Fire-Protection Considerations for the Design and Operation of Liquefied Petroleum Gas (LPG) Storage Facilities

API PUBLICATION 2510A
SECOND EDITION, DECEMBER 1996

REAFFIRMED, DECEMBER 2015

AMERICAN PETROLEUM INSTITUTE

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Downstream Segment

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FOREWORD

This publication covers aspects of the design, operation, and maintenance of liquefied petroleum gas (LPG) storage facilities from the standpoints of prevention and control of releases, fire-protection design, and fire-control measures. The storage facilities covered are LPG installations (storage vessels and associated loading/unloading/transfer systems) at marine and pipeline terminals, natural gas processing plants, refineries, petrochemical plants, and tank farms. This publication provides background, philosophy, methods, and alternatives to achieve good fire protection.

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SECTION 1—GENERAL

1.1 Scope

1.1.1 This publication addresses the design, operation, and maintenance of LPG storage facilities from the standpoints of prevention and control of releases, fire protection design, and fire-control measures. The history of LPG storage facility failure, facility design philosophy, operating and maintenance procedures, and various fire protection and firefighting approaches are presented. This publication, since it supplements API Standard 2510 and provides the basis for many of the requirements stated in that standard, must be used in conjunction with API Standard 2510. In case of conflict, API Standard 2510 shall prevail. Alternate designs are acceptable provided equal safety can be demonstrated.

1.1.2 The storage facilities covered by this publication are LPG installations (storage vessels and associated loading/unloading/transfer systems) at marine and pipeline terminals, natural gas processing plants, refineries, petrochemical plants, and tank farms. The following types of LPG installations are not addressed:

a. Underground storage, such as buried tanks, storage caverns, salt domes, or wells.
b. Mounded storage tanks.
c. Refrigerated storage at pressures below 15 pounds per square inch gauge.
d. Installations covered by API Standard 2508.
e. Installations covered by NFPA Standards 58 or 59.
f. Department of Transportation (DOT) containers.
g. Those portions of LPG systems covered by NFPA 54 (ASME Z223.1).
h. Small installations with a single LPG tank of less than 2000-gallon capacity.
i. Process equipment for LPG manufacture or treatment preceding LPG storage.

1.2 Retroactions

The provisions of this publication pertain to new installations, but may also be used to review and evaluate existing storage facilities. The applicability of some or all of these provisions to facilities and equipment already in place or in the process of construction or installation before the date of this publication will have to be considered on a case-by-case basis.

1.3 Introduction

1.3.1 In developing fire-protection guidelines for an LPG storage facility, the greatest concern is the massive failure of a vessel with a full inventory of LPG. The probability of this type of failure can be made virtually negligible with properly engineered and operated facilities. The fire-protection principles of this publication are intended to prevent fire-induced vessel failure.

1.3.2 Most LPG fires originate as smaller fires that have the potential to become larger and more hazardous. It is important to note that LPG fires usually occur, not as a result of tank failure, but because of pump seal leaks, piping leaks, or failure to follow safe work procedures. Human failure such as overfills and piping leaks from poor drawoff (water and sample) procedures can lead to LPG release and consequent fire. This publication treats the prevention and control of such incidents and provides various fire extinguishment and containment methods.

1.4 Failure History

1.4.1 The most serious LPG release is a massive failure of a storage vessel. Such failures are rare and seldom occur without exacerbating circumstances such as exposure to fire or external explosion.

1.4.2 To project LPG storage vessel failure frequency, fire-protection professionals have reviewed applicable U.S., British, and German failure statistics for pressure vessels.[1] These statistics reveal that the failure rate for pressure vessels from causes other than pre-existing fires or explosions, has been about 1 failure per 100,000 vessel years. To assume this failure rate for hydrocarbon storage vessels is conservative, since most of the data in these studies are for steam boilers and drums operating under more adverse conditions.

1.4.3 A more likely LPG incident, and in the context of this publication a more relevant one, is leakage from piping or other components attached to or near the vessel followed by ignition, a flash fire or vapor cloud explosion, and a continuing pool fire and pressure (torch) fire. The possibility of a pool fire is greater with lower-vapor-pressure LPG or in cold climates. Should flames impinge on a nearby LPG vessel, a boiling liquid-expanding vapor explosion (BLEVE) involving one or more storage vessels may ensue. Injury to facility or neighboring personnel and damage losses of several million dollars can be incurred in these types of LPG incidents.

[1] Spencer H. Bush, "Pressure Vessel Reliability," *Transactions of the ASME: Journal of Vessel Technology,* February 1975.

1.4.4 An examination of the 100 largest hydrocarbon-chemical accidents over a 30-year period has made it possible to estimate the probability of major accidents (losses of $12,000,000 or more in 1983 dollars) in LPG storage facilities.[2] This data and the 1984 disaster near Mexico City[3] demonstrate that there were about three major incidents worldwide every 10 years involving pressurized liquid light-hydrocarbon storage facilities. The number of such facilities in operation during the 30-year period examined was between 600 and 1000. Hence, the probability that any one facility will have a major LPG accident in any one year is from less than 1 in 2000 to less than 1 in 3333. Since a typical facility is likely to contain several vessels, the frequency of a major accident at any one facility is probably on the order of 1 per 20,000 vessel years. A consideration of the nine major LPG storage facility incidents studied suggests that many if not most of the incidents would probably not have occurred or would have been much less severe if the practices described in this publication had been observed. Hence, implementation of the recommendations described herein should reduce the frequency of major LPG storage facility fires from 1 per 20,000 vessel years to about 1 per 100,000 vessel years.

1.4.5 Some of the causes for releases that have occurred at facilities that transfer and store pressurized LPG are listed below:

a. Leakage from an LPG transfer pump seal.
b. Leakage from valve stem seals and flange gaskets.
c. Leakage when taking a sample or drawing water.
d. Leakage from transfer piping because of corrosion, mechanical damage, or from screwed piping connections.
e. Failure of a transfer pipe flexible joint or cargo hose at the interface between a fixed facility and a tank truck, railroad tank car, or tank ship.
f. Leakage from a storage vessel because of corrosion.
g. Tank overfilling, which forces liquid out the pressure safety valves.
h. Failure of a storage vessel because of direct flame impingement on the unwetted shell.

1.5 Safety Analysis

1.5.1 Where site location, equipment spacing, or limited built-in fire protection increase the risk to the public or the potential for damage to an industrial area, a safety analysis of the LPG facility should be performed. The analysis should include possible but realistic scenarios of accidents that may occur, including LPG release, ignition, and fire. Refer to OSHA 29 CFR 1910.119 for additional information and guidance for evaluating the safe design, operation, inspection and maintenance of a facility.

1.5.2 The safety analysis should be periodically reviewed to ensure that conditions have not significantly changed and that the current level of fire prevention and fire suppression is still appropriate.

1.5.3 A smaller storage facility that is remotely located, such as at an oil field producing site, should not require as much built-in fire protection as a major facility in an industrial or urban area. An evaluation should be made to establish the value of the facility, the economic impact if it were lost, and the exposure risk to people and neighboring installations. The level of fire protection incorporated in the design should be commensurate with the exposure risk and value of the facility, provided that any reductions in fire protection would not result in unacceptably high risks to people.

1.6 LPG Properties

1.6.1 At normal temperature and atmospheric pressure, LPG is in a gaseous state. It can be liquefied under moderate pressure or by cooling to temperatures below its atmospheric pressure boiling point but will readily vaporize upon release to normal atmospheric conditions. It is this property that permits LPG to be transported and stored in a liquid form but used in the vapor form.

1.6.2 Liquefied petroleum gas consists of light hydrocarbons with a vapor pressure exceeding 40 pounds per square inch absolute at 100°F. Examples include propane, propylene, butane (normal or isobutane), and butylene (including isomers). The most common LPG's are propane and normal butane or a mixture of these, and thus only the properties of these gases will be discussed. The properties of propane and normal butane are shown in Tables 1 and 2.

1.6.3 Concentrated LPG vapors are heavier than air; thus they tend to stay close to the ground, collect in low spots, and disperse less readily than lighter-than-air gases. Undiluted propane vapor is 1½ times more dense than air, and normal butane vapor is twice as dense. However, once LPG is released, it mixes with air to form a flammable mixture, and the density of the mixture becomes essentially the same as air. Natural air currents, diffusion, and dispersion will eventually dilute the mixture to below the lower flammable limit (LFL).

1.6.4 Since LPG is stored under pressure and vaporizes readily when released, it is difficult to control leaks once they occur. The vapor cloud from a leak tends to stay close to the ground and drift downwind toward low areas. This property makes it essential that leaks be prevented, ignition sources kept at a safe distance, and vapor from leaks be dispersed before it is ignited. Wind significantly reduces the dispersion distance, that is, the size of the flammable vapor cloud, for any given leak rate.

[2] "One Hundred Largest Losses: A Thirty-Year Review of Property Damage Losses in the Hydrocarbon-Chemical Industries," Marsh & McLennan Protection Consultants, 1986.
[3] "Analysis of the LPG Incident in San Juan Ixhuatepec, Mexico City, November 19, 1984," TNO, Netherlands, May 6, 1985.

Table 1—Properties of Two Common LPG's

Property	Propane	*n*-Butane
Specific gravity of gas (air = 1.0)	1.5	2.0
Vapor pressure at 60°F, psia[a]	105	26
Vapor pressure at 60°F, psia[a]	190	52
Boiling point, °F	-44	+31
Cubic feet of gas/gallon of LPG at 60°F	36.4	31.8
Lower flammable limit (LFL), percent in air	2.0	1.5
Upper flammable limit (UFL), percent in air	9.5	9.0
Gross Btu/ft^{3b} of gas at 60°F	2516	3262

Note: *n* = normal.
[a]psia = pounds per square inch absolute.
[b]Btu/ft^3 = British thermal units per cubic foot.

Table 2—Tank Pressures for Two Common LPG's

Liquid Temperature (Degrees Fahrenheit)	Tank Pressure[a] (Pounds per square inch gauge)	
	Propane	*n*-Butane
31	50	0
60	90	11
100	175	37
130	250	65
140	290	80

Note: *n* = normal
[a]Vapor pressure at the listed temperature. Actual tank pressure can exceed these values if the vessel contains noncondensable gases such as nitrogen.

1.6.5 Both propane and normal butane have low boiling points. Since the boiling point of liquid propane is far below temperatures typically found in nature, propane generally does not form a liquid pool when spilled. However, liquid normal butane is more likely to remain liquid if accidentally released at low ambient or storage temperatures, due to its 31°F atmospheric pressure boiling point.

1.6.6 Other characteristics of LPG include the following:

a. LPG exerts a chilling effect from vaporization when released or vented to a lower pressure. This effect is known as auto-refrigeration; the liquid temperature approaches its boiling temperature at atmospheric pressure (see boiling point in Table 1).
b. The density of the liquid is approximately half that of water, and thus water will settle to the bottom in LPG.
c. Small quantities of liquid will yield large quantities of vapor as shown in Table 3.
d. High rates of vaporization and strong turbulence will result when LPG is spilled on water or water streams are added to an LPG spill.
e. Liquefied petroleum gas, when vaporized, leaves no residue.
f. Pure LPG is noncorrosive to steel and generally noncorrosive to copper alloys. However, when sulfur compounds and other impurities are present in the LPG, corrosion can be a serious problem.
g. Liquefied petroleum gas has no lubricating properties, and this fact must be taken into account when specifying LPG-handling pumps, compressors, and so forth.
h. Liquefied petroleum gas is colorless. However, when the liquid evaporates, the cooling effect on the surrounding air causes condensation of water vapor in the air, which usually makes it possible to see an escape of LPG. This may not occur in the case of a vapor release if the vapor is near ambient temperature and its pressure is relatively low.
i. Pure LPG is practically odorless. For safety purposes, it is required that an odorizing agent (such as ethyl mercaptan) be added to commercial grades of LPG to make them detectable by smell.

1.7 Definitions

Terms used in this publication are defined in 1.7.1 through 1.7.19.

1.7.1 adiabatic: A closed thermodynamic system in which changes take place with no net gain or loss of energy.

1.7.2 autorefrigeration: The chilling effect from vaporization of LPG when it is released or vented to a lower pressure.

1.7.3 boiling liquid-expanding vapor explosion (BLEVE): A phenomenon that occurs when an LPG vessel fails catastrophically releasing its contents. The most common cause of a BLEVE of a LPG vessel is prolonged, direct exposure to a fire with flame contact above the liquid level. A BLEVE can occur when a vessel containing a liquid fails with the liquid at a temperature above the boiling point of its components at atmospheric pressure.

1.7.4 excess flow valve: A device designed to close when the flow rate of the liquid or vapor passing through it exceeds a prescribed value as determined by pressure drop.

1.7.5 fireproofing: A fire-resistant insulating material applied to steel to minimize the effects of fire exposure by flame impingement, to reduce the steel's rate of temperature rise, and to delay structural failure.

1.7.6 inert substance: A substance that is chemically unreactive (usually a gas when referred to in this publication).

1.7.7 lower flammable limit (LFL): The lowest concentration of vapor in air that can be ignited. For normal butane, it is 1.5 percent; for propane, it is 2.0 percent.

Table 3—Vapor Volumes Obtained for Two Common LPG's

Liquid	Quantity (Gallons)	Vapor Volume Gallons	Vapor Volume Cubic Feet	Volume of Gas/Air Mixture at LFL (Cubic Feet)
Propane	1	270	36	1680
n-Butane	1	230	32	1630

Note: *n* = normal.

1.7.8 may: Indicates provisions that are optional.

1.7.9 minimum pressurizing temperature: The lowest temperature at which a pressure greater than 40 percent of the maximum allowable working pressure should be applied to the vessel.

1.7.10 must: Indicates provisions that are mandatory.

1.7.11 net positive suction head (NPSH): The net positive pressure in feet of liquid at the inlet to a pump.

1.7.12 pressure safety valve (PSV): Used to limit pressure to a predetermined safe maximum.

1.7.13 remote location: A location that is 4000 feet or more from populated or industrial areas. Locations without this clear zone may also be considered remote through a safety analysis.

1.7.14 root valve: The valve located at the vessel or equipment for the connection of a pipe. It is the starting point or "root" of the piping connection and is used to isolate the piping from its source.

1.7.15 sample container: A small hand-held pressure container used to collect LPG samples for transport to a laboratory.

1.7.16 shall: Indicates provisions taken from API Standard 2510 that are mandatory.

1.7.17 should: Indicates supplemental provisions that are recommended but not mandatory.

1.7.18 upper flammable limit (UFL): The highest concentration of vapor in air that can be ignited. For normal butane, it is 9.0 percent; for propane, it is 9.5 percent.

1.7.19 weep hole: A drain hole at the low point of a pressure safety valve atmospheric vent stack.

