a significant hazard to firefighters if improper extinguishing agents or methods are used. Once the electrical circuit is de-energized, the fire is then treated as a Class A or B, depending upon the fuel involved.

Class D fires are those involving combustible metals such as sodium, aluminum, magnesium, titanium, etc.

Class K fires are kitchen fires with special concern for oils and grease as the fuel that could be relevant to facilities with cooking facilities such as cafeterias. See NFPA 10.

A.4 Properties of Petroleum Products

There are several physical properties exhibited by petroleum products that have a significant impact on their fire and explosion potential. These include the following.

A.4.1

auto-ignition temperature

Minimum temperature to which a fuel in air must be heated to start self-sustained combustion without a separate ignition source. This means that, should a leak occur on a line containing a petroleum product above its ignition temperature, ignition can occur independent of an ignition source.

A.4.2

boiling point

The temperature at which the vapor pressure of a liquid equals the surrounding atmospheric pressure. For purposes of defining the boiling point, atmospheric pressure shall be considered as 14.7 psia (760 mm Hg). For mixtures that do not have a constant boiling point, the 20 % evaporated point of a distillation performed in accordance with ASTM D86 shall be considered as the boiling point.

A.4.3

fire point

The temperature (usually a few degrees above the flash point) at which a liquid produces enough vapors to sustain combustion. The difference between flash and fire points is so small that it has no practical significance for materials such as gasoline.

A.4.4

flammable range

A range of vapor-to-air ratios within which ignition can occur. The lower flammable limit (LFL) is the minimum vapor- to-air concentration below which ignition cannot occur. Atmospheres below the LFL are referred to as too lean to burn. The upper flammable limit (UFL) is the maximum vapor-to-air concentration above which ignition cannot occur. Atmospheres above the UFL are referred to as too rich to burn. Flammable ranges can vary widely, as illustrated by flammable vapor-to-air ranges for gasoline (1.4 % to 7.6 %) and acetylene (2.5 % to 100 %).

A.4.5

flash point

The lowest temperature at which a liquid gives off enough vapor to produce a flammable mixture with air immediately above the surface. A source of ignition is needed for flash to occur. When this temperature is above ambient, vapors will ignite but will not continue to burn until heated to the “fire point” (see NFPA 30). The flash point temperature can be very low for volatile petroleum products; for instance, the flash point for gasoline is typically quoted as about –45 °F (–43 °C).

A.4.6

specific gravity

Ratio of the weight of a given substance to the weight of an equal volume of a standard substance (water for liquids and air for gases). This is frequently referred to as vapor density for gases. Since the specific gravity of the standard equals one, liquids with a specific gravity less than one will float on water (unless they are water soluble like most alcohols). Most liquid petroleum products have specific gravities less than one. Likewise, gases with a specific gravity of less than one (e.g. hydrogen and methane) will rise in the atmosphere, whereas gases with a specific gravity greater than one (e.g. almost all hydrocarbons with two or more carbon atoms such as ethane, propane, and butane) will tend to stay close to the ground and seek low-lying areas.

A.4.7

vapor pressure

The pressure exerted by the vapor of a substance when the substance and its vapor are in equilibrium. Equilibrium is established when the rate of evaporation of a substance is equal to the rate of condensation of its vapor. In general terms, the higher the measured laboratory vapor pressure the more likely that liquid is to give off vapors under “real world” conditions. Reid vapor pressure, a measure commonly used to characterize gasoline and another hydrocarbon volatility, is measured at 100 °F (37.8 °C) in a closed container.

The importance of these basic vapor generation and combustion properties can be seen in the way flammable and combustible liquids are classified (see the following discussion and NFPA 30 for more information).

Flammable liquids have flash points below 100 °F (37.8 °C) and vapor pressures not exceeding 40 psia (2068.6 mm Hg) at 100 °F (37.8 °C). Liquids with vapor pressures above 40 psia (276 kPa) at 100 °F (37.8 °C) are considered gases by NFPA 30.

Flammable liquids are subdivided into three classes (in decreasing hazard), based on flash point and boiling point:

— Class IA—Flash point below 73 °F (22.8 °C) and boiling point below 100 °F (37.8 °C),

— Class IB—Flash point below 73 °F (22.8 °C) and boiling point above 100 °F (37.8 °C),

— Class IC—Flash point at or above 73 °F (22.8 °C) and below 100 °F (37.8 °C). Combustible liquids have flash points at or above 100 °F (37.8 °C).

