

Fire Protection in Refineries

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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 (CO₂), 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 discharge pieces of reciprocating compressors to avoid blowing gas into the compressor crankcase during start-up.

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.

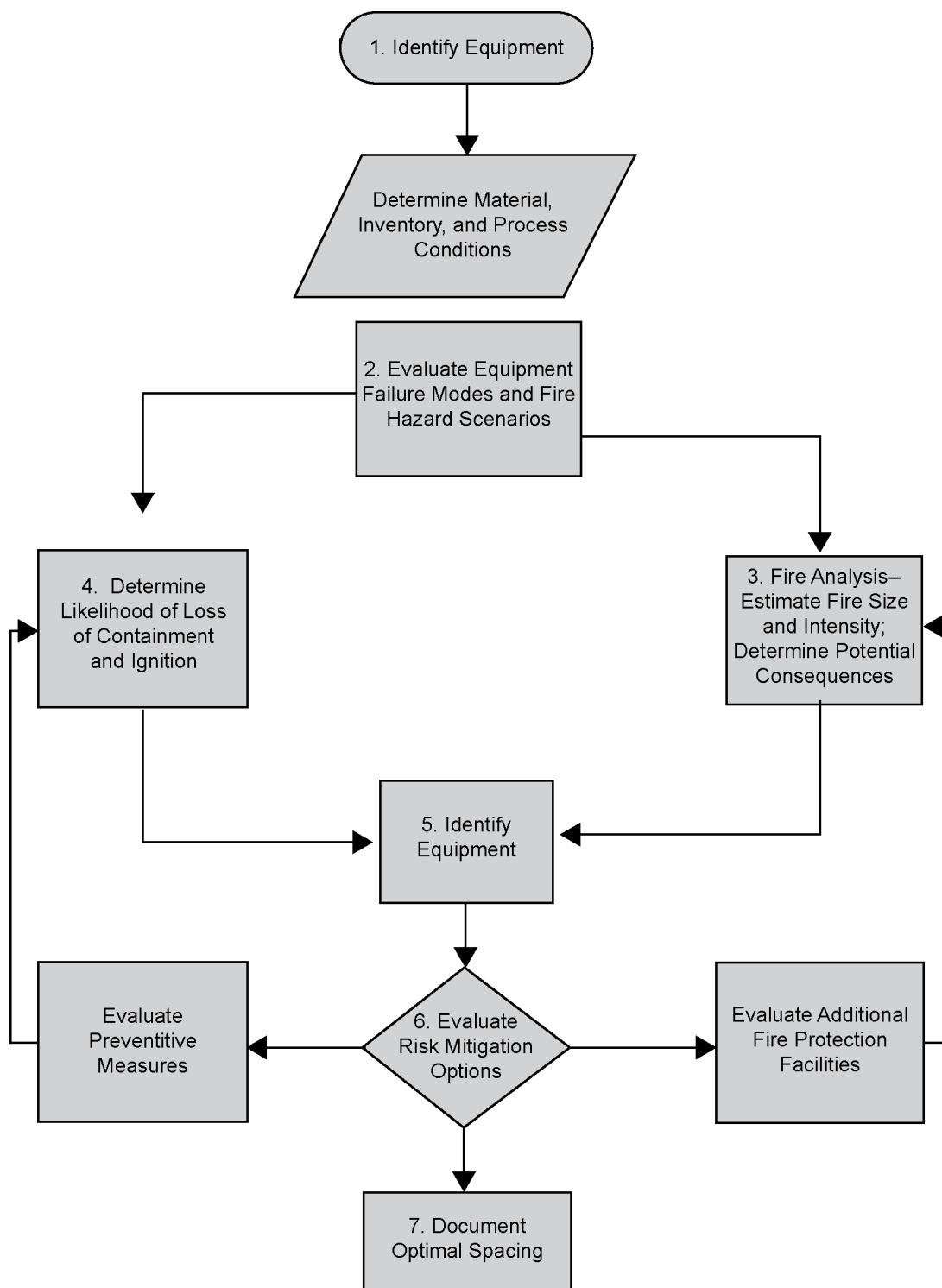


Figure 1—Risk Assessment Work Process Example

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;