1.8 Referenced Publications

The following standards, codes, publications, and recommended practices are cited in this publication:

API

RP 500 *Classification of Locations for Electrical Installations at Petroleum Facilities*
RP 510 *Pressure Vessel Inspection Code*
RP 520 *Sizing, Selection, and Installation of Pressure-Relieving Devices in Refineries*
RP 521 *Guide for Pressure-Relieving and Depressurizing Systems*
RP 576 *Inspection of Pressure Relieving De-vices*
Publ 920 *Prevention of Brittle Fracture of Pressure Vessels*
RP 2003 *Protection Against Ignitions Arising Out of Static, Lightning, and Stray Currents*
Publ 2009 *Safe Welding and Cutting Practices in Refineries, Gasoline Plants, and Petrochemical Plants*
Publ 2015 *Cleaning Petroleum Storage Tanks*
Publ 2030 *Guidelines for Application of Water Spray Systems for Fire Protection in the Petroleum Industry*
Publ 2214 *Spark Ignition Properties of Hand Tools*
Publ 2217 *Guidelines for Confined Space Work in the Petroleum Industry*
Publ 2218 *Fireproofing Practices in Petroleum and Petrochemical Processing Plants*
Std 2508 *Design and Construction of Ethane and Ethylene Installations at Marine and Pipeline Terminals, Natural Gas Processing Plants, Refineries, Petrochemical Plants, and Tank Farms*
Std 2510 *Design and Construction of Liquefied Petroleum Gas (LPG) Installations*

Manual of Petroleum Measurement Standards

Validation of Heavy Gas Dispersion Models With Experimental Results of the Thorney Island Trial (Volume I–text; Volume II–appendix)

AICE[4]

Guidelines for Hazard Evaluation Procedures

ASME[5]

Boiler and Pressure Vessel Code, Section II, "Material Specification," Section VIII, "Pressure Vessels"
B31.3 *Chemical Plant and Petroleum Refinery Piping*

OSHA[6]

29 CFR 1910.110 *Storage and Handling of Liquefied Petroleum Gases*
29 CFR 1910.119 *Process Safety Management of Highly Hazardous Chemicals*

[4] American Institute of Chemical Engineers, 345 East 47th Street, New York, New York 10017.
[5] American Society of Mechanical Engineers, East 345 47th Street, New York, New York 10017.
[6] Superintendent of Documents, Government Printing Office, Washington, D.C. 20402.

NFPA[7]

54 *National Fuel Gas Code* (ASME Z223.1)
58 *Storage & Handling of Liquefied Petroleum Gases*
59 *Storage & Handling of Liquefied Petroleum Gases at Utility Gas Plants*
25 *Water-Based Fire Protection Systems*
600 *Industrial Fire Brigades*

SECTION 2—FACILITY DESIGN PHILOSOPHY

2.1 Introduction

Adherence to the design considerations and requirements of this section will significantly reduce fire risk at LPG facilities and will limit the spread of fire and extent of damage should a fire occur. This section is intended to be used as a supplement to API Standard 2510.

2.2 Site Selection

2.2.1 Liquefied petroleum gas storage facilities should be located to minimize the exposure risk to adjacent facilities, properties, or population. The location, layout, and arrangement of a storage facility should be based primarily on the requirement for safe and efficient operation in normal use. Recognition of safety requirements in plant layout and equipment spacing is essential in the early design of new facilities and has a direct impact on both the risk and the potential magnitude of loss. Typical considerations are listed in 3.1 of API Standard 2510.

2.2.2 For remotely located storage facilities, such as those in producing areas or at facilities where the quantity of stored LPG is limited, the amount of built-in fire protection warranted may be less than that needed for larger facilities located in populated or developed industrial areas. Thus, the remoteness of the location is a major factor in determining the degree of fire protection to be included in the design. A safety analysis, discussed in 1.5, can help to establish a realistic exposure risk to aid in deciding on the amount of protection necessary.

2.2.3 Risk assessment and dispersion modeling can be useful tools in estimating setback distances to limit exposure to adjacent facilities.[8] For additional information, see the API report *Validation of Heavy Gas Dispersion Models with Experimental Results of the Thorney Island Trials* June 1986, Volumes I and II.

2.3 Layout and Spacing

2.3.1 GENERAL

2.3.1.1 Spacing and design of LPG facilities are interdependent and must be considered together. Spacing requirements used shall be in accordance with 3.1 of API Standard 2510.

2.3.1.2 Spacing should be sufficient to minimize both the potential for small leak ignition and the exposure risk to adjacent vessels, equipment, or installations should ignition occur. Prudent spacing will not necessarily protect against a major accident, but it may prevent a minor incident from escalating into a major one. The remaining design features of this document and API Standard 2510 are intended to prevent a major incident from occurring.

2.3.2 MINIMUM DISTANCE REQUIREMENTS FOR ABOVEGROUND LPG VESSELS

2.3.2.1 The spacing of aboveground LPG vessels shall be as given in 3.1.2 of API Standard 2510.

2.3.2.2 Good engineering judgment should be used in selecting spacing distances. Many factors should be considered. For example, when three or more horizontal vessels are in a group, an increase in shell-to-shell spacing to 10 feet will result in a repositioning of the drainage from an area immediately adjoining each vessel to a low point midway between adjacent vessels. This arrangement will minimize flame contact between adjacent vessels in a fire except under some wind conditions, since the drainage channel will be centered between the vessels. Further increases in spacing are normally not justified, since other requirements of this publication minimize the risk of a major unconfined leak and fire. There may be value in spacing greater than 10 feet for vessels larger than 10 feet in diameter, since larger vessels tend to stand higher and would have greater surface area exposed to potential flame impingement from a spill fire in the drainage path. These comments apply to 3.1.2.2, Item b, in API Standard 2510. Similar engineering judgment should be exercised as appropriate for other design features.

2.3.3 SITING OF ABOVEGROUND PRESSURIZED LPG VESSELS

The site selection for aboveground LPG vessels shall be as given in 3.1.3 of API Standard 2510. The emphasis should be on limiting exposure of the vessels to fire, explosion, or mechanical damage from adjacent facilities or properties, and on protecting those facilities or properties from an incident involving the storage vessels.

[7] National Fire Protection Association, 1 Batterymarch Park, Quincy, Massachusetts 02269.
[8] "Canvey Summary of an Investigation of Potential Hazards from Operations in the Canvey Island/Thurrock Area," *Health and Safety Executive*, England, 1978.

2.4 Drainage and Spill Containment

2.4.1 Proper design of drainage and spill containment systems is important in LPG storage facilities. For spill containment requirements refer to 3.2 through 3.5 in API Standard 2510. The pronounced volatility of LPG generally allows impoundment areas to be reduced and in some cases, such as for smaller propane vessels in warm climates, containment may not be warranted. Even though high-vapor-pressure LPG may not form a pool when released, the principles of good drainage should nevertheless be considered. The provisions that follow are intended to accomplish the following objectives:

a. To prevent the accumulation of liquid under LPG storage vessels.
b. To minimize as much as practical the chance of flame impingement on a vessel from a burning spill.
c. To provide a location for accumulating liquid that will, to the greatest extent, minimize the risk to critical facilities, piping, and equipment if the pool of liquid ignites.
d. To confine a spill to the smallest area practical in order to reduce the vaporization rate of the liquid that collects, thus reducing the size of the resultant vapor cloud.

2.4.2 Grading at a minimum 1-percent slope shall be provided under each vessel to rapidly carry a spill to an impoundment (spill containment) area. The drainage path to the impoundment area should not come closer than 5 feet to the edge of any other storage vessel, or exposed piping, or other hydrocarbon-containing equipment. The low point of drainage from between adjacent vessels should be centered between the vessels. This may result in the drainage path being closer than 5 feet from the shell of adjacent vessels spaced less than 10 feet shell-to-shell.

2.4.3 The surface under each vessel, the impoundment area, and drainage paths between the two locations should be stabilized to prevent erosion. The surface of the drainage path and impounding area should not be constructed of loose material such as gravel or rock. The surface should be resistant to LPG liquid retention.

2.4.4 Diking or impounding shall be as required in 3.4 and 3.5 of API Standard 2510 where liquid spills may endanger or expose other important facilities, nearby properties, or public areas.

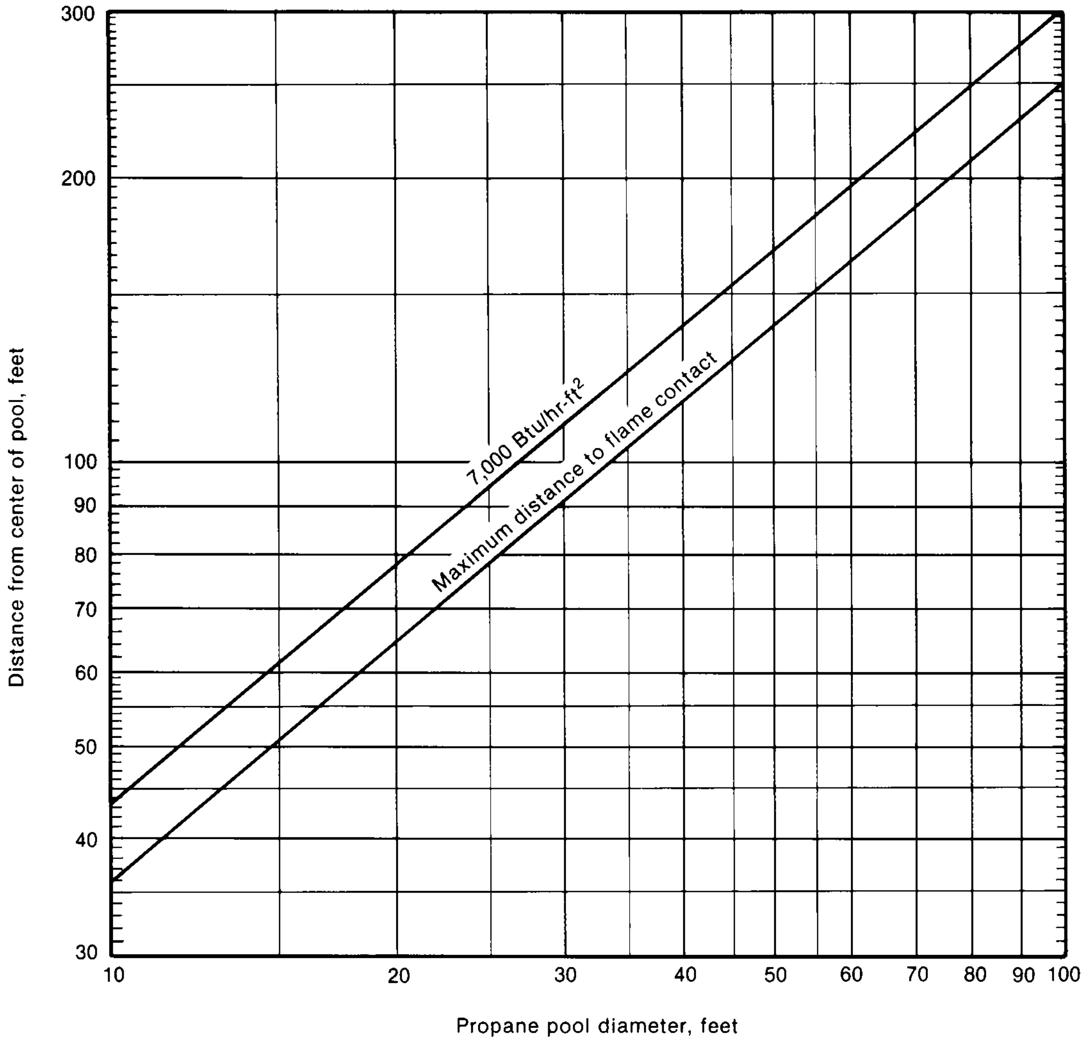
2.4.5 Impoundment areas may be either inside or outside of a dike surrounding the vessel storage area and should have the following features:

a. The liquid capacity shall be as required in 3.2.3.4 or 3.2.4.3 of API Standard 2510.
b. Liquid that pools in the impoundment area should expose a vessel on one side only.
c. The impoundment area, where practical, should be located to minimize the chance of flame impingement on a storage vessel. The distance necessary to accomplish this depends primarily on the size and shape of both the pool and the vessels, and the wind conditions. The distance required for a specific case should be determined by an engineering analysis. The chance of flame contact on a storage vessel from a fire in the impoundment area is reduced significantly by increased spacing up to about 100 feet, beyond which there is little risk under most conditions (see Figure 1). Shown in Figure 1 is a line that indicates the maximum distance for flame contact on a vessel shell at a point 20 feet above grade.
d. The impoundment area should be designed to keep the surface area of the contained liquid as small as practical in order to minimize the vaporization rate. A slope at the bottom of the impoundment area may help reduce the vaporization rate in case of a partial spill.
e. Drains shall be provided to remove water from the diked and impoundment areas. An accessible valve outside the enclosure shall be provided and it normally shall be closed.
f. When an impoundment area serves multiple LPG storage vessels in a common diked area, drainage must be arranged from each vessel so that it goes to the impoundment area without passing under other storage vessels or piping. Suitable intermediate dikes may be appropriate.
g. When dikes are used for impoundment, they should not exceed an average of 6 feet in height above the interior grade to control risk of vapor accumulation due to lack of ventilation, and to assure safe emergency access and egress for personnel. When dikes must be higher than 6 feet, see 3.5.5 in API Standard 2510.
h. The extent of vaporization can be reduced by judicious arrangement of drainage paths, including the use of shallow ditches or trenches when applicable, and by the use of special substrates such as insulating concrete.
i. The effects of thermal shock associated with spilling LPG (shock resulting from the autorefrigeration temperature) should be considered in selecting the materials for all components of a spill containment facility.
j. The impoundment area should be at least 200 feet from furnaces and other fixed ignition sources.

2.5 Ignition Source Control

2.5.1 Ignition source control is an essential consideration in the safe design and operation of LPG storage facilities. All ignition sources must be recognized, identified, and restricted to safe (nonhazardous) areas or contained safe enclosures (see API Recommended Practice 500).

2.5.2 Case histories of accidental ignition indicate that fires have been caused by improper hot work procedures, unauthorized use of motor vehicles, smoking/matches in restricted areas, and improperly maintained or designed electrical



Note: This chart assumes a 20-mile-per-hour wind blowing toward the vessel.

Figure 1—Pool Fire Radiant Heat Flux

equipment (see API Recommended Practice 2003, Publications 2009, and 2214).

2.5.3 In some cases, greater zones of restriction may be appropriate for specific LPG release scenarios. For example, restricting continuous ignition sources, such as furnaces, within the downwind vapor cloud (where the vapor concentration is calculated to reach 100 percent of the LFL) should be considered. Release of LPG to the atmosphere from pressure safety valves (PSV's) and vent stacks should also be reviewed before defining the zone of restriction. However, the jet stream dilution effect is usually sufficient to disperse releases to below the LFL before reaching grade level, provided the LPG is released as a vapor. This is discussed in 2.10.2.

2.5.4 Other ignition source control considerations for LPG storage facilities include the following:

a. Smoking should be permitted only in designated and properly signposted areas.

b. Welding, cutting, hot work, use of portable electric tools and extension lights, and similar operations should be performed only at times and places specifically authorized. Hand-operated (non-powered) tools made of special nonsparking alloys are not required in LPG storage facilities (see API Publication 2214).

c. Operating vehicles and other mobile equipment that constitute potential ignition sources should be prohibited within diked areas or within 50 feet of storage vessels except when specifically authorized and under constant supervision, or when loading or unloading at facilities designed specifically for the purpose.

d. Grounding and bonding for control of static and stray currents should be provided in accordance with API Recommended Practice 2003 (see 7.4 of API Standard 2510).

2.6 Vessel Design

2.6.1 GENERAL

Vessels shall be designed in accordance with the provisions of API Standard 2510, Section 2, and applicable codes as described therein. The paragraphs that follow (2.6.2 through 2.6.4) contain considerations in addition to those in API Standard 2510.

2.6.2 DESIGN TEMPERATURE

Both a minimum and a maximum vessel design temperature should be specified. In determining a maximum design temperature, ambient temperature, solar input, product rundown temperature, including realistic upset conditions, are some of the factors that should be considered. In determining a minimum design temperature, the preceding factors, plus the autorefrigeration temperature of the stored product when it flashes to atmospheric pressure, should be considered. The minimum pressurizing temperature should be in accordance with the ASME *Boiler and Pressure Vessel Code,* Section VIII to control the risk of metal embrittlement and spontaneous rupture (see API Publication 920).