Combustible liquids are subdivided into three classes (in decreasing hazard), based on flash point:

— Class II—Flash point at or above 100 °F (37.8 °C) and below 140 °F (60 °C),

— Class IIIA—Flash point at or above 140 °F (60 °C) and below 200 °F (93 °C),

— Class IIIB—Flash point at or above 200 °F (93 °C).

OSHA uses NFPA 30 definitions for flammable and combustible liquids. Alternate systems using 140 °F (60 °C) as the dividing point between flammable and combustible appear in ANSI/CMA Z129.1-1994 and the regulations of the U.S. Department of Transportation and the United Nations. The NFPA classification system is used in this document and is widely used for facility-based fire protection purposes in the United States. For regulatory compliance purposes (such as labeling for off-site transportation), reference should be made to the specific regulations or codes governing the activity of concern.

A.5 Oxygen

Oxygen is readily available as air contains about 21 % oxygen under normal circumstances. A minimum oxygen concentration of 10 % to 12 % is typically required to support combustion. Refinery piping, processing, and some closed storage systems containing hydrocarbon products are intentionally maintained with insufficient oxygen to support combustion. Most refinery fires occur when hydrocarbon leaks to the atmosphere where there is enough oxygen to support combustion. This is true even in the case of furnace fires, where hydrocarbons from furnace tubes leak to the "atmosphere" inside the firebox. A fire in a closed refinery process system is unlikely to occur during normal operations, although equipment operated under vacuum can be vulnerable to air leaks. A significant air leak into equipment or piping under vacuum can result in a fire inside the piping or equipment under operating conditions. Although infrequent, fires inside normally pressurized process piping and equipment usually occur during start-up, shutdown, or maintenance activities, after air enters equipment when it is opened and contacts flammable or pyrophoric material.

Some materials that contain oxygen in their chemical composition (such as alcohols and ethers) require less atmospheric oxygen to support combustion.

A.6 Heat (Source of Ignition)

A.6.1 General

Oxygen is always available from the ambient environment. Rigorous efforts aim to prevent hydrocarbon leaks to atmosphere. However, if leaks occur there is the potential for a flammable mixture of fuel and air to exist. Therefore, in addition to preventing leaks, emphasis is placed on limiting sources of ignition. An attractive approach would be the strict exclusion of all possible ignition sources from areas in which flammable substances could be present. However, strict application of this principle is impractical (for instance, furnaces are often needed to provide process heat).

The five general categories of heat energy are chemical, electrical, mechanical, nuclear, and solar. Those heat energies applicable to petroleum products are discussed further in the following sections.

A.6.2 Chemical Ignition Sources

A.6.2.1
heat of combustion
The heat energy, in the form of a flame, that is released by the chemical reaction of a fire.

A.6.2.2
heat of solution and heat of dilution
Represent heat released by dissolving matter in liquid or mixing of unlike liquids. While not an ignition source, substantial quantities of heat can be generated creating a potential fire hazard in certain circumstances. The heating of caustic (sodium hydroxide) or acid process materials can raise temperatures, vaporize liquid materials, and result in container failure and releases of hydrocarbon providing accessible fuel for a fire.

A.6.2.3
spontaneous heating
The heating of an organic substance without the addition of external heat. A common example is oily rags that slowly oxidize releasing heat. In the petroleum industry, spontaneous heating can occur from pyrophoric iron sulfide deposits. These deposits may form in equipment handling petroleum products containing hydrogen sulfide or other sulfur compounds when there is insufficient oxygen to fully convert the sulfur compounds to sulfates. Pyrophoric iron sulfide deposits are generally not a problem if they stay wet or remain in an oxygen deficient environment. However, once exposed to air, they can oxidize and generate heat, providing a source of ignition for any flammable petroleum vapors present or evolved as a result of pyrophoric heating.

A.6.3 Electrical Ignition Sources

A.6.3.1
arcs and sparks
The energy released by current flowing across an air gap can cause significant heating of the air and of the electrodes (equipment) across which the arc or spark travels. Arcing can occur when current flow is initiated or interrupted by opening or closing a switch or by the intermittent contact of loose connections. Sparks and arcs from normal AC or DC refinery equipment are assumed to provide sources of ignition and this equipment must be used with appropriate precautions as discussed in API 500.

A.6.3.2
lightning
Static electricity on a very large scale. Protection against direct lightning strikes is difficult. The floating roofs of storage tanks use shunts to metallic shoes sliding on the grounded tank shell to provide a path to ground as protection from induced charge sparks caused by lightning. See API 2003 and API 545 for more in-depth information.

A.6.3.3
static electricity
The buildup of a positive charge on one surface and negative charge on another is a natural phenomenon associated with the flow of fluids (such as hydrocarbons) through pipes. Charge separation and the accumulation of a static charge are inherent properties of low-conductivity hydrocarbon fluids. The charges are attracted to each other and a spark can occur when the voltage differential is sufficient to ionize an air gap and provide a path to transfer electrons between the surfaces to become evenly charged again. Grounding and bonding are used during petroleum transfer operations to provide a conductive path through which accumulated static charges on the hydrocarbon surface can recombine with opposite charges on the vessel shell or loading arms to prevent sparking and potential ignition.

A.6.4 Mechanical Ignition Sources

Friction is heat created by the rubbing of two surfaces against each other. High-energy friction sparks, such as those produced by failure of pump bearings leading to rubbing of mechanical seals, can ignite flammable mixtures. Typical low-energy sparks produced by the impact of steel, stone, or other hard substances (including hand tools) will not ordinarily ignite petroleum vapors.

A.6.5 Hot Surfaces as Ignition Sources

Although not a type of heat, hot surfaces can be a source of ignition if they are large enough and hot enough. The hot surface vaporizes the liquid, a flammable atmosphere forms, and the hot surface raises the flammable atmosphere to its autoignition temperature. Generally, the smaller the heated surface, the hotter it must be to provide a source of ignition. The heat flow from the hot surface must overcome the cooling effect of the evaporating liquid or expanding vapor while providing enough energy to heat the vapor to autoignition temperature. As a result, the larger the heated surface in relation to the quantity of vapor-to-air mixture, the more rapidly ignition will take place and the lower the surface temperature necessary for ignition. Because of the heat absorbed by vaporization, it is usually more difficult for a hot surface to ignite flammable liquids than the vapors. Less volatile combustible liquids that evaporate at higher temperatures can be ignited more readily by contact with hot surfaces, as evidenced by the burning of motor oil splashed on a hot automobile exhaust manifold where gasoline may vaporize from a hot manifold without ignition. See API 2216 for additional information.

A.7 Special Situations, Considerations, and Hazards

The inherent properties of hydrocarbon materials processed and produced in refineries present several unique hazards related to hydrocarbon storage. Some of these phenomena have the potential to cause substantial damage. These should be addressed while designing for fire prevention and planning for emergency response. Operational precautions, such as outlined in this recommended practice, and well-planned emergency response can reduce the likelihood of occurrence and help prevent escalation in the event of an incident.

A.7.1

boiling liquid expanding vapor explosion BLEVE

Catastrophic failure of a container into two or more major pieces when the container contents are well above their atmospheric pressure boiling point temperatures. Classic cases of BLEVE have involved fire exposure of LPG containers such as LPG rail cars. In one “classic” scenario the contents of the fire-exposed LPG container heat until the vapor pressure reaches the set point of the pressure relief device. The PRV operates properly; it opens, releasing flammable gas to prevent overpressure of the container. Subsequent localized heating of an unwetted portion of the container shell wall (such as by jet fire impingement) weakens the container. If the shell wall is weakened to the point where the failure pressure of the container falls to the set pressure of the relief device, the container wall can rupture, even when the relief device is properly sized. The contents of the container vaporize “instantly” when the container fails and ignite causing a large fireball. The BLEVE phenomenon is applicable to volatile liquids as well as to LPG. (See NFPA’s *Flammable and Combustible Liquids Code Handbook* for further information.)

A.7.2

boilover

Sudden overflow or ejection of the contents of an oil storage tank (crude oil or certain other viscous liquids) during a full surface fire due to a heat wave (layer of hot, heavy oil) reaching water or water-oil emulsion at the bottom of the tank. The water flash boils and turns to steam with rapid expansion, which can send the tank contents a significant distance. Boilover occurs only with tanks containing oils with a wide boiling range, including both a viscous fraction and light ends (e.g. like crude oil but not gasoline). In extreme cases, substantial amounts of flammable liquids can be expelled creating a serious hazard for hundreds of feet surrounding the tank. See *NFPA's Flammable and Combustible Liquids Code Handbook* for more information.