2.6.3 DESIGN PRESSURE

The design pressure shall be no less than the vapor pressure of the stored product at the maximum design temperature. However, the additional pressure resulting from the partial pressure of noncondensable gases in the vapor space, and the hydrostatic head of the product at maximum fill, should also be considered.

Ordinarily, the latter considerations, plus the need to provide realistic and practical relief valve specifications, dictate that design pressure be higher than the maximum product vapor pressure.

2.6.4 DESIGN VACUUM

Liquefied petroleum gas storage vessels should preferably be designed for full vacuum. If they are not so designed, the provisions of 2.3 in API Standard 2510 should be followed. If a vacuum relief valve is provided and the vessel is under vacuum, the valve will open to the atmosphere and air will enter the vessel. See 3.2.2.3 and 3.6 for a discussion of potential hazards resulting from the accumulation of air in LPG storage vessels. Air entry can be minimized by setting the vacuum relief valve at the highest vacuum permitted by the design of the vessel.

When using inert gas, natural gas, or fuel gas to avoid a vacuum, a means must be considered to prevent contamination of the gas supply if the vacuum breaker valve fails in the open position or leaks while the vessel is under positive pressure. If either air or inert gas is used to prevent a vacuum, a means should be provided for venting the noncondensable gases when the vessel is refilled. Natural gas or fuel gas may be used to break the vacuum if this does not unnecessarily compromise product specifications.

It should be noted that some LPG products, particularly those containing a significant proportion of butane, have vapor pressures at low ambient temperatures that are below atmospheric pressure.

2.7 Piping

2.7.1 PIPING DESIGN

2.7.1.1 As a minimum the requirements of API Standard 2510, Paragraph 2.5 and Section 6, shall be followed. Areas requiring special consideration are discussed in 2.7.1.2. Ordinarily, it is not necessary to implement all of the listed measures in any one installation. A means should be considered for remotely isolating the vessel from the main product transfer lines, either by providing remote operation capability on the vessel isolation valve, or by using a fusible link valve that can also be remotely operated. On dedicated fill piping, a backflow check valve is an acceptable minimum. Excess flow valves or flow-restricting design features should be considered if it is necessary to limit the maximum leak rate so as to protect vulnerable areas, such as nearby residential areas, from vapor-cloud hazards. As an alternate to leak rate control, hydrocarbon detectors can be used in combination with remote shut-off capabilities to limit the size of vapor clouds.

2.7.1.2 Other considerations for piping design are as follows:

a. Keep the number of shell penetrations on a storage vessel to the minimum required for safety and operability.

b. All shell piping penetrations below liquid level on horizontal vessels should be outside the supporting pedestals, and preferably at one end of the vessel in order to minimize and control the potential area of fire exposure.

c. Avoid, to the extent feasible, blinded or capped pipe penetrations. Where they are required, they should be short.

d. Where permitted by vessel code, use welded construction up to and including the first isolation valve used to shut off the flow. The vessel nozzle and the first valve may be flanged.

e. Use raised-face or ring-joint flanged connections between the vessel shell and the first block valve. Other types of pipe connectors are acceptable provided that their integrity under fire conditions has been proven.

f. Use socket-weld connections in preference to threaded connections because of the greater strength of socket-weld connections under stress or vibration. If screwed connections are used, refer to 6.2.2 in API Standard 2510 for guidance. Any piping to be seal-welded in existing storage facilities should first be disassembled and inspected for deterioration. Piping should be reassembled with clean threads free of joint compounds or tape. See ASME B31.3 for seal-welding requirements.

g. Use flanged valves or valves with bodies that cover the flange bolts. Flangeless wafer-type valves that are clamped between flanges by long bolts shall not be used because in a fire they quickly begin to leak, and the connection may fail.

h. Ensure that any valve or other device that can act to throttle the liquid flow, and at least part of the downstream piping be constructed of metals suitable for the lowest autorefrigeration temperatures, since such devices may potentially experience autorefrigeration temperatures.

i. Install backflow check valves on dedicated vessel fill piping and locate them immediately adjacent to the vessel isolation valve. For this service, the check valve shall be a flanged body valve without exposed long bolts.

j. Consider the use of the following types of devices to aid in the control of spills, with or without fire, caused by piping, equipment leaks, or other factors:

1. *Remotely operated isolation valves* may be installed at the piping connection to the vessel in place of manually operated valves. An advantage of remotely operated isolation valves is that they can be activated for any size leak or other undesirable condition. Also, they can be electrically connected to initiate shutdown of pumps feeding the tank, thereby avoiding pressure surges and water hammer effects. First the spill must be detected by some means; then corrective action is required. Hydrocarbon detector/alarm systems may be used for spill detection, and corrective action may be undertaken through automatic actuation by hydrocarbon detectors or other instrumentation. It may also be necessary to consider a timed closing rate to avoid pressure surges in piping.

2. *Excess flow valves* provide automatic isolation when major pipe failures occur. For these valves to be effective, the downstream piping must have a flow capacity greater than the design shutoff point of the excess flow valve. The main advantages of these valves are that (a) they operate automatically to stop massive leaks, and (b) do not require that fire conditions be present for them to close. Also, they can limit the maximum possible leak rate in order to protect nearby areas. On the other hand, they are (a) difficult to test, (b) have uncertain reliability, and (c) permit leaks smaller than the design flow-rate to continue unabated.

3. *Passive flow-restricting devices,* such as restriction orifices on or near the vessel nozzle, or short sections of smaller-diameter piping, fulfill some of the functions of an excess flow valve but with greater simplicity and reliability. However, they are not capable of stopping flow completely and may require resizing if the system flow requirement is increased.

4. *Heat-activated valves* or other types of valves that close automatically when exposed to fire ensure that the tank will be isolated from the piping during a major fire. They operate regardless of leak rate, or if the pipe in which they are installed is the source of a spill. Additional advantages are that they require no instrumentation, utilities, or operator intervention and can be very reliable.

The main disadvantages are (a) that they do not operate until a fire is already in progress; and (b) they may shut off against incoming pumped flow with resulting pressure surges unless designed for a timed close rate. The former problem can be handled by incorporating a remote operating capability in the valve design so that the valve will close not only through heat activation but through remote control as well. Heat-activated valves also have the disadvantage of requiring regular testing and maintenance to be reliable, as they may stick in position if not routinely operated and checked.

2.7.2 WATER DRAW SYSTEMS

2.7.2.1 The water draw-off line shall have two valves (see 6.7.3 and A.2.1.11 in API Standard 2510). Liquid LPG, when released through a throttle valve, will flash vaporize and autorefrigerate. This can freeze moisture at the throttling valve and prevent closure. To safely draw water and to prevent valve freeze-up, the water draw should include the following features:

a. Locate the inside valve immediately at the vessel nozzle and keep it closed under normal circumstances.

b. Open the inside valve fully when drawing water.

c. Use the outside valve as a throttle to control flow.

d. The outside valve should be a spring-loaded “dead man” valve that will automatically close if the operator must leave the area quickly.

e. Both valves must be readily accessible by the operator; and handles or a handwheel must be permanently installed.

f. Use a fire-resistant, quarter-turn valve for the inside valve to ease its closing in an emergency.

2.7.2.2 The discharge end or outlet of the water-drawoff line shall be run out from beneath the vessel and away from the operator (see 6.7.3 and 6.7.4 in API Standard 2510). In case of problems resulting in LPG release during these operations, the LPG will be directed away from the vessel. Any developing fire will not impinge on the vessel. The outlet point, however, must be observable by the operator from the throttling valve operation point. The discharge end of the water-draw piping must be restrained to prevent movement from reactive thrust during drawoff. The outlet should be located where there is little risk of an accidental release of LPG vapor reaching an ignition source.

2.7.2.3 In view of the pressure inside the vessel, water-drawoff lines normally do not need to be larger than 2 inches to handle needed flow in a reasonable time. Unnecessarily large valves can be more difficult to operate rapidly than smaller valves.

2.7.2.4 Where freezing weather conditions exist, freeze protection should be provided (see A.1.6 in API Standard 2510). One method to accomplish this is to use a nonfreeze drain design as shown in Figure 2. The upper valve connection is used to allow LPG to replace water in the lower connection as it drains back to the vessel through the water-draw pipe. This design permits the draining of all water from the exterior piping after drawoff is completed, and prevents water from freezing in the external nozzle or piping up to the first valve. When drawing water, it should be noted that the first liquid to be drawn off will be the LPG contained in the water nozzle and the internal extension.

2.8 Pumps

The provisions in 2.8.1 through 2.8.12 are intended to minimize the likelihood of pump or seal failure or both and to mitigate the consequences of leaks from these and other failures if they occur (see 7.2 and 7.3 in API Standard 2510).

2.8.1 Pumps should be capable of being shut down from a remote location in case the local start-stop switch is not accessible because of fire or vapor cloud.

2.8.2 For pumps in remote areas that are operated relatively infrequently, consider providing local start-stop capability with remote shutdown at an attended location.

2.8.3 Remotely-operated pumps should be provided with a low-flow shutdown device on the discharge side; or a means should be provided to assure that a required minimum flow is maintained through the pump to avoid pump overheating or damage.

2.8.4 A device should be provided to shut down LPG pumps if there is cavitation or loss of suction.

2.8.5 Pumps should be selected and installed with sufficient net positive suction head (NPSH) to avoid cavitation under both normal and abnormal operating conditions. In cases of uncertainty, it may be necessary to run a factory test to certify the actual NPSH for the pump selected.

2.8.6 A check valve on the pump discharge should be considered for any pump handling LPG. However, a check valve shall be installed on the discharge side of all centrifugal pumps (see 6.6.2 in API Standard 2510).

2.8.7 Low-level alarms should be considered on vessels supplying LPG to pumps.

2.8.8 A means should be provided to isolate LPG pumps from the source of LPG. This can be done by (a) using valves located a safe distance from the pump, (b) using a discharge check valve, or (c) using remotely-operated isolation valves at the pump that can be operated during a fire.

2.8.9 Any pump capable of producing a pressure high enough to damage any component on the discharge side shall be equipped with a suitable relief device that discharges to a safe location (see 7.3.1 in API Standard 2510). Where such a device is used, it should be located upstream of the low-flow shutdown device mentioned in item 2.8.3.

2.8.10 Consider the use of hydrocarbon detectors, television surveillance, fire detectors, or other means for detecting leaks or fires in unattended areas that contain LPG pumps.

2.8.11 Pumps shall be located outside the LPG vessel drainage and impound area (see 3.1.3.2 in API Standard 2510). Drainage should be provided to prevent liquid accumulation around a pump, and to drain a spill to a safe area to minimize exposure to other pumps or piping.

2.8.12 Pumps associated with LPG storage vessels should be located far enough away from vessels to prevent a pump fire from impinging on a vessel (see 3.1.2.5, Item d of API Standard 2510).

2.8.13 Pumps with mechanical seals should be fitted with close clearance throttle bushings to limit leak rates in the event of a seal failure.

2.9 Instrumentation

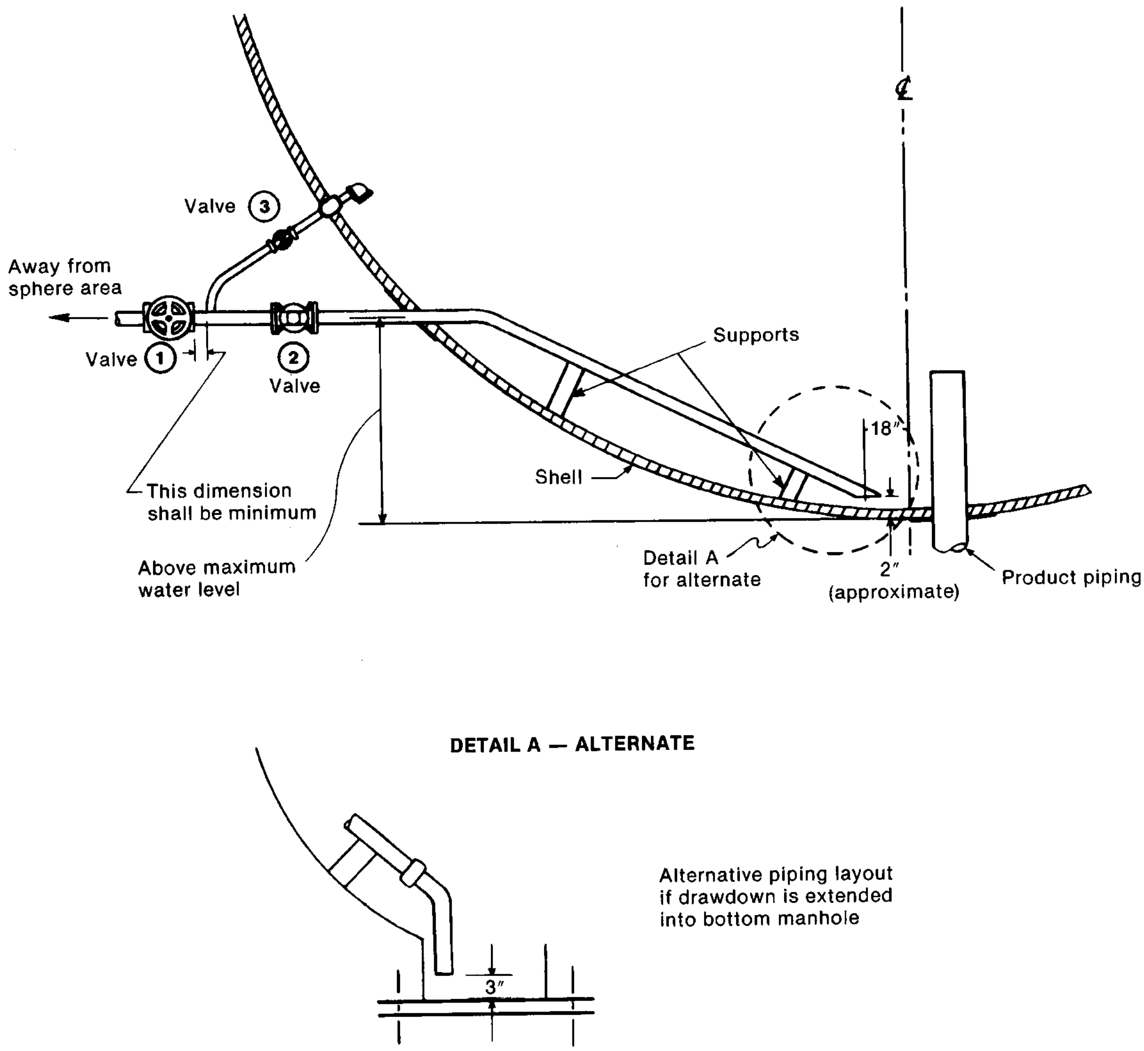
As a minimum, the requirements in API Standard 2510, Section 5, shall be followed. In addition, the considerations given in 2.9.1 through 2.9.5 are relevant.

2.9.1 LEVEL MONITORING EQUIPMENT

The provisions of 5.1.2, 5.1.3 and 5.1.4 in API Standard 2510 shall be followed. For vessels that have a variable horizontal cross section, such as spheres or horizontal cylindrical drums, the important parameter is percent fill, rather than liquid height. Hence, level monitoring equipment should register percent fill either directly or via a suitable calibration chart that is always available at the readout locations. Since overfilling these storage tanks constitutes such a serious hazard, it is essential that accurate gauging equipment be available and that readings be immediately accessible to an operator in a position to take corrective action if an overfill becomes imminent. An independent high-level alarm should also be provided.

2.9.2 LPG/WATER INTERFACE INSTRUMENTS

LPG/water interface instruments can reduce the chance of LPG being released during water drawoff because they indicate the water level. Water drawoff can be stopped before LPG is released. LPG/water interface instruments should be



Note: The drawoff is operated as follows:
1. To draw water, first open Valve 2 wide and then throttle with Valve 1.
2. After water has been drawn, close Valve 1 and open Valve 3.
3. Allow time to displace water from the drawoff line and then close Valves 2 and 3.
4. When water is not being drawn, all valves should remain closed.