A.7.2.1

frothover

Overflowing a container not on fire when water boils under the surface of a viscous hot oil. This is one reason product rundown temperatures to tankage should be monitored and controlled.

A.7.2.2

slopover

Results from a water stream being applied to the hot surface of boiling oil, when the oil is viscous, and its temperature exceeds the boiling point of water.

More information on the hazards involved with petroleum products and the fire prevention/protection measures available to deal effectively with these hazards can be found in other sections of this publication and in cited references.

Annex B
(informative)

Cold Weather Hazards, Winterizing, and Freeze Protection

B.1 Introduction

B.1.1 General

Freezing weather affects the whole spectrum of refinery operations. Facilities that operate in areas with recurrent seasonal freezing weather typically have winterization programs in place. Cold weather is part of the geographical culture. Moderate climate facilities may encounter freezing weather infrequently; however, if freeze protection is not part of the local or facility culture there can be more vulnerability to problems caused by a freeze situation. These facilities should consider review of preparation procedures to address the hazards that accompany low temperatures. Freeze protection reviews should recognize and anticipate that problems caused by freezing conditions may not appear until thawing begins.

This annex encourages the review of winterizing programs and integration of appropriate considerations into written facility operating and emergency programs and procedures. The material in this section and the references should prove useful in program review. Some facilities have used a "snow brigade" or "freeze team" of employees to review preparation needs, search for potential problems, and monitor implementation and effectiveness.

B.1.2 Piping Freeze Basics

Since piping failures play a part in some freeze-related incidents a review of pipe basics provides useful background. Like most materials, metal contracts (decreases in volume) as its temperature goes down, by contrast, when liquid water in a pipe freezes to become solid ice at 32 °F (0 °C) it increases in volume by 9 %. (Note that liquids other than water shrink when they freeze.) The specific heat of ice is one half that of water and thus is easier to cool further. If an ice "freeze plug" results in liquid blockage in a pipe, the 9 % expansion tries to compress the liquid resulting in very high pressures. If this high pressure exceeds the strength of the piping material, a release can result. The consequences of the release depend on the nature and quantity of the liquid released and the characteristics of the environment. Similar breakage can occur where water freezes when confined in valves. A critical time may be when the temperature rises above freezing and the ice melts.

B.2 Freezing Weather Concerns

Freezing weather brings concerns regardless of normal climate. Concerns include conditions that could lead to a hydrocarbon release (such as frozen dead-legs in process piping), compromising of instrumentation, or interference with water supplies for process or emergency response.

Some possible problems encountered in freezing weather are:

— hazardous working conditions for personnel;

— impairment of water-based fire suppression capability (manual or automatic), including fire water: piping, pumps, source (tanks, ponds, lakes, rivers, or reservoirs), delivery (piping and hydrants), or application systems (sprinklers, deluges, or monitors);

— ice, snow, and accompanying loads on buildings and tank roofs;

— increased stress on heat-generating equipment;

— instrument malfunction;

— freezing of windsocks preventing them from indicating wind direction;

— communications interruption;

— failure or ice blockage of solenoids with external latches;

— freezing of vulnerable piping (whether in or out of service, such as dead-legs or infrequently used piping, i.e. vacuum truck piping and valves);

— atmospheric tank vent blockage from freezing [vent screens or pressure/vacuum (P/V) valves];

— power loss;

— decline of battery performance (fire trucks, diesel fire pumps, battery UPS);

— condensation and carryover of liquid condensate into fired heater burners (see 5.4.3.10);

— metal cold temperature embrittlement;

— equipment, piping, or metallic failure due to cold stress or repeated freezing and thawing.

B.3 Examples of Incidents Related to Freezing Weather

Table B.1 provides examples of a range of events that can occur in winter. They are real and illustrate phenomena that have occurred multiple times, but not necessarily with the same consequences. They do not include "slip, trip, fall" personal injury incidents that, although significant, are not fire safety concerns.