Figure 2—Nonfreeze Drain for LPG Vessels

resistant to fire-exposure damage. The use of gauge glasses should be avoided (see 5.1.4 in API Standard 2510).

2.9.3 TEMPERATURE AND PRESSURE INDICATORS

As a minimum, temperature and pressure indicators shall be provided at grade at each storage vessel (see 5.1.5 and 5.1.8 in API Standard 2510). Routine logging of temperature and pressure can provide an indication of the proportions of noncondensable gases present if the vapor pressure of the product at various temperatures is known. If noncondensable gases are present in the vapor space, they should be vented before the relief valve set pressure is reached and before a potential exists for the presence of hazardous concentrations of air, if it is possible for air to accumulate (see 3.2.2.3).

2.9.4 VAPOR SPACE OXYGEN CONCENTRATION

Provisions for drawing gas samples from the vapor space for laboratory analysis of the oxygen concentration should be provided. See A.1.2 in API Standard 2510 for general requirements for sample connections. Fixed oxygen analyzers are usually not needed. Information on oxygen concentration can be used to determine whether it is safe to vent the vessel vapor space to a flare system.

2.9.5 TEST INSTRUMENTS AND ALARMS

Critical instruments and alarms should be designed and installed to permit on-stream testing and repair of all components in the instrument/alarm loop.

2.10 Relief Systems

2.10.1 GENERAL

2.10.1.1 Properly designed pressure relief systems are essential to the integrity of LPG storage facilities. They are necessary to limit pressure buildup, under certain operating conditions or emergency contingencies, to levels acceptable for vessels and associated equipment. The overpressure protection system must also provide for safe disposal of relief materials in order to avoid the creation of other hazards.

2.10.1.2 Requirements and recommended practices for relief systems on LPG equipment are discussed in 5.1.6, 6.6.3, 6.6.4 and A.1.5 in API Standard 2510.

2.10.1.3 In considering sizing of pressure relief protection for LPG storage vessels, the two most important contingencies are fire and overfilling. The potential for each of these contingencies should be evaluated, and the relief valve should be sized for the larger of the two relief flow requirements. Operationally, overfilling presents the greatest risk, but the design pressure of some storage facilities can be sufficiently high to prevent overpressure from the fill system.

2.10.1.4 When relief valves discharge directly to the atmosphere, as is common in most storage installations, release of liquid LPG to the atmosphere is an unacceptable situation. The resultant formation of large vapor clouds can cause flammable vapors to spread over wide areas and possibly reach an ignition source. Either the discharge from such relief valves must be tied to a closed disposal system (see 2.10.3), or positive design (see 2.9.1) or operational steps (see 3.3.2) must be taken to guard against overfill.

2.10.1.5 If positive design or operational steps are taken to prevent overfill, it is acceptable to discharge pressure relief valves directly to the atmosphere. In many cases no flare or closed disposal systems are available. Relief valves and discharge systems must be adequately designed with equal importance given to sizing both the valve and the discharge piping. When the releases go directly to the atmosphere, the provisions of 2.10.2 must be considered.

2.10.2 ATMOSPHERIC RELIEF SYSTEMS

2.10.2.1 Either design or operational steps or both must be taken to ensure that liquid will not be released as a result of overfilling. Reliable gauging and high-level instrumentation are essential. Operator awareness of the high risks associated with liquid overfill and resultant attention to filling operation precautions are also essential. Means of rapidly interrupting the filling operation by remote or automatic shutdown of pumps on fill lines should be considered (see 5.1.5.5, 5.1.6.5.2, and A.1.3 in API Standard 2510).

2.10.2.2 Assuming only vapor release, the discharge stack should point vertically and be in accordance with 5.1.6.5 in API Standard 2510 and API Recommended Practice 521. Dispersion calculations affirm that vapor release from relief valves with this arrangement will be diluted below the flammable range while still within the jet momentum release plume (see API Recommended Practice 521). A release will not create wide area flammable clouds at grade as long as the exit velocity of the vapor is 100 feet per second or more and there is no liquid carryover into the discharge. Also, should the release be ignited in a fire, the burning plume will not impinge on any other equipment to cause localized failure. The radiant heat to the vessel may be sufficient to raise the metal temperatures to dangerous levels; therefore, application of water to the top of the vessel may be advisable for prolonged releases that have ignited.

2.10.2.3 Weep holes are normally provided in the bottom of the discharge stack elbow to avoid buildup of water, which could be frozen by atmospheric temperature or by autorefrigeration from leaking liquid (see 5.1.6.5.4 in API Standard 2510). Vapor released from these weep holes when the valve is blowing, if ignited in a fire, could cause localized overheating on the vessel surface or nearby piping where the jet impinges. The normal remedy is to provide a 90 degree elbow in the weep holes so that any vapor jet release will not impinge on any vessel or piping. Small weep holes (3/8-inch in diameter) will limit the release rate and minimize the potential for jet flame impingement. Attention must be given to keeping these weep holes open. Rust readily forms in the stacks that discharge to the atmosphere, and will plug these holes if they are too small. Severe plugging problems exist where attempts are made to run small piping from weep holes to the side of the vessel or to grade.

2.10.2.4 The vertical stack from the valve should be supported independently of the valve. Otherwise, the flow reaction forces can impose stresses on the valve discharge flange resulting in flange leakage. This could result in flame impingement problems if the leakage were ignited. For the same reasons, all bolts should be installed in the discharge flange of the valve.

2.10.2.5 Metal caps or hinged covers placed over the discharge stacks to prevent entry of rain or snow into the stack should be avoided. Hinged connections can rust and prevent full opening during safety release, thus creating high back-pressure and severely reducing valve capacity. Likewise, metal caps can freeze in place with the same consequences. Loose-fitting plastic caps may be used. In any case, attention must be given during winter weather to ensure that freezing in the outlet does not occur. Even with a cover, a weep hole must be provided.

2.10.3 CLOSED RELIEF SYSTEMS

2.10.3.1 A closed relief header collects relief valve discharges from LPG storage vessels and routes them to a flare system. Any liquid that might be released in case of an accidental overfill can be retained within the discharge header system to be recovered or allowed to vaporize to the flare and safely burn.

2.10.3.2 When a closed discharge header is used, it should be recognized that overpressure protection for the storage vessels is dependent on the design capacity of the header. The header must never become restricted or blocked by damage as a result of fire or explosion; these conditions also cause the storage vessels to overpressure.

2.10.3.3 The other design features covered in 2.10.3.3.1 through 2.10.3.3.5 should be taken into account.

2.10.3.3.1 The piping must not have any low spots or traps from the relief valve outlet flange to the blowdown or collecting drum where liquids will be removed. Trapped sections in the piping can accumulate water, with the associated freezing or hydrate problems causing blockage of these relief systems. In addition, moisture accumulations can cause severe internal corrosion problems, including accumulations of rust and scale. Also, liquids accumulated in trapped sections can be accelerated down the line by expanding vapor during a relief valve discharge with resultant relief header damage or failure from surge or water hammer problems.

2.10.3.3.2 The materials of the discharge piping and liquid collecting drums should be able to withstand shock-chilling associated with flashing light-hydrocarbon liquid without the risks of metal embrittlement and spontaneous rupture.

2.10.3.3.3 The pressure drop through the relief system to the disposal point must be adequately analyzed during design to avoid excessive back pressure on the pressure relief valve. See API Recommended Practice 520 and Recommended Practice 521 for back pressure limitations for conventional spring-loaded relief valves. Higher built-up back pressure on such valves can severely reduce capacity and cause equipment damage from relief valve chatter. But where higher pressure is unavoidable, bellows valves or some pilot-operated valves are acceptable. If bellows valves are used, the bonnet vent holes must be maintained open and oriented, or fitted with short elbows to prevent venting gases from impinging on the nearby vessel or piping in case of bellows failure. Because of the variety of pilot-operated valve designs, their uses and possible limitations should be reviewed with the manufacturer.

2.10.3.3.4 If more than one storage vessel relief is connected to a closed system, the common discharge header should be sized for the combined fire exposure of all vessels that may be involved in the same incident. In some cases, this may include all vessels at the storage area (see A.1.5 in API Standard 2510).

2.10.3.3.5 A safety analysis evaluating realistic incidents that may result in a storage vessel relief valve discharge with consequent damage restricting or blocking the common header should be considered. Where this risk is found unacceptable, a second full-capacity relief valve may be installed on each vessel. This back-up relief valve should be vented to the atmosphere, and be set to a slightly higher pressure to ensure overpressure protection under all fire emergency conditions without the danger of venting to the atmosphere during operational upsets.

2.10.4 RELIEF VALVE TESTING

2.10.4.1 It is important that all pressure relief valves be shop-tested on a periodic basis to ensure their continuing reliability. Refer to API RP 576 which provides information on testing procedures, and a basis for establishing test frequencies.

2.10.4.2 In order to allow the isolation of relief valves for testing and servicing without shutdown of the associated storage vessel, block valves are allowed by the ASME Code on the inlets to pressure relief valves and on the outlets where closed system discharge is involved (see 5.1.6.4.5 in API Standard 2510). With block valves, and with some three-way valves, care must be taken to ensure that the block valve is not left in a partially-open position. A partially-closed block valve can cause severe relief valve flow restrictions due to inlet or outlet high pressure drop. Also, mechanical failures or foreign objects may prevent the valve from opening completely. Radiography can be used to verify that a valve is in its fully open position prior to placing a storage vessel into service.

2.11 Vapor Depressurizing Systems

2.11.1 Generally, vapor depressurizing systems appear to have very limited application in LPG storage. Vapor depressurizing can be used to reduce the storage vessel pressure under emergency conditions. For information on this method of protection see API Recommended Practice 521.

2.11.2 Vapor depressurizing systems should be carefully evaluated, particularly under fire emergency conditions, before deciding to install them on LPG storage vessels. The reason for concern is that vapor depressurizing lowers the liquid level as the contents are vaporized by depressurizing. The lower the liquid level, the more shell surface area is exposed above the level of the liquid contents. This factor increases the risk of overheating the shell, which can lead to catastrophic failure unless the pressure is reduced quickly to a level where stress rupture is not of immediate concern.

2.11.3 API Recommended Practice 521 suggests that a depressurizing system be sized to depressurize a storage vessel within 15 minutes during fire exposure. For this method of protection to be effective under the worst case condition, the calculations for sizing the depressurizing system should be based on the vapor generated from adiabatic autorefrigeration plus the vapor generated by fire-heat-input from the maximum reasonable fire exposure. This may, in some cases, be total flame envelopment of the vessel. Such a situation can result in large depressurizing rates requiring a large-size depressurizing system.

2.11.4 The depressurizing system should be designed to prevent liquid entrainment and to handle the low temperatures encountered during rapid vaporization of the liquid contents safely. It is also necessary to decide if the depressurizing system instrumentation should be designed to fail open, fail closed, or fail in position. The consequences of each design as well as the safe disposal of the depressurizing vapors should be carefully considered before a decision is made.

2.12 Loading Trucks and Rail Cars

The design considerations and requirements covered in 2.12.1 through 2.12.8 supplement API Standard 2510. For additional information, see API Standard 2510, Section 7.

2.12.1 Piping and equipment used for loading LPG should be of high-melting-point material such as steel. Materials that do not retain adequate strength, or melt at temperatures attained in a fire shall not be used. An exception to this is in the case of materials used for hose or swivel joint seals for the transfer of LPG between the fixed piping and a truck, rail car, or marine vessel (see 7.5 in API Standard 2510).

2.12.2 If there is a reinforcing wire within LPG loading hose it should be in electrical contact with the end couplings on the hose to minimize the risk of an electrostatic charge collecting on an electrically isolated wire within the hose or on the exterior of the hose. This is to reduce the chance of a charge becoming sufficiently great to spark from the hose wall, or from a section of the reinforcing wire which may become exposed by hose wear or damage, to the nearest conductive surface. Intermediate joints or couplings in a nonconductive hose should not be permitted because they can accumulate a charge sufficiently great to spark to an adjacent conductive object.

2.12.3 Transfer hose or swivel pipe should be equipped with a shutoff valve at the discharge end to minimize vapor escape when the hose or pipe is disconnected after product transfer. This protects the loader from exposure to vapor and reduces the risk of fire. The valve should have a pressure rating at least that of the hose or swivel pipe, but need not be fire resistant. A pressure relief valve must be installed to protect against liquid thermal expansion pressure buildup in the transfer hose or pipe.

2.12.4 When the diameter of the loading/unloading hose or swivel pipe is less than the size of the truck or rail car connection, the adapter to which the hose or swivel is attached should be equipped with a backflow check valve, a properly sized excess flow valve, or a shutoff valve with a method of remote-closing to protect against uncontrolled discharge from the truck or rail car. This requirement is important, for if an LPG transfer line is ruptured or torn away, the existing excess flow valve in the truck or rail car piping might not function as designed because of the smaller-sized transfer line. This requirement does not apply if the truck or rail car is equipped with a quick-closing internal valve that can be remotely closed.

2.12.5 Vapor return lines should have check valves installed to prevent backflow of vapor.

2.12.6 Drainage should be designed to drain spills to a safe area, away from the loading positions. It is important to locate catch basins so they are not under any portion of the truck or rail car. Catch basins should be equipped with water seals to prevent migration of vapor from the drain system, and the drain system must be designed for LPG.

2.12.7 The loading rack area must be designed so that each loading spot is relatively level to prevent the truck or rail car relief valve connection from being submerged, thus causing a liquid pressure release.

2.12.8 Truck loading racks should be located and designed so that the possibility of a truck hitting LPG pipe or equipment is minimized.

SECTION 3—OPERATING PROCEDURES

3.1 Introduction

3.1.1 The key to overall safety in any phase of petroleum operations, including pressure storage, is knowledgeable, well-trained operators. Some industry statistics have shown that about 66 percent of all fires are the result of failure to follow proper operating procedures. Thus, it is imperative to establish sound operating practices. Clear operating instructions should be prepared covering normal as well as emergency situations. Each facility is unique in its location, design, and personnel and should be evaluated individually to understand and control potential risks. These instructions should be reviewed at reasonable intervals to ensure they are up-to-date. There must be periodic training to ensure that the operators fully understand these instructions so that the facilities can be operated safely.

3.2 Placing Storage Vessels in Service

3.2.1 Liquefied petroleum gas storage vessels contain air after initial construction and after internal inspection and repairs. In general, it is preferable that the LPG storage vessel be pressurized before filling it with any significant quantity of liquid LPG. Otherwise, the liquid LPG will initially vaporize and refrigerate to its boiling point at the prevailing pressure, which could possibly cause brittle failure of the vessel or piping if the metals involved are not suitable for the low temperature. The minimum pressurizing temperature for the vessel shall be taken into consideration before the vessel is pressurized (see API Publication 920 and the ASME Code, Section VIII). Several alternative methods to put vessels into LPG service are described in 3.2.2.1 through 3.2.2.4. Use whichever method is most convenient based on the guidelines of 3.2.2.

3.2.2 For vessels that are to be hydrotested, the method in 3.2.2.1 is preferred. For vessels that must vent noncondensable gases and vapors to a blowdown system, either of the methods in 3.2.2.1 or 3.2.2.2 is preferred. For vessels that can vent noncondensable gases and vapors to the atmosphere, any of the methods given below may be used. During initial pressurization and filling, the system should be carefully checked for leaks. Check for proper functioning of all instruments and piping components. Use of a prestartup safety checklist is suggested.