Table B.1—Historical Freezing Weather Incident Examples

Type of Facility or Equipment	Incident Description	Proximate Cause	Contributing Cause(s)	Conse-quence	Proposed Remediation	Source
Storage tank, United States	Residual fuel tank roof buckles when withdrawing product	Ice-plugged vent	Insulating tank increased water vapor flow through vent that froze	Damage to tank	Redesign and insulate vent piping	*API Safety Digest of Lessons Learned, Section 6: Safe Operation of Storage Facilities* (pp. 33–34)
Storage tank, United States	Roof sank at angle and poked hole in floor causing product release	Roof drain plugged with ice allowing water/ ice/ snow buildup on roof		Damage to tank environmental release	Revised drain system and used flexible piping; use antifreeze in drain piping	Private communication
Storage tanks at U.S. refinery	VCE and tank fires; 10 °F in "sunbelt"	Ethane-propane line shut in when freezing and expanded when temperature rose; line rupture ignited by pickup truck	Weak spot in line; fire water and steam driven pumps frozen	2 fatalities; 15 tanks damaged	Established cold weather procedures and revised fire water system	Private communications and news media
LPG processing unit, United States	LPG pipe ruptured; VCE and fire	Freezing water in idle dead-leg cracked piping	Lack of fireproofing on pipe rack supports	3 serious burn injuries; property damage and production loss	Added fireproofing and removed dead-legs	CSB Case Study Report No. 2007–05-I-TX
Instruments	Ice-blocked SIS solenoid valve					*DOE Operating Experience Summary, Issue Number 2009-10, Article 2*

B.4 Written Freeze Protection Program

Areas with freeze potential should establish written prevention programs to verify that vulnerable active and out-of- service equipment and piping is protected from freezing failure. These should include periodic inspections to identify freeze hazards in dead-legs or infrequently used piping and equipment where water could collect. These programs may be "stand alone" or be incorporated into facility operating or maintenance procedures. Winterizing programs will vary depending on whether freezing weather is common or infrequent.

CAUTION Locations that do not often experience freezing weather may be most vulnerable. Facilities where freezing weather is uncommon can be more "at risk" because freeze protection is not necessarily part of the culture and protection techniques may be unfamiliar.

A typical freeze protection process includes the following elements:

— identify and document equipment vulnerable to freezing weather,

— evaluate protection options (including revision or elimination of vulnerable equipment or piping),

— choose freeze protection options,

— establish equipment-specific written plans,

— identify responsible action function to implement plans,

— prioritize options and where applicable implement and document using MOC principles,

— periodically audit program implementation,

— periodically repeat vulnerability assessment and revise plan as needed.

B.5 Freeze Protection Program Purpose

Freeze protection should be provided to reduce potential for ice formation in vulnerable equipment because of the following.

— Systems for fire water, safety showers, or eye washes may freeze and make them unavailable for emergencies during and after freezing weather.

— Equipment connected to process might accumulate water that could freeze, expand, and fracture, resulting in release of process materials with the potential for ignition and fire. Equipment examples are bottom gauge glasses, bleeders and valve manifolds, low spots in pipe runs, and draw connections.

Dead-leg pockets in out-of-service process piping represent a special hazard. Dead-legs should be sought out and receive special attention to be eliminated where possible or protected. Freeze failure of piping dead-legs has resulted in rupture, hydrocarbon release, and serious incidents including major fires and personnel injuries.

NOTE For an example, see CSB Case Study Report No. 2007–05-I-TX, July 2008.

B.6 Specific Freeze Protection Approaches

Typical approaches to freeze protection include (but are not limited to):

— eliminating vulnerable piping (especially dead-legs),

— increasing “bird screen” mesh size on tank vents from $^1/_2$ in. to $^3/_4$ in.,

— placing piping underground,

— using dry barrel or “traffic type” fire hydrants,

— using dry-pipe sprinkler or deluge systems,

— moving vulnerable equipment indoors (or building protective shelter),

— blowing water from lines with air,

— maintaining flow in water lines,

— heat tracing (steam or electric—FM 9–18/17–18 provides background),

— insulating vulnerable resources,

— inspection prior to/during/after freezing weather.

B.7 Example Winterizing and Freeze Protection Program

One example of a freeze protection approach used by some facilities is:

— establish formal written programs to find cold weather vulnerabilities;

— agree on “ownership” and accountability for freeze protection;

— provide technical, operations, and maintenance personnel education and training to help them understand and recognize potential problem situations;

— enable those persons working with field equipment to recognize potential freeze hazards and identify them for remediation before bad things happen;

— educate technical and maintenance personnel through similar training to help them avoid inadvertently creating freeze hazards as they modify equipment, revise designs, or design new equipment;

— systematically do a careful review of out-of-service piping or units to identify potential problems to rectify;

— “design out” dead-legs, including process bypass piping;

— integrate identified concerns with facility priorities;

— provide a process so that identified situations from this review are evaluated and subjected to the facility’s MOC process where appropriate.

The preceding is an example. Other approaches may be effective. Sample checklists and audit aids are shown in Table B.2, Table B.3, and Table B.4.

Table B.2—Winterization Audit Checklist

Type of Item	Concern	What to Look for (Examples)	Potential Remedy
Conceptual format—Intended to be Guidance for “Build Your Own Inspection Checklist”			
			All—Surveillance
Heat Tracing—Safety showers and eyewashes	Not protecting freeze vulnerable lines or equipment Not available when needed	Steam tracing cold—blockage or ice Electric tracing	Heated water Heated enclosure Dry-pipe system
Water Seals—Steam heat tracing	Not protecting freeze vulnerable lines or equipment Overheating	Condensation Water or ice on insulation Tracing cold	Temperature monitoring Steam “telltale” bleeds Insulating piping See FM 9–18/17–18
Dead-Legs—Electric heat tracing	Not protecting vulnerable lines or equipment Overheating	Condensation Electric tracing cold Trouble alarms	Temperature monitoring Instrumentation See FM 9–18/17–18

Type of Item	Concern	What to Look for (Examples)	Potential Remedy
Fire water, including hydrants, fire pumps, and reserve tankage	Freezing or rupture of piping inoperable pumps, frozen tankage making systems unavailable	Water or ice at hydrants Water or ice above buried lines Dead batteries on diesel pumps Temperature of fire water tanks	Heat pump houses Use temperature alarms Continuous flow
Deluge, sprinklers, and water spray	Freezing or rupture of piping	Water or ice at outlets	Use dry-pipe system Drain systems
Water seals on flame arresters (such as on flares)	Liquid water must remain in seal to function as a flame arrester	Ice on liquid surface	Temperature monitoring Antifreeze, alternate fluid, heating or heat tracing
Tank roof vents	Ice plugging of P/V vent or flame arrester	Ice buildup, pressure, or vacuum in atmospheric tank	Remove ice
Electrical cable trays or bus ways	Melting snow or ice refreezing causing arc path	Plugged drainage in open trays Snow/ice/water in closed trays	Prevent snow entry Remove snow and ice
Temperature sensitive supplies	Freezing Overheating		Temperature monitoring
NOTE See Table B.3 for more specific dead-leg surveillance.			

Table B.3—Winterization "Discovery" Dead-leg Surveillance—Sample Checklist for Evaluating Dead-legs

Dead-leg location	Is Dead-leg tagged? If not, attach ID tag	What is ID?	Notify Dead-leg coordinator with ID and copy of this form
Does dead-leg show evidence of past freezing (i.e. paint cracked or swelling of line)?	No	Yes	Evidence now and what seen
Is line connected to active process?	Yes	No	
Is line in service or out of service?	Yes	No	
Is dead-leg isolated?	Yes (How)	No	Blind, double block and bleed, pipe gap
Is there likelihood of water being in this line?	1 Not expected	2 yearly 3 monthly 4 wet line	If water is present what is the likely source or cause? For example, slow accumulation from wet product ppm moisture, or unit upset, or drier failure
Potential Water Source			
Is this a dead-leg because of a potential lineup change?	Yes	No	
Describe the lineup that makes this a dead-leg			
Is the dead-leg winterized in any way?	Yes	No	
If yes, is dead-leg insulated and traced?	Yes	No	

Dead-leg location	**Is Dead-leg tagged? If not, attach ID tag**	**What is ID?**	**Notify Dead-leg coordinator with ID and copy of this form**
Is dead-leg insulated?	Yes	No	If yes, steam or electric?
Is dead-leg heat traced?	Yes	No	
Is insulation and tracing working order?	Yes	No	Date checked
Are there other methods of winterization used? Describe	Example: Methanol injection		
Does the dead-leg support other piping? If yes, describe	No	Yes—Piping supported	
Name of person who identified dead-leg for follow-up questions			
Other notes or actions to manage freeze potential?			
Is this piping a candidate for management of change review? If yes—Identify the person to whom the situation has been referred Date			

Table B.4—Sample—Winterization Checklist—Example of One Approach

Separate Unit-Specific Lists Are Used for Each Unit **"Required Action" column to be completed by Shift Team Leader or Top Operator** **"Item Complete" and "Return to Normal" columns to be initialed by performing Operator**			
Date: **Action**	**Required Action**	**Item Complete (Initial)**	**Return to Normal (Initial)**
I. Safety			
Crack open to allow small continuous flow:			
a) #4 SRU Unit Fire Monitors	a)	a)	a)
b) #5 SRU Unit Fire Monitors	b)	b)	b)
c) ARU Unit Fire Monitors	c)	c)	c)
d) SWS Unit Fire Monitors	d)	d)	d)
Crack open to allow small continuous flow:			
a) #4 SRU Unit Fire Hydrants	a)	a)	a)
b) #5 SRU Unit Fire Hydrants	b)	b)	b)
c) ARU Unit Fire Hydrants	c)	c)	c)
d) SWS Unit Fire Hydrants	d)	d)	d)
Block-in the following:			
a) #4 SRU Unit Fire Hydrant/Monitors	a)	a)	a)
b) #5 SRU Unit Fire Hydrant/Monitors	b)	b)	b)
c) ARU Unit Fire Hydrant/Monitors	c)	c)	c)
d) SWS Unit Fire Hydrant/Monitors	d)	d)	d)
Confirm heat tracing operable:			
a) #4 SRU Safety Showers/Eye Wash Stations	a)	a)	a)
b) #5 SRU Safety Showers/Eye Wash Stations	b)	b)	b)
c) ARU Safety Showers/Eye Wash Stations	c)	c)	c)
d) SWS Safety Showers/Eye Wash Stations	d)	d)	d)
Monitor fire monitors and safety showers/eye wash stations on rounds			
Comments:			
NOTE This facility has chosen to use a combined approach of continuous water flow, removing water by blocking in and heat tracing—confirmed by auditing on operator rounds.			

B.8 Cold Weather Preparation

The U.S. Department of Energy (DOE) publication *DOE Operating Experience Summary*, Issue Number 2009-10, Article 2, provides the following guidance for nuclear power generating facilities. The concerns are comparable to petroleum facilities in many respects. The DOE bulletin includes advice for buildings (such as shops, offices, or warehouses) as well as process equipment.

Useful freeze protection measures that address potential cold weather-related hazards include:

— increase surveillance of building pipelines, flow lines, and safety-related equipment during periods of extreme cold;

— examine wet-pipe sprinkler systems for areas susceptible to freezing and develop preventive or compensatory measures to ensure operation;

— check heating systems to ensure sufficient heat is delivered to keep sprinkler piping from freezing, especially during idle periods when temperatures are extremely cold;

— install temperature alarms or automatic backup heat sources on vulnerable systems that require special protection because of hazards or costs associated with freeze damage;

— inspect outside storage pads and unheated storage areas and provide additional protection if needed to ensure that stored materials are not affected by inclement weather or freeze damage;

— inspect and repair outdoor circuits (e.g. those used for vehicle block heaters and power tools);

— ensure that any systems that may have outdoor components or vehicles that may be parked outdoors for long periods of time are included in freeze protection planning and maintenance programs.

The initial concern with freezing water in a fire water storage tank is impairment of fire suppression capability. FM Global and NFPA 25 note other concerns for water tanks such as used for fire protection supply—be wary if withdrawing water from a tank with a solidly frozen surface more than 2 in. thick. If the ice layer seals the tank, a vacuum may form and collapse a tank wall. Falling ice chunks may damage a tank. And broken fittings may cause problems with flooding and freezing. Heating or insulating fire water storage tanks should be considered. Maintaining water circulation may provide another means of freeze protection for both the tank and the piping.

B.9 Winterizing References

Winterizing references are included in a separate section in the bibliography. As indicated, Annex B includes information from industry technical papers and private correspondence in addition to those in the bibliography.

Annex C
(informative)

Conversion Factors

C.1 General

Table C.1 lists the conversion factors.

Table C.1—U.S. Customary (USC) to Metric (SI) Units of Measure

USC Unit	SI Unit	Conversion Factor
Fluid Volume		
	liter, L	1 g = 3.785 L
U.S. Gallon, USG	cubic decimeter, d m^3 (e.g. one liter)	1 g = 3.785 d m^3
The unit "gallon" in this document refers to U.S. gallons.	cubic meters, m^3 cubic inches	1 m3 = 264.2 g 1 USG = 231 $in.^3$
	U.K.(Imperial) gallons	1 U.K. = 277.42 $in.^3$ = 1.2 USG
Barrel (42 USG)	Liter	1 barrel = 158.988 L
Weight		
		2000 lb = 907.18 kg
Short ton	kilograms, kg	2240 lb = 1016.05 kg
Long ton	kilogram, kg	1 lb = 0.45359 kg = 454 g
Pound	Metric ton	1 kg = 2.20462 lb
		1000 kg = 2204.62 lb
Density of Foam Application		
Gallons/minute/square foot, gpm/ft^2	liters per minute per square meter, L/min-m^2	1 gpm/ft^2 = 40.746 L/min-m^2 4.1 L/min-m^2 = 0.1 gpm/ft^2
Volumetric Flow Rate		
Gallons per minute	cubic meters per hour	1000 gpm = 227 m^3/hr 1000 gpm = 3785 Lpm 1 bbl/hr = 0.158987 m^3/hr 1 m^3/hr = 6.28981 bbl (U.S. Oil)/hr
Barrels (oil)/hour, bbl/hr	Liters/minute = Lpm	
	cubic meters/hour	
Pressure		
pounds per square inch, psi	mm Hg	1 psi = 51.7 mm Hg
pounds per square inch, psi	pascal, Pa	1 psi = 6894.757 Pa = 6.9 kPa
pounds per square inch, psi	bar	1 psi = 0.0689 bar
	bar	1 bar = 105 Pa
pounds per square inch, psi	kilopascal, kPa	1 psi = 6.895 kPa
Length		
foot, ft	meter, m	1 ft = 0.3048 m
inch, in.	meter, m	39.37 in. = 1 m
Area		
Square feet, ft^2	Square meters, m^2	1 ft2 = 0.0929 m^2 1 m2 = 10.76 ft^2
Temperature		
Degrees Fahrenheit, °F	Degrees Celsius, °C (e.g. Centigrade)	(°F – 32)/1.8 = °C °F = 32 + (1.8 × °C)
Heat		
BTU/hr	Watts, W	1 BTU/hr = 0.293 W
BTU/hr/ft^2	kW/m^2	1 BTU/hr/ft^2 = 3.155 W/m^2 1.00 kW/m^2 = 317 BTU/hr/ft^2

NOTE Measurements in this document are generally provided in both USC and SI units. To avoid implying a greater level of precision than intended, the second cited value may be rounded to a more appropriate number. Where specific code or test criteria are involved an exact mathematical conversion is used.

Annex D
(Informative)

Marine Firefighting

D.1 General

Marine firefighting (MFF) on board vessels is a specialty skill. If information is desired on marine firefighting, refer to NFPA 1005 and the corresponding publication, *IFSTA-Marine Firefighting for Land Based Firefighters*.

While terminal personnel are not required (nor allowed in most cases) to board vessels to fight fires is critical information they need to know in case of a fire. This includes details about what operations are occurring at the terminals, the various parties involved, and the potential impact(s) to the terminal. Initial actions of the terminal personnel are stopping transfer of cargo and initiating a 911 call.

If the event is escalated to a Unified Command, the following personnel shall respond:

— Municipal FD's commensurate upon their experience in MFF,

— USCG,

— Salvage and MFF contracted,

— EMS.

Terminals will need to understand what operations will be occurring at their terminals in the event of a marine fire, who this involves and how they affect the terminal. Initial actions of the terminal are of course stopping transfer of cargo and initiating a 911 call involving a ship fire.

Among responding personal if the event is escalated to a Unified Command are the following, to mention just a few.

— Municipal FD's commensurate upon their experience in MFF.

— USCG

— Salvage and MFF contracted personal.

— EMS

Terminals, even though not boarding a vessel to actively fight a fire should consider the following in their Emergency Response Plan for the berth(s).

— Active combined drills (full or table-top) with the USCG, Municipal FD, Vessel owners and SMFF groups. These might involve the terminal assisting in providing an additional water supply to the ship, assist with dockside cranes, communications plans, etc.

— Work with and be part of the UC. Critical decisions may need to be made by the USCG such as moving the vessel or fighting the fire in place. There are dangers involved with both directions. Under no circumstance should a marine terminal take it upon themselves to let go a ship from a berth involved in active firefighting without the USCG approving such a move.

— Integrating the Area Contingency Plan (USCG) into the terminal/berth concept of operations and SOP.

It is highly encouraged for terminal Fire Brigades to be aware of what MFF operations consist of. Attention to the mentioned NFPA 1005 and IFSTA publication provides important information to the terminal and its interest.

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