3.2.2.1 Fill storage vessel with water to displace all air. Then displace water with LPG vapor, which is usually backed-in under pressure from another vessel. The LPG vapor should be supplied at a rate sufficient to maintain a positive pressure on the vessel. The pressure should be measured at the top of the vessel. When the water has been drained, pressurize the vessel with LPG vapor before bringing in liquid LPG.

3.2.2.2 Fill the storage vessel with an inert gas such as nitrogen; then pressurize the vessel with LPG vapors backed-in from another vessel. When liquid LPG is brought into the vessel, it will be necessary to monitor the vessel pressure carefully during filling, and to vent the mixture of LPG vapor and noncondensable inert gas as necessary to avoid popping the vessel relief valve. Vent LPG vapors in a safe manner or follow the procedure given in 3.2.2.3.

3.2.2.3 Pressurize the air-filled vessel with LPG vapor backed-in from another vessel to bring the atmosphere quickly through the flammable range and make it too rich to burn. This procedure is safe, since there are no ignition sources within a storage vessel. When filling with liquid LPG, it will be necessary to monitor the vessel pressure and to safely vent the mixture of LPG vapor and air as necessary to avoid lifting the vessel relief valve. The vented mixture should be above the UFL, but will rapidly disperse as a result of the jet effect of the venting stream in cases where it is vented to the atmosphere. Venting to the atmosphere is preferred. If the mixture must be vented to a flare or incineration system, it is essential that the mixture not be in the flammable range. Flammable mixtures can occur as a result of incomplete mixing of dense vapor or, particularly with butane, when a previously overrich mixture enters the flammable range through compression of a mixture containing vapor that condenses at the higher pressure.

3.2.2.4 Liquid LPG may be brought directly into an air-filled storage vessel, provided that adequate consideration is given to the autorefrigeration temperature of the liquid LPG as it initially vaporizes in the bottom of the vessel at atmospheric pressure. The primary concerns are as follows:

a. Does the metal of the vessel shell lose adequate ductility at this temperature as determined by the minimum pressurizing temperature of the vessel?
b. Does localized refrigeration in the bottom of the vessel cause excessive stress due to differential thermal contraction? Generally, these concerns are much greater with propane (-44°F boiling point) than with normal butane (+31°F boiling point) because of the much lower autorefrigeration temperatures encountered.

A suggested filling procedure is as follows:

a. Introduce successive small quantities of liquid LPG into the storage vessel, interspersed each time by waiting periods for temperature equalization.

b. Monitor the temperature of the vessel shell bottom and the pressure in the vessel to ensure that the minimum pressurizing temperature limitations are met.

As in the procedure 3.2.2.3 the atmosphere in the vessel will pass through the flammable range and becomes too rich to burn. It will be necessary to monitor the vessel pressure during filling and to safely vent the rich mixture of LPG vapor and air as necessary to avoid lifting the vessel relief valve.

3.3 Product Transfer

3.3.1 GENERAL

One aspect of LPG operations that involves risk is the transfer of products. This risk includes hazards such as tank overfill, tank overpressure, product contamination, and transfer hose failures (ruptures/leaks).

3.3.2 TANK OVERFILL PROTECTION

3.3.2.1 One of the first steps in controlling transfer is to verify that the product is going to the proper storage vessel or other destination. Clear labeling of piping and valves is a logical step in preventing operating mishaps due to wrong routing of product. Incidents have occurred in which, through improper valve alignment, product routing to the wrong storage vessel has led to overfills. Also, sending high-vapor-pressure liquids to a vessel intended for lower-vapor-pressure stocks can lead to rapid pressure rise and large vapor release or overpressure. There should be a control step early in all transfer operations to verify that the product is actually being routed to its intended destination. See the level gauging information in 2.9.1 of this publication and 5.1.2 and 5.1.3 in API Standard 2510.

3.3.2.2 During actual filling, it is good practice to include periodic level checks to confirm that the filling rate is proceeding according to the forecast conditions. Operator attention to local or remote gauge readings, or computer level-check programs may be used to accomplish this surveillance. Although high-level alarms or shutdown instrumentation may be provided as part of the overfill-prevention equipment, they should be used only for emergency protection and not as the normal means of controlling and monitoring filling operations. The operators, not emergency level instrumentation, should be in control. Clear, enforced procedures provide the best chance of avoiding mishaps.

3.3.3 TANK OVERPRESSURE

Other contingencies that can arise during transfer of product from process units include (a) pressure buildup because of accumulation of or noncondensable gas in the vessel, (b) the introduction of off-specification product, or (c) cross-contamination caused by improper valve alignment or closure. Regular checks of vessel pressure can help to identify some of these hazardous conditions before they fully develop. Adequate shutdown devices or isolation valves in the transfer system must be used to allow operators to handle such contingencies properly, should they occur.

3.3.4 TRANSFER HOSE PRECAUTIONS

Transfer hoses must be inspected and hydrostatically tested before being put into service and at regular intervals during their service lives. Test intervals may vary from 6 months to 1 year, or at any time their physical condition indicates deterioration (see 7.5.1.3.3 in API Standard 2510). Hoses may be conductive or nonconductive and should be of one continuous length without intermediate joints or couplings.

3.3.5 LOADING TRUCKS AND RAIL CARS

3.3.5.1 If the transport equipment is not used exclusively for a particular type of LPG, loading should not start before a check has been made to determine if any liquid remains in the transport equipment. This can be done safely after the loading hose or pipe has been connected by venting to the loading hose vent system, provided it is designed for some retained liquid.

3.3.5.2 A visual inspection of trucks and cars should be made before loading to detect obvious problems with their structural integrity and to confirm there is no evidence of leakage.

3.3.5.3 The truck or rail car should be filled so there is room for thermal expansion of the liquid without excessive pressure buildup that could result in venting liquid. For additional information regarding this, see 7.8 of API Standard 2510.

3.3.5.4 Care must be taken so that containers are not overpressured during filling. A vapor-return line to vent the receiving container back to the container being emptied, or another means to prevent overpressure is needed.

3.3.5.5 Safe loading instructions should be posted at the loading facility.

3.3.5.6 Loading hoses or swivel pipes should be vented to reduce pressure before connecting or disconnecting.

3.3.6 UNLOADING TRUCKS AND RAIL CARS

3.3.6.1 Before unloading trucks and rail cars, the shipping notice should be checked to be certain that the correct quantity and type of product is in the container. The receiving tank should be checked to be sure there is room to receive the cargo without overfilling the tank.

3.3.6.2 During cold weather, the temperature in a truck or rail car may drop below 31°F. Below this temperature, normal butane vapor pressure will be below atmospheric pressure, and unloading may be difficult. Air shall not be used to pressure the container. Nitrogen can be used if safeguards are taken to ensure the container is not overpressured. The container shall not be artificially heated by direct flame contact to increase the temperature and vapor pressure of the liquid contents.

3.3.7 SAFETY CONSIDERATIONS FOR RAIL CARS

3.3.7.1 Warning signs or safety devices should be placed at the active ends of the rail siding.

3.3.7.2 Wheels should be chocked to prevent car movement.

3.3.7.3 A derail device should temporarily be placed near the beginning of the spur to protect the tank cars at the rack from an errant car or locomotive.

3.4 Water Drawing

3.4.1 Water can accumulate under certain conditions in LPG storage vessels and must be removed for product quality reasons. Also, in freezing climates, ice formation in bottom connections can rupture piping and lead to major LPG releases. Thus, facilities must be provided and procedures established to safely handle water drawoff.

3.4.2 Within process areas, water drawoff is often done through closed systems, which in some cases are under automatic control. Such water-removal facilities are not usually available in storage areas, and the drainage of the water to the ground or open drainage system connections are common practice. The drainage system must be capable of safely handling LPG.

3.4.3 See the water-drawing system information in 2.7.2 in this document and 6.7 and A.1.6 in API Standard 2510.

3.4.4 Considering the potential risk associated with improper handling of water removal, a detailed written procedure should be prepared and followed. The operator must be in continuous attendance at the valves during this entire process. The procedure outlined in 3.4.4.1 through 3.4.4.3 is recommended.

3.4.4.1 With the outside valve closed, fully open the inside valve.

3.4.4.2 Open the outside valve slowly to establish water flow at a reasonable rate.

3.4.4.3 When visual indication of LPG entrainment with water occurs, shut the outside valve first and then close the inside valve.

3.4.5 If a nonfreeze drain is provided, as shown in Figure 2, perform the following procedures:

a. Fully open the inside valve 2 and then throttle with the outside valve 1.

b. After water has been drawn, close the outside valve 1 and open valve 3.

c. Allow a few minutes for any water displaced in the water-draw manifold to drain back to the vessel and then fully close valves 2 and 3.

3.5 Sampling

3.5.1 When sampling, there is a potential for release of LPG vapors. At each location a careful review is needed to establish proper procedures and suitable storage for the particular samples required from the standpoints of quality control and safety. The specific procedures for each type of sampling are beyond the scope of this document, and reference should be made to other available information such as the API *Manual of Petroleum Measurement Standards*.

3.5.2 Some points for consideration in reviewing the safety of sampling facilities and procedures at each installation are covered in 3.5.2.1 through 3.5.2.6.

3.5.2.1 See A.1.2 in API Standard 2510 regarding sampling connections.

3.5.2.2 Hoses are often used for flexibility and ease of hookup. Hoses of proper type and pressure rating must be employed. They should be electrically-conductive to prevent a sample container accumulating an electrostatic charge during sampling; or, the container should be bonded to the piping. They should also be inspected frequently to identify defects and any developing failure points.

3.5.2.3 The piping for sampling should be double-valved with one valve at the sample source takeoff point. A second valve, separated from the first valve by at least 6 inches, should be installed to protect against autorefrigeration icing, leakage due to improper connection, or atmospheric release at the sample attachment point. Both valves should be within easy reach of the operator.

3.5.2.4 Wherever possible, the sample container connection point should be out from under the vessel so that release and fire will not impinge directly on the vessel.

3.5.2.5 When displacement or flushing of the sample containers is required before taking the sample, care must be taken in selection of the disposal point. It should be away from the operator to avoid exposure to released vapors. Also, ignition sources in the area must be avoided.

3.5.2.6 Sample containers that do not incorporate floating pistons have specified maximum liquid-fill levels. These levels are specified to avoid failure caused by liquid expansion when samples are brought into laboratories or other buildings for analysis. Proper filling procedures, usually including use of built-in dip tubes, are needed to allow for this expansion.

3.6 Venting Noncondensables

3.6.1 Noncondensable gases, including air, can enter a vessel through a variety of means, including the following:

a. Dissolved or entrained gases from processing, such as sweetening.
b. Operation of vacuum breakers.
c. System leaks while under vacuum.
d. Air or inert gas in a vessel when it is put into service.
e. Vapor-return lines from trucks or rail cars that contain air or inert gas prior to loading.

3.6.2 These gases may cause the relief valve to operate when the liquid level is subsequently raised and the noncondensable gases are thereby compressed.

This problem can be prevented by periodically venting the vapor space to remove noncondensable gases. Criteria can be developed to vent the space when the oxygen concentration exceeds a specified value, or when the headspace pressure exceeds the product vapor pressure by a specified amount. The vapor space should preferably be vented to the atmosphere. If regulations require venting to a flare system, then caution is necessary, since the vented gas may contain air. In these cases, precautions must be taken to prevent sending a flammable mixture to the flare.

3.7 Removal of Vessel from Service

3.7.1 See 4.4 of this publication on vapor-freeing and isolating of LPG storage tanks. The general procedure for removing a vessel from service is as follows:

a. Pump out all liquid.
b. Close all isolating valves nearest the vessel.
c. Depressurize in a safe manner. Depressurize first to the flare (if available); then vent to the atmosphere.
d. Blind all connections except those needed for the purging operation.
e. Gas-free (purge) the vessel to below the LFL and verify the purging with a gas test.
f. Complete blinding of all piping connections.
g. Open manways.
h. Reconfirm that vessel contents are below the LFL.
i. Obtain necessary work permits.

3.7.2 Before entering an LPG storage tank, written policies covering work in confined spaces should be established. API Publication 2217 should be reviewed in this regard.

3.8 Emergency Procedures

3.8.1 The primary emphasis of this section has been on the establishment of sound practices in LPG storage operations to forestall the development of risk situations. Each of the subsections on product transfer, water drawoff, sampling, and venting of noncondensables covers procedures that can lead to unwanted LPG releases to the atmosphere if improperly performed. Although avoidance of such risks is of prime importance, emergency situations may still occur. Effective pre-emergency planning and the use of written emergency procedures at each location for each potential emergency can significantly reduce any adverse impact on plant personnel and neighboring properties. Pre-emergency planning enables thoughtful analysis of each contingency under unstressed conditions and helps to assess the adequacy of the existing organization, personnel, and equipment. Testing a plan using training exercise or drills is an important part of pre-emergency planning.

3.8.2 A major concern associated with LPG storage is accidental LPG release to the atmosphere. Whether or not these releases are ignited, the principle considerations in emergency planning must be as follows:

a. What steps should be taken to terminate the release?
b. What should be done to disperse a vapor cloud to minimize the exposure to personnel, facilities, or the community?

3.8.3 Some of the contingencies that might be addressed in the written emergency procedures are listed below along with considerations appropriate to each situation:

a. *Fire*. See Section 6 for fire control and extinguishment procedures.
b. *Overfilling*. Are high-level instruments installed to warn of an imminent overfill condition? Can flow be shut off, or will rapid closing of valves cause surge or overpressure elsewhere in the transfer system? Are adequate shutdown and isolation valves available to rapidly stop or divert flow? What is necessary to avoid overpressure when flow is stopped?
c. *High vessel pressure*. Is high pressure caused by accumulation of noncondensables? Can they be safely vented? Could high pressure be temporarily reduced by pump-out from the vessel or by cooling the shell of the vessel with water spray? Is depressurizing by venting possible? Are unit rundown temperatures too high, causing the LPG vapor pressure to be too close to the pressure relief valves set pressure? Has cross-contamination occurred with a higher vapor pressure liquid?
d. *Pressure relief valve leakage*. If high vessel pressure is the cause of pressure relief valve leakage, see the previous item. If vessel pressure is less than 90 percent of pressure relief valve set pressure, can the block valve under the relief valve be closed and immediately reopened to see if the relief valve closes?

CAUTION: This should not be done when any transfers are being made. Can the vessel be vented or pumped out to lower the internal pressure?

e. *Ice plugs in water draw*. Is the primary root valve available and accessible to shut off the line? Could water be injected into the vessel to flood the vessel bottom and stop the LPG release, and thus permit the ice to thaw so the root valve can be shut off?

f. *Flange leak or piping failure*. Is a valve available to isolate the leak? Would water-flooding of the vessel displace LPG and convert the LPG leak to a water leak? Could a water jet be useful in dispersing vapor until the system is depressurized? Can the vessel be depressurized by venting in order to reduce the leak rate?

g. *Transfer pump failure and LPG release*. Can the suction side be readily isolated from the supply vessel? If the pump has a long discharge line, can the discharge valve be closed to stop the release? Check valves may leak and LPG may continue to back flow until essentially all liquid in discharge piping has vaporized.

SECTION 4—MAINTENANCE PROCEDURES

4.1 Introduction

This section presents good preventive maintenance practices intended to forestall the uncontrolled, sudden release of LPG from a storage vessel, piping, or associated equipment. Inspection and maintenance of LPG storage vessels shall be in accordance with applicable codes, standards, and regulations.

4.2 Vessel Inspection

4.2.1 An LPG storage vessel should be inspected periodically for external and internal corrosion or other distress that may increase the risk of leak or failure. LPG is normally a clean, noncorrosive product, so the interval for internal inspection can be several years and should be determined by corrosion history or on-stream inspection techniques. Refer to API 510 for guidance.

4.2.2 There should be ready access to the shell exterior for on-stream inspection. If the vessel is covered with thermal insulation or other material that inhibits external inspection, access to the shell should be provided at a sufficient number of locations to enable determination of the vessel's condition. If the shell's protective coating is impervious to moisture penetration, it is not necessary to remove portions of the coating for inspection; however, periodic visual inspection of the coating is required. Records of vessel inspection should be maintained.

4.3 Vessel Accessories, Including Relief Valves

4.3.1 Instrumentation to monitor and control LPG storage vessels for safe operation should be maintained, serviced, and tested periodically, since the failure or malfunction of instruments can result in overfill or other conditions that may lead to release of LPG to the atmosphere. It is good practice to keep records of alarm checks or other tests of critical devices or systems.

4.3.2 Relief valves, vapor depressurizing systems, emergency shutoff valves, critical backflow check valves, or other equipment to prevent or control the accidental release of LPG should be tested and serviced periodically. The frequency of testing and servicing will depend on the type of device or system, the risk associated with failure or malfunction, and the history of trouble with the device or system. Proper working condition must be assured for safe operation (see API RP 576).

4.3.3 Valves used to isolate instrument and safety devices from the vessel should be maintained in good condition so that preventative maintenance or repairs may be performed without removing the vessel from service. A procedure must be in place to ensure that the isolation valves are in the open position during operation. This can be by means of locking devices, check lists, tagging procedure, and so forth.

4.4 Vapor Freeing and Isolating Equipment

4.4.1 Equipment and tanks in LPG service should be isolated positively from piping systems or other sources of ignitable vapors and liquids and be vapor-freed prior to entry, weld repairs, or other work that may introduce ignition sources to the interior of the tank or equipment. Ignition sources must be controlled when preparing equipment for repair and when opening flanges for blinding, depressurizing, and vapor-freeing. Equipment to be repaired may be removed from an LPG storage or handling area prior to performing any hot work (work that introduces ignition sources) in order to reduce risk of ignition should an unrelated incident release LPG.

4.4.2 When equipment removal is impractical, as in the case of repair work to a vessel, other precautions should be taken to guard against unexpected LPG release or ignition should a release occur. These precautions may include increased operator surveillance, discontinuing LPG transfer into adjacent tanks during hot work, or additional vapor detection and alarm devices in the area between hot work and potential vapor sources.

4.5 Work Permits

When a tank or equipment is determined to be vapor-free and safe for entry or hot work, a work permit should be issued. The work permit should include verification that the equipment is free of vapor and that the work may safely be performed, the type work for which the permit is issued, and all safety precautions or limitations that are required, including control of ignition sources.

4.6 Repair of LPG Equipment

4.6.1 Repair work to pressure vessels, piping, or other equipment that was constructed under the provisions of a specific code should conform to the relevant edition of the applicable code.

4.6.2 When preparing for maintenance work on equipment in LPG service, see API Publication 2015.

4.7 Fireproofed Surfaces

4.7.1 To reduce the risk of structural failure from hidden corrosion or the risk from fire because fireproofing was loosened or damaged by underlying corrosion, all fireproofed surfaces should periodically be inspected. Openings or cracks that may allow moisture to enter and reach the surface of the protected metal should be repaired or caulked. On vertical surfaces, such as legs for spheres, a drip stop or flashing should be provided at the top edge of the fireproofing to prevent water from entering between the fireproofing and the protected metal.

4.7.2 Visual inspection is normally sufficient to detect areas of underlying corrosion. When such areas are identified, the fireproofing should be removed and repairs made as appropriate. The repaired area should be repainted with a corrosion-preventive material, and fireproofing should be reapplied.

SECTION 5—FIRE PROTECTION DESIGN CONSIDERATIONS

5.1 Introduction

5.1.1 This section addresses fire-protection design considerations for minimizing fire damage at LPG facilities once a fire occurs, whereas the preceding sections address the prevention of releases that may lead to fire. Water is the primary means of fire protection for LPG storage facilities.

5.1.2 The degree of fire protection needed will be affected by several factors. Remotely-located facilities may need less protection than major facilities in developed industrial areas or populated areas. firewater may not be needed for remote facilities, assuming that loss of the facility is an acceptable risk.

5.1.3 Remotely-located facilities are those that have few exposure risks within 4000 feet. This criterion is based on experience and reports of past incidents[9] that have demonstrated that vessel fragments, vapor travel, and damaging blast overpressure are extremely unlikely beyond 4000 feet. Locations without this clear zone may also be considered remote if this determination is made through a safety analysis.

5.2 Water-Application Rates

5.2.1 Vessels exposed to external fire can fail through overpressure if inadequate pressure relief is available or through metal failure caused by excessive shell metal temperature. The maximum pressure load on an LPG storage container usually occurs when a vessel, fully involved in fire, is filled to a level at least as high as the maximum elevation at which direct flame impingement occurs. Maximum metal temperatures, on the other hand, occur when the liquid level is below the maximum flame height and flames impinge directly on portions of the vessel wall that are not internally wetted by the liquid contents.

5.2.2 The effect of fire on spheres or drums is predictable. If no fire protection is available, or that which is available is not used or is inoperable, the vessel will probably fail in a prolonged fire. This failure, usually from excessive metal temperatures, can occur within a few minutes if the initial liquid level is significantly below the maximum flame height and the flames impinge on the shell. Water applied to the outside of a vessel exposed to an external fire serves the following two purposes:

a. The volume of vapor that must be vented by the pressure relieving system is reduced, and the peak pressure developed in the given relief system may be somewhat lessened. (API Recommended Practice 520 does not allow credit for this factor in sizing the relief valve or system.) The application of water also reduces product loss during a fire; and the risk of direct flame impingement on metal unwetted by the liquid contents is somewhat reduced.

b. Application of water in sufficient quantity can prevent vessel failure due to excessive metal wall temperatures even in an empty, or nearly empty vessel.

5.2.3 The minimum required water-application rate is that necessary to satisfy the second objective, namely, to protect an empty or nearly-empty vessel from failure due to excessive metal wall temperatures caused by flame impingement on the vapor space of the vessel. Additional water may be provided

[9] "Analysis of the LPG Incident in San Juan Ixhuatepec, Mexico City, November 19, 1984," TNO, Netherlands, May 6, 1985.

if it is considered desirable to limit heat input even further to reduce the amount of vapor that must be vented through the relief valve on a full or partly-full vessel.

5.2.4 See 3.3 in API 2510 for the minimum required water-application rates. The justifications for higher application rates in special situations are discussed in 5.2.5, 5.2.6.2, and 5.2.6.3. The water-application rates discussed herein are based upon the following:

a. Vessel shell surfaces receiving more than 7000 British thermal units per hour per square foot will require cooling to prevent overheating and loss of strength (see Figure 1).
b. The surface area of the vessel that may be exposed to fire is the surface area of the vessel above the level of the liquid contents at the vessel's lowest operating level.

5.2.5 A water-application rate of 0.1 gallon per minute per square foot is adequate for cooling needs in many fire-exposure situations. If there is concern or risk of a vessel being fully engulfed by flame because of its location, piping configuration, or impounding or drainage design, supplemental cooling streams should be provided, or the application rates should be increased to 0.25 gallon per minute per square foot. Water rates above the minimum of 0.1 gallon per minute per square foot may also be required if a substantial portion of one side of a vessel is subjected to direct flame impingement. The required rate should be determined on a case-by-case basis using realistic fire-exposure scenarios.

5.2.6 Three basic fire emergency situations that deserve special consideration are shown in Table 4. They are listed in increasing order of severity. Additional information and explanations of water-application rates for each case are in 5.2.6.1 through 5.2.6.3.

5.2.6.1 Radiation From Fires Without Direct Flame Impingement

5.2.6.1.1 Both distance from the fire, and the extent to which the vessel is surrounded by fire, affect the amount of radiant heat received by the vessel. If the fire is not directly beneath the vessel, less water is required for protection. If the fire is remote enough, little or no water is needed except for product conservation, if desired.

5.2.6.1.2 When evaluating whether or not cooling-water is needed for a storage vessel, the decision should be based on (a) the amount of radiant heat it will receive from an adjacent fire of a given diameter; and (b) the maximum temperature that the unwetted shell will reach if it is not cooled. Conservative estimates can be made using Figure 1. Figure 1 allows a determination of the distance between the vessel and the center of the pool fire at which the maximum incident heat flux to the vessel shell surface will be at the critical value of 7000 British thermal units per hour per square foot for a propane pool fire of a given diameter. Therefore, the spacing distances obtained from Figure 1 can help to decide if the application of cooling-water is necessary, or if it can be delayed until a relief valve lifts. The vessel can still be considered in a safe condition with the relief valve venting, since the shell metal temperature will be below the threshold for *stress creep rupture*—the bulging, thinning, and consequent rupturing of the shell.

5.2.6.1.3 The procedure for using Figure 1 to calculate spacing distances is described below. The analysis considers the radiant heat from a propane pool fire with a 20-mile-per-hour wind blowing directly toward the subject vessel. Under these conditions, an incident heat flux of 7000 British thermal units per hour per square foot upon the vessel will result in a maximum shell temperature of 800°F. It is assumed that the shell is reradiating heat from only one side, that is, no heat is lost from the inside of the shell. The relief valve is sized to prevent the vessel pressure from rising more than 21 percent above the design pressure during a fire. To determine the distance between the vessel and the center of the pool fire at which cooling will become necessary for a fire of a given diameter, proceed with the following actions:

a. Locate the diameter of the pool fire along the x-axis of Figure 1.
b. Locate the point along the 7000 Btu/hr-ft^2 line in Figure 1 that is intersected by an imaginary vertical line extending from the diameter value selected on the x-axis.
c. Extend an imaginary horizontal line from the point on the 7000 Btu/hr-ft^2 line intersected by the imaginary vertical line from the x-axis. The point on the y-axis to which this horizontal line extends is the distance between the vessel and the center of the pool fire at which cooling water should be applied.
d. As an example, if the diameter of the propane pool fire is 20 feet, the distance between the vessel and the center of the pool at which cooling will become necessary is 78 feet.

Under lower wind speed conditions, allowable heat flux will decrease as a result of reduction in convective cooling

Table 4—Fire Emergency Situations Requiring Special Consideration

Fire Exposure	Water Application Rate
Exposure to radiant heat and no flame contact	0-0.1 gpm/ft^2 [a]
Exposure to fire with direct flame contact	0.1-0.25 gpm/ft^2
Exposure to a high-velocity jet flame	250-500 gpm[b] at point of jet contact

[a]gpm/ft^2 = gallons per minute per square foot.
[b]gpm = gallons per minute.

of the vessel, but the incident heat flux from the fire will decrease even faster as the wind speed is reduced.

5.2.6.1.4 The spacing determined using Figure 1 is conservative for the following reasons:

a. It assumes the wind is blowing directly toward the vessel.
b. This chart is based on propane pool fires, which produce longer (that is, taller) flame columns and more radiant heat flux than similar size fires of heavier hydrocarbons.
c. Calculations use the maximum incident heat flux; the average incident heat flux would be much lower.

5.2.6.2 Pool Fires With Direct Flame Impingement

5.2.6.2.1 With direct flame impingement there is greater heat input to a storage vessel. Therefore, higher water-application rates are required to control the rate of temperature rise of the liquid contents and prevent the relief valve from lifting, or the shell above the liquid level from being weakened by high metal temperatures.

5.2.6.2.2 Water-application rates should be at least 0.1 gallon per minute per square foot. This rate should only be used if the design of the storage vessel, piping, and spill containment incorporates the fire prevention features in Section 2. If the design increases the risk of full engulfment of the vessel or even substantial flame contact on one side, the application rate should be increased to 0.25 gallon per minute per square foot.

5.2.6.3 High-Velocity Jet Flame Impingement

5.2.6.3.1 The design features discussed in Section 2 are intended to minimize the risk of impinging high-velocity jet fires because effective cooling of a vessel shell that is exposed to jet flames is difficult to achieve. The velocity of the jet stream may deflect a water spray pattern or fog pattern from a fire hose. Therefore, a fixed or portable monitor is the recommended method of water application to areas of a vessel shell with a potential for jet flame impingement.

5.2.6.3.2 Application rates are based on nozzle size sufficient to overcome the effects of the jet flame. Combination fog/straight stream nozzles rated for 250-500 gallons per minute are recommended.

5.3 Methods of Water Application

5.3.1 GENERAL

There are three primary methods that may be used to apply water to LPG storage vessels exposed to fires: water deluge, fixed monitors, and water spray. In addition, portable equipment may be used but should not be considered a primary method of water application. A summary of the advantages and disadvantages of the various methods of water application is given in Table 5.

Critical in considering which method to use are the reliability and certainty of water application to the area of flame contact with a vessel shell or where severe radiant heat exposure is probable. See 8.3.2 in API Standard 2510 for additional information and requirements.

5.3.2 WATER DELUGE

5.3.2.1 A water deluge is a system in which water is applied at the top of the vessel and allowed to run down. As a result, this type of system is most effective for spheres because the vessel geometry assists in evenly distributing the water. A major advantage of this system is that it can be built from large-diameter piping that is not prone to plugging and is more likely to survive an explosion. A possible disadvantage is that soot and carbonaceous deposits may inhibit wetting of the surface, particularly on the underside of the vessel. This may require that additional water be available to protect the underside from monitors or from supplementary sprays.

Note: It is not clear how serious this wettability problem is with clean burning paraffin-type LPG. In addition, the design of the drainage system should make a pool fire under the vessel unlikely, and thus the effectiveness of water application to the underside of the vessel is not a major concern. Furthermore, the lower portion of the vessel is likely to be cooled from the vaporization of the liquid contents.

5.3.2.2 Observations in the field confirm that, under non-fire conditions at least, water follows the vessel contour very well, even below the equator of a sphere. Distribution of water over a vessel may be accomplished through use of a high-capacity spray head or heads at the top of the vessel, water distributors fashioned from perforated pipe, or by a distribution weir. *Underflow weirs* are generally more prone to clogging from debris and may require periodic inspection and flushing. *Overflow weirs* are susceptible to unequal water distribution because of tank settlement. Drain holes are needed in an overflow weir to prevent accumulation of standing water and consequent accelerated corrosion of the vessel shell. Water distribution from a weir may be less effective for horizontal cylindrical vessels, since it is difficult to ensure that the weir is level enough for equal water distribution over the vessel surface, and wind may have a greater effect on the water distribution. The effect of wind would be more severe for horizontal vessels than for spheres.

5.3.3 FIXED MONITORS

When fixed monitors are used to apply cooling water to the shell of a storage vessel, the monitors should be located within 50 to 125 feet of the vessel which is the typical effective range with a nozzle supply pressure of 100 pounds per square inch gauge. The quantity and location of the monitor must be such that water will be distributed to all parts of the vessel. The monitors must be located so they are safely accessible during a fire; or they must be remotely activated and controlled. Effective cooling of a vessel exposed to a jet

Table 5—Water-Application Methods

Water Deluge	Fixed Monitors	Water Sprays	Portable Equipment
	Advantages of Each Method		
Rapid activation Can be activated automatically Less subject to damage from vapor cloud explosions Less subject to plugging Less sensitive to wind Single valve actuation	Easily activated and directed at exposures Can be activated automatically Less vulnerable to vapor cloud explosions Quickly directs water to exposed areas Reduced water rates possible when vessel only partly exposed to fire Effective for jet (torch) fires Less subject to plugging	Rapid activation Can be activated automatically Reduces concerns about wettability and run down Less sensitive to wind Single valve actuation	Less vulnerable to vapor cloud explosions Can direct water to specific areas Reduced water rates possible when vessel only partly exposed to fire
	Disadvantages of Each Method		
Possible problems with wettability and run down May need to be supplemented with water sprays at vessel supports or pipe connections For horizontal cylinders, good water distribution may be difficult May not be effective for jet (torch) fires	Slower activation if manual Exposure risk to personnel if manually operated Affected by wind Limited reach of water stream Larger water demand for total coverage	Vulnerable to damage in vapor cloud explosions Subject to plugging, which may result in unequal application Larger water demand than needed for localized fire hazard May not be effective for jet (torch) fires	Longer time for deployment Not automatic Greatest risk to personnel Affected by wind

flame requires that the water be delivered at the specific location where the flame impingement occurs. This is best accomplished by hand-directed fixed or portable firewater monitors.

5.3.4 WATER SPRAYS

Water spray systems consist of network of water spray nozzles arranged in a grid pattern over the surface of the vessel. This type of system is more susceptible to spray nozzle plugging from scale, which can result in unequal water application. Water spray is prone to being displaced and ineffective for pressure or jet fires. Water spray systems are also more susceptible to damage from a vapor cloud explosion than deluge or fixed-monitor systems (see API Publication 2030). Hybrid deluge/spray systems in which half the water is applied through a deluge system at the top of the vessel and half through water sprays over the lower half of the vessel have also been used.

5.3.5 PORTABLE HOSE STREAMS

Portable hose streams, whether using portable monitors or handlines, are not acceptable as the primary means of water application, since they may require more time for full deployment than may be available to prevent vessel failure. Portable hose streams also require the presence of personnel near the vessel. However, portable streams can be a useful supplement to fixed systems to compensate for wind effects, for partial damage to the fixed system when extinguishing small fires, or to apply additional water to locations subject to an LPG jet fire.

5.4 Design Considerations for Water Supply

See 8.3 in API Standard 2510 for design requirements for a firewater supply system. Further guidance is given in 5.4.1 through 5.4.13.

5.4.1 A looped firewater system for LPG storage should have isolation valves provided no more than 1000 feet apart to prevent a single break in the water main causing a loss of the grid.

5.4.2 Block valves on the firewater lines for protection of storage vessels should be located outside the dike or fire wall of the vessels when a dike is provided. If no dike is present, the valve should be located where drainage and grading will prevent an LPG pool from accumulating closer than 50 feet to the valve.

5.4.3 Flame- or heat-activated devices that automatically actuate water deluge, fixed-monitor, and spray systems should be provided for unattended facilities, if warranted (see

1.5 and 5.1). The need for such devices at attended facilities should be evaluated on a case-by-case basis.

5.4.4 Remotely-activated valves should be used with full-sized manual bypass valves or be capable of manual operation, if accessible.

5.4.5 Oversized pipe shall be used in designing firewater supply systems to deliver specific flow rates, since internal corrosion and scale formation in unlined steel pipe will reduce the flow capacity over a period of time (see 8.3.1.10 in API Standard 2510).

5.4.6 Strainers with valved blow-off connections should be provided for water spray systems to minimize the likelihood of plugging spray heads. Full-sized manual bypass valves should be incorporated to permit water spray function if the strainers become plugged.

5.4.7 Activation of automatic systems should be announced by an alarm in an attended location.

5.4.8 Water application systems should not be activated by hydrocarbon detectors, since in the case of a liquid leak, this may result in a larger vapor cloud in the absence of fire. Water spray application can help to dilute a vapor cloud by mixing it with air. Manual activation allows the emergency to be evaluated prior to deciding on spray actuation.

5.4.9 Collection/diversion troughs or locally directed water sprays should be provided for spheres where the support legs join the vessel. Also, water sprays may be needed to protect shell areas or appurtenances such as valves, pipe connections, and so forth, that may interrupt the flow of the water film. The need for these water sprays can be determined by observation during system flow tests.

5.4.10 Water-application systems should be tested and maintained at a sufficient frequency to ensure their reliability and demonstrate adequate flow rate and coverage of the protected equipment. Refer to NFPA 25 for additional information.

5.4.11 The need to protect supports for water piping exposed to flame impingement should be evaluated. Protection should be provided where necessary to ensure structural integrity during a fire.

5.4.12 A water flood connection, valved and blinded when not in use, should be provided on the main product transfer line at a safe distance from the vessel. The purpose for this connection is to permit water to be pumped into the bottom of the storage vessel to control leaks. Double block valves and check valves or other means should be employed when the connection is in use to prevent the contamination of the firewater supply by LPG products. The connecting point for water injection should be clearly identified, and the required injection pressure should be marked.

5.4.13 Firewater (cooling) systems in freezing climates shall be suitably protected to prevent freezing.

5.5 Detection Systems

5.5.1 GENERAL

Fire and hydrocarbon detection systems should be considered for use in LPG storage facilities to detect and alarm in the presence of hydrocarbons and fire. They may also be used to activate isolation and fire protection systems automatically to respond to the condition detected. Water application systems should not be activated by hydrocarbon detection systems unless fire has been confirmed by fire detection systems as well, see 5.4.8. See 8.4 in API Standard 2510 for additional information.

5.5.2 HYDROCARBON VAPOR DETECTORS

Hydrocarbon vapor detectors may be provided for area surveillance and are best used as a prefire vapor-detection early warning system. Early warning enables personnel to control the source of the leak and disperse the vapor cloud. To minimize the number of false alarms, a single detector should be used only for alarming purposes, and automatic equipment activation should only occur when hydrocarbon vapor detection is confirmed by a second detector. Water application systems should not be activated by hydrocarbon detection systems unless fire has been confirmed by fire detection systems as well, see 5.4.8. The detection system should have sufficient sensors to ensure that a leak will be detected at two locations. The number of sensors should be decided on a case-by-case basis.

5.5.3 HEAT DETECTORS

Thermally-operated detectors that sense a high temperature or a rate of temperature rise beyond a preset limit can be used for early warning of a fire condition. With scheduled testing and maintenance, reliability of these devices is sufficient to allow automatic action to be initiated by a single detector. Automatic action may include sounding an alarm, closing valves, or activating automatic firewater (cooling) systems. For the detector to be effective, it must be located where heat exposure from a particular fire source is expected.

5.5.4 FLAME DETECTORS

Flame detectors are designed to sense infrared or ultraviolet radiation emitted from a flame. Flame detectors provide area coverage and will detect flames at locations removed from expected fire sources. The rapid response time of flame detectors provides immediate warning of a fire condition and permits remedial actions such as sounding an alarm, closing valves, or activating automatic firewater (cooling) systems. The disadvantages of flame detectors include possible false alarms by sunlight or other sources of radiant energy or impaired operation caused by obstructions or dirty lenses. The sensitivity of a detector will dictate its placement; that will have a direct affect on the size of flame that the detector can "see" at a given distance. It is important to follow the manufacturer's recommendations. To minimize the risk of unnecessary emergency actions, consider the effects of arc welding, lightning storms, and the like, in selecting detectors and their locations.

5.6 Portable Fire Extinguishers

Portable fire extinguishers are important as a first line of defense against LPG fires of limited size. See 8.5 in API Standard 2510 for requirements and further information.

5.7 Foam for LPG Fires

Foam is not recommended for use in fighting LPG fires. In general, fire-fighting foams that are effective against common hydrocarbon liquid spill fires are ineffective against LPG fires. LPG fires are typically pressurized jet fires. For a larger LPG pool fire, the effective use of foam is questionable because the applied foam is a source of heat and promotes LPG vaporization from the refrigerated pool (See 8.6 in API Standard 2510).

5.8 Fireproofing

5.8.1 GENERAL

5.8.1.1 Fireproofing of LPG vessel supports, LPG vessels, instrumentation and control tubing, and valve operators should be considered when evaluating the fire-protection systems for LPG storage. See API 2218 for additional information. The primary function of fireproofing is to reduce the rate of temperature increase of a metal surface when it is exposed to a fire. The mechanism for this is absorption of heat through the chemical breakdown of the fireproofing or thermal insulation, depending on the nature of the fireproofing system.

5.8.1.2 As a passive fire-protection system, fireproofing provides protection independent of detection systems or alarms. Mechanical or electrical failures have no effect on its performance. Unlike water deluge or spray systems, the effectiveness of fireproofing is impaired only by the most severe vapor cloud explosions.

5.8.1.3 Fireproofing provides only a finite period of protection. Without the application of water, fire-exposed equipment protected by fireproofing will fail if the fire burns long enough. Also, the type of fireproofing selected must be compatible with the storage area environment with respect to both ease-of-application or installation and long-term durability.

5.8.1.4 Fireproofing used in combination with water-application systems will provide fire protection until the water system is activated. It will also function as a temporary backup in case the water supply is interrupted or the water-application rate is inadequate.

5.8.2 APPLICATIONS FOR FIREPROOFING

5.8.2.1 General

In LPG facilities, fireproofing should be considered for use in the areas covered in 5.8.2.2 through 5.8.2.6. Fireproofing is mandatory for some applications (see 8.7 and 8.8 in API Standard 2510).

5.8.2.2 Structural Support

Fireproofing used on the steel structural supports of LPG vessels can prevent their collapse in the event of fire. On spherical and vertical cylindrical vessels, structural supports shall be fireproofed from ground level to the intersection of the support with the vessel shell. For horizontal cylindrical vessels, steel saddles and vertical support steel shall be fireproofed to the intersection of the saddle with the tank if the saddle is greater than 12 inches in height at its lowest point. When a vertical vessel is supported by a skirt, the exterior of the skirt shall be fireproofed. The interior should be fireproofed if there is more than one access opening in the skirt that is not covered with a plate. See 8.8 in API Standard 2510 for fireproofing requirements.

5.8.2.3 Vessel Shell

5.8.2.3.1 When applied to vessel surfaces, fireproofing reduces the rate of heat input to the vessel in a fire, which in turn reduces both the amount of product vented, and the load on the pressure relief system. Additionally, on surfaces above the liquid level, fireproofing is a deterrent to metal shell rupture and provides more time to respond to the fire and set up cooling-water streams. The thickness of the fireproofing and the duration of its protection in a fire should be selected based on the degree of firewater protection available. If portable equipment is the only means of applying firewater, the fireproofing should meet the requirements of 8.7 in API Standard 2510.

5.8.2.3.2 Fireproofing materials generally require metal mesh reinforcement mechanically attached to the substrate being protected. When fireproofing is required for LPG vessels, the attachment method must be compatible with the vessel's metal composition and with safe operation of the storage facility. In some cases, welded steel pins may be the only available method to attach the mesh. Additionally, if vessels that have water deluge or spray protection are fireproofed, an unevenly-fireproofed surface may affect the rundown pattern of the water. Accordingly, care must be exercised to achieve as smooth a surface as possible.

5.8.2.4 Instrument and Control Systems

5.8.2.4.1 Fireproofing instrument and control cables, and motor-operated valves, can provide sufficient operational capability in a fire to start, stop, or divert production flow or activate alarms or water systems. For example, if the control cabling for motor-operated valves necessary in an emergency is at risk during the first 15 minutes of a fire, it should be fireproofed for a 15-minute fire exposure. Alternatively, wire that is resistant to fire damage should be used. See 8.11 in API Standard 2510 for additional information.

5.8.2.4.2 Systems available for fire-protecting cabling and motor-operated valves vary from fibrous insulation overwraps that include weather protection to sheet metal enclosures covered with mastic fireproofing coatings. The system selected should permit easy access for repair, maintenance, and modification. An alternative to fireproofing is to use electrical wire that is rated for at least 15-minutes operation in a fire.

5.8.2.4.3 Instrument and control systems that do not need to be operated during a fire emergency should be designed to fail safe, that is, fail to a safe position when exposed to fire.

5.8.2.5 Pipe Supports

Fireproofing for pipe supports should be provided where collapse of the supports may cause failure of storage vessel piping connections and further release of LPG. Supports for piping in the vicinity of mechanical equipment such as pumps or compressors, or supports in a potential spill area or drain path, should also be considered for fireproofing. See 8.8.5 in API Standard 2510.

5.8.2.6 Supports for Fire Protection

Supports for fire-protection equipment and piping that may be exposed to fire should be fireproofed to prevent failure and loss of the protection during a fire. The thickness of the fireproofing should be equivalent to a fire endurance of 1½ hours per UL 1709 when tested on a 10W49 column.

5.8.3 FIREPROOFING TYPES

5.8.3.1 General

Once fireproofing is installed, it is difficult to determine if corrosion is occurring under the fireproofing until telltale rust stains appear. Accordingly, before fireproofing is applied, metal surfaces that will be fireproofed must be prepared through such means as abrasive blasting and corrosion-protective primers. If the fireproofing requires metal mesh attachment through welded steel pins, the primer should be repaired after welding. Particular attention should be given to the top junction of the fireproofing and the protected metal in order to prevent water from getting behind the fireproofing and causing corrosion. Waterproofing can be achieved by caulking or flashing to seal the junction. Regular inspection is required to maintain the junction seal.

5.8.3.2 Concrete

The use of concrete fireproofing is generally limited to steel supports of LPG vessels and piping because of weight considerations. Steel supports requiring protection should be fireproofed with 2 inches of reinforced poured-in-place or pneumatically applied concrete. Normally, fireproofing need not be applied to wind or earthquake bracing.

5.8.3.3 Proprietary Fireproofing Compositions

There are a number of lightweight proprietary fireproofing compositions suitable for protecting both steel supports and LPG vessels. These materials range from lightweight inorganic cementitious compositions to mastics. The fireproofing selected should be weather-resistant and moisture-proof. A moisture-barrier coating should be applied over the fireproofing if the fireproofing is porous or if LPG storage conditions are such that condensation is expected to form on the surface below the liquid level. The manufacturer's recommendations should be followed.

5.8.3.4 Fibrous Insulation

In some cases inorganic fibrous insulation that has been installed on LPG vessels for ambient temperature insulation may, in addition, provide the necessary fire endurance. The governing factors are insulation thickness and insulation type. The weather jacket covering the insulation needs to be of high-melting-point material such as steel or stainless steel if the insulation is to provide fire resistance. Removable inspection plugs with this type of fireproofing facilitates inspection for corrosion of the protected steel.

SECTION 6—FIRE CONTROL AND EXTINGUISHMENT

6.1 Prefire Plan

6.1.1 Fires involving LPG pressure storage vessels can have very serious consequences. In these fires immediate action is often needed to prevent escalation, which can terminate in the rupture of a storage vessel. To avert escalation of a fire and possible vessel rupture, it is imperative to have a comprehensive and up-to-date prefire plan and to test this plan frequently.

6.1.2 Because of the importance of immediate and correct decisions early in an LPG fire, the prefire plan should include several possible but realistic scenarios and the recommended emergency response for the facility under consideration. Some typical scenarios are as follows:

a. Sample draw fire.
b. Relief valve vent fire.
c. Ignited and unignited pressure leak.
d. Ignited and unignited pool (primarily for storage of butane or refrigerated LPG).
e. Pump fire.
f. Truck or rail car loading/unloading fire.

6.1.3 Effective prefire plans should include basic procedures to be performed by firefighting personnel in all LPG fires as well as other more general considerations to ensure orderly disposition of the fire and minimize its impact on facility personnel and neighboring properties. The elements of a good prefire plan are set forth in 6.1.3.1 through 6.1.3.4.

6.1.3.1 The following are some general concerns that should be addressed in the prefire plan:

a. A command chain should be designated; it should be consistent with the Incident Command System in use by the local emergency response organizations.
b. Measures to guarantee effective communications.
c. Access and escape routes and personnel muster points should be established.
d. A notification list with telephone numbers should be compiled.
e. An evacuation agreement with public officials should be in effect if required.
f. Traffic control procedures should be decided.

6.1.3.2 The following information is typical of what should be included in a prefire plan:

a. Facility name and location (street address or directions from a known landmark).
b. Emergency phone numbers for fire department, rescue/ambulance, and other critical service organizations.
c. Name and address of facility managers and backup contacts.
d. The facility emergency Incident Commander and structure of the Incident Command System organization.
e. Phone numbers for regulatory agency notification, as applicable (police, fire, environmental agencies, Coast Guard, etc.)
f. Sketch of the facility plot plan and immediate surroundings, showing equipment location, vessel contents, and access routes, preferably to scale.
g. List and show on the plot plan emergency equipment, emergency valves, shutdown switches, main electrical disconnect, etc.
h. Identify special hazards, hazardous materials and any required personal protective equipment.
i. List of surrounding occupancies and unusual concerns such as schools, homes, adjacent flammable liquid storage, or critical facilities.
j. List fire-fighting equipment both on site and available through mutual aid agreements.
k. Locate on the plot plan and describe firewater supplies, hydrants, ponds, canals, firewater monitors, main valves, and firewater pumps.

Periodic prefire plan reviews and practice drills should be scheduled to test the plan and to train facility operators and personnel who would respond to an emergency.

6.1.3.3 Firefighting personnel should be instructed to ascertain the following basic information for all LPG fires:

a. The time of the fire's inception if there is flame impingement or engulfment of the vessel.
b. The liquid level in the storage vessel and whether it is above or below the area of flame contact on the shell.
c. The identity and location of ignition sources downwind from the fire and the means to eliminate them to avoid possible re-ignition of vapor if the fire is accidentally extinguished.

6.1.3.4 Firefighting personnel should have knowledge of the following:

a. The technique for using hose streams or water curtains to dilute and disperse vapor.
b. The danger of extinguishing an LPG fire without shutting off the fuel supply.
c. The method if injecting water to displace LPG from a leak in bottom connections or piping.
d. The ways of recognizing that tank rupture (BLEVE) is imminent and that the area should be evacuated. See 6.3.1.

6.2 Training

6.2.1 Firefighting personnel should be trained in the use of the fire-control equipment available at the site and in the use of safe tactics that will reduce their risk of injury.

[10]The API Pilot series may be obtained through the following address or telephone number: Howell Training Company, 5201 Langfield Road, Houston, Texas 77040; 713-460-4460.

6.2.2 A training program should include fire emergency drills to test procedures and to prepare the participants for various fire situations. Helpful material can be found in the API Pilot series on fire training.[10] Training programs should include the considerations of 6.2.2.1 and 6.2.2.2. See NFPA 600 for additional information.

6.2.2.1 The following procedures should be addressed in the training program:

a. The techniques for immediate cooling of vessel shells when exposed to flame contact above the level of the contents.
b. The use of water streams to disperse and dilute vapor.
c. The ways of recognizing that tank rupture is imminent and that the area should be evacuated. See 6.3.1.

6.2.2.2 The training program should ensure that firefighting personnel are versed in the following precautions:

a. To approach no closer than required for water from a straight stream nozzle to just reach the target vessel.
b. To conserve personnel and water, do not cool vessels that are not exposed to flame. They are at a low risk from radiant heat (see Figure 1).
c. To approach the fire from upwind and eliminate ignition sources in the vapor travel area. Avoid entering the area where a vapor cloud could occur—after extinguishment—if all fuel sources are not isolated.
d. To shut off fuel sources before extinguishing an LPG fire because of the danger of flashback or explosion.

6.3 Assessing the Fire

6.3.1 Initial assessment of LPG storage fires is essential for the safety of personnel. Imminent danger of vessel failure and injury to personnel exists under the following conditions:

a. There is flame impingement on the unwetted portion (vapor space) of the storage vessel.
b. There is no application of cooling water to the impingement area.
c. There is no fireproofing on the flame impingement area.
d. These three conditions have persisted for 10 minutes or more.

Under these conditions immediate evacuation is recommended. Before a vessel ruptures, bulges may be visible in the shell, and a metallic pinging sound may be audible indicating that the vessel shell is overstressed. If the relief valve is venting, however, it is doubtful that metallic pinging can be heard.

6.3.2 Indications that the fire is escalating are as follows:

a. The relief valve lifts, indicating considerable heat input to the tank.
b. The relief valve lifts and does not reseat even though cooling streams have been applied.
c. The noise level of a venting relief valve increases, indicating ineffective cooling of the exposed vessel.

6.3.3 When it has been determined the fire is safe to approach, a plan of attack should be developed and should include the following considerations:

a. What storage vessels will need cooling in addition to the one involved?
b. What water application rates will be needed, and is there sufficient water supply?
c. What is the source of fuel to the fire, and can it be safely shut off?
d. Is there a safe evacuation route if conditions change?

6.4 Applying Cooling Water

6.4.1 Flame impingement can cause an LPG storage vessel to fail within a few minutes due to increased internal pressure and reduced shell strength caused by rising metal temperatures. One method for preventing excess heat influx is to apply cooling water to the tank. If sufficient water is applied properly, the temperature of the tank contents and the tank shell will not increase to dangerous levels.

6.4.2 Flame-exposed areas of a storage vessel should have cooling-water applied within the first 10 minutes of a fire by means such as water deluge, fixed monitors, or water spray as described in 5.3. Supplemental cooling with portable monitors or hand-held streams may be needed if a high-velocity jet fire impinges on a vessel shell.

6.4.3 Radiant heat from an LPG fire at one storage vessel is seldom severe enough to require the cooling of adjacent vessels. Closely spaced horizontal vessels may be an exception. If there is no flame contact on the shells of the adjacent vessels and the relief valves have not lifted, if there is sufficient distance between the fire and the vessel shells of concern and cooling can be delayed or not applied at all. When the relief valves lift, the need for cooling-water must be assessed. See 5.2.6.1 for specific guidance.

6.4.4 The following is a technique to determine if cooling is needed:

a. Apply a firehose stream to the shell of the vessel and then remove it.
b. If the shell stays wet a few seconds or longer, further cooling at that time is not needed.
c. If the water boils when it is applied to the shell, cooling should continue until the metal temperature is below the boiling point of water.

6.5 Isolating Fuel Sources

6.5.1 GENERAL

6.5.1.1 If an LPG fire is extinguished, but the fuel source has not been shutoff, the fuel will continue to vaporize rapidly, creating a flammable vapor cloud that will travel downwind. If it encounters an ignition source, a vapor cloud explosion may occur, and the fire will begin anew. This is why it is advisable to shutoff the fuel source before extinguishing an LPG fire.

6.5.1.2 There are numerous methods for stopping the flow of fuel during an accidental release (see 2.7.1). These methods range from pre-engineered, automatic systems to totally manual valves.

6.5.2 EXCESS FLOW VALVES

Excess flow valves and backflow check valves are often used in LPG vessel systems to automatically stop the flow of fuel from the vessel in case of pipe breakage. Of course, backflow check valves can only be used on dedicated inlet lines. An excess flow valve closes automatically if the flow rate through it exceeds a predetermined level. This level must be chosen carefully, or the valve may close during normal system operation. Unnecessary closing of an excess flow valve may result in hydraulic pressure surges and piping or equipment damage or failure. Another consideration is that small-to-moderate leaks up to the predetermined level will not activate an excess flow valve; thus leaks may continue unchecked.

6.5.3 AUTOMATIC AND REMOTELY OPERATED VALVES

6.5.3.1 Remotely operated valves—whether hydraulically, pneumatically, or electrically actuated—can be very useful in stopping the flow of fuel. It is advisable to have more than one valve-operating location. Fail-safe valves are preferred, since these valves automatically close if their operating signal is lost. Unless fireproofing is provided, motor-operated valves may not do this, since they require electricity to move the valve actuator. Pneumatic or hydraulic valves which require pressure to open can be spring-loaded to close automatically if the pneumatic or hydraulic pressure is lost. Special protection may be required for motor-operated valves and their electrical supply to ensure that they will work during an emergency (see 8.11 in API Standard 2510).

6.5.3.2 Remotely operated valves can also be controlled by various devices that will automatically close them in an emergency. For example, fusible links are often incorporated in spring-loaded valves to effect valve closure if the fusible link is exposed to fire. The pneumatic supply to a valve can be routed through small-diameter plastic tubing; if the tubing is melted by a fire, pressure will be lost and the valve will shut. Motor-operated valves on withdrawal lines from tanks can be interconnected with the transfer pumps so that the valves will always be shut unless the pumps are operating. This same arrangement can be accomplished hydraulically. There are also numerous other possibilities.

6.5.4 MANUALLY OPERATED VALVES

Manually operated valves can also be used to stop the flow of fuel. If the proper valve is not accessible because of heat from a fire, it is often possible to reach the valve by advancing behind at least two hose streams that are producing a semifog pattern. The water spray pushes the flame back and provides cooling for the attack teams. This technique requires personnel training if it is to be successful. Careful location of such valves is essential if they are to be safely operated in an emergency.

6.6 Firefighting Tactics and Leak Control

6.6.1 GENERAL

Unfireproofed pressure storage vessels and uninsulated pipelines require some special firefighting tactics that are not needed with atmospheric tanks and pipelines, and each situation requires a slightly different approach and decision-making process. There are also several methods for controlling LPG leaks, and the choice of method should be based on the circumstances. Adequate prefire plans and drills that simulate realistic occurrences will help assure proper choices. Personnel safety and the conservation of water are major considerations.

6.6.2 SMALL FIRE UNDER A VESSEL

6.6.2.1 Assume there is a small LPG leak from a pipeline near ground level under an unfireproofed storage vessel. The LPG is burning with a 6-foot flame that contacts the bottom of the tank.

CAUTION: Do not extinguish the flame with a dry chemical fire extinguisher because the accumulated vapor may reignite, seriously injure firefighters, and damage equipment.

The following two methods of control are possible:

6.6.2.2 Try extinguishing the fire by closing valves to shut off the fuel source for the leaking section of the pipeline. If flames or radiant heat make the valves unapproachable, use water spray streams, if practical, to enable personnel to approach and close the valves.

6.6.2.3 While depressurizing the pipeline, use fixed water deluge, monitors, or water spray, if available, for cooling the flame-exposed tank. If a fixed system is not available or does not give proper coverage, use water spray streams from hand lines or fixed or portable monitors. If water distribution to areas of the tank with flame contact is impeded by dirt or soot deposits from the fire, special attention is necessary using supplemental water cooling by a stream from a hand-held hose. Prefire training and testing may indicate some local areas possibly resistant to fixed-spray cooling (see 6.6.3).

6.6.2.4 If the fire is not controlled promptly, set up water streams to cool the vessel while the system is being depressurized. This may include depressurizing the vapor space of the vessel (see 2.11).

6.6.3 LARGE FIRE UNDER A VESSEL

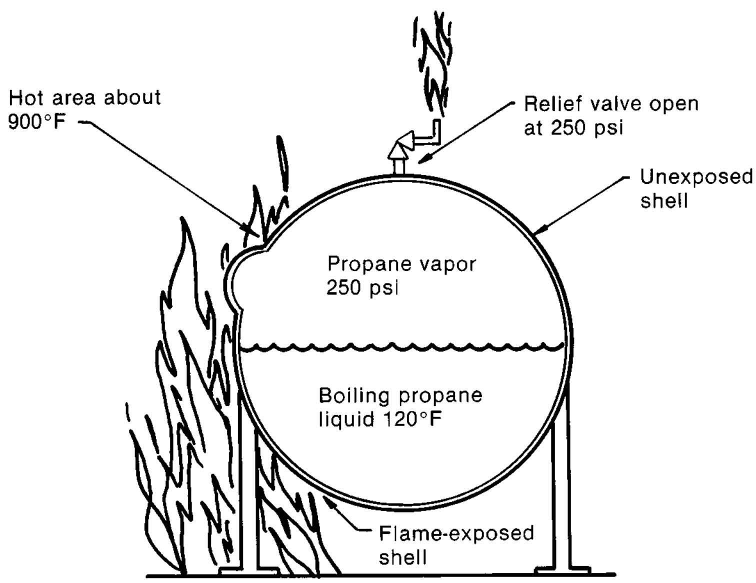
6.6.3.1 General Considerations

6.6.3.1.1 Assume there is a large LPG leak from a pipeline or other source producing flame impingement above the liquid level of an unfireproofed pressure vessel. Such a fire is illustrated in Figure 3. Various methods of control are presented in 6.6.3.2.1 through 6.6.3.2.5.

CAUTION: Fires impinging on the outside surface of an unfireproofed pressure storage vessel above the liquid level can be very dangerous. After approximately 10 to 30 minutes of direct flame exposure, the vessel usually ruptures violently. The time lapse depends on the heat intensity and the thickness of the exposed area of the vessel shell. Some vessels have ruptured after exposure of approximately 10 minutes, and there have been occasional reports of vessel failure in less than 10 minutes, but this is rare.

6.6.3.1.2 When the flames heat the portion of the vessel shell above the liquid level to approximately 900°F to 1000°F, the shell starts to bulge because the tensile stress caused by the vapor pressure of product in the vessel exceeds the yield strength of the metal shell at the elevated temperature. The vessel shell at the bulged area thins, and the bulging continues, unless there is cooling, until rupture occurs. When a vessel ruptures, the superheated liquid in the vessel is sprayed out under pressure and quickly vaporizes to produce a large volume of vapor. The vapor ignites instantly and burns on the outside envelope where the flammable vapor-air mixture is present. This outside fire heats and expands the inner too-rich-to-burn core, which takes an approximate spherical shape—hence, the term *fireball.* The fireball enlarges and rises until all of the vapor is consumed. A typical aerial fireball is shown in Figure 4, which demonstrates that 29,000 gallons of LPG can produce a fireball approximately 1000 feet in diameter 300 feet above ground level. Firefighters who are not protected by structures or by adequate overhead spray from hand lines may be burned seriously by the radiant heat at some distance from the vessel.

6.6.3.1.3 The rupture of a vessel with combination aerial and ground-level flash fires or explosions is especially dangerous because of the direct, severe flame contact at long distances from the vessel. Firemen's conventional full-turnout protective clothing may not prevent burn injuries.



Notes:
1. The overheating causes a metal bulge because of internal vapor pressure.
2. psi = pounds per square inch.

Figure 3—Vessel Shell Overheated Above Liquid Level

Note: In a boiling liquid-expanding vapor explosion (BLEVE), such as the one pictured above, direct flame impingement on the vapor space of a horizontal LPG vessel can result in early catastrophic failure. Some vessels have failed as early as 11 minutes into the fire.

Figure 4—Rupture of a Horizontal LPG Vessel

6.6.3.1.4 History has shown that an increasing pitch in the sound of a relief valve may indicate the impending rupture of the vessel.

6.6.3.1.5 Although the vessel can have adequate relief-valve capacity based upon fire conditions to meet requirements of API Standard 2510, it still may rupture because the metal shell loses its strength in the area where it is overheated. The fact that the vessel can rupture in so short a time is of importance to firefighters, as they can be fatally injured by the radiant heat from the fireball or ground-level flash. This problem requires good emergency supervision.

6.6.3.2 Fire Control and Firefighting Tactics

6.6.3.2.1 Assess the fire problem quickly and put cooling water on the hot part of the vessel shell immediately. Vacate the area if cooling water cannot be applied promptly (within 10 minutes).

6.6.3.2.2 When the vessel is protected with an automatic, fixed firewater system, check the following:

a. Is the system functioning as intended?
b. Is the fire intensity at one area so severe that supplemental cooling from monitors or hand lines is needed quickly?
c. Are there any dry spots on the vessel surface above the liquid level that need supplemental cooling? If so, are portable monitors quickly available?
d. Where is the liquid level in the vessel? After the fire has burned for a while, sometimes the liquid level may be indicated by a horizontal line on the exterior surface of the vessel. However, at night, or if smoke is involved, the visibility may be limited, and the line may be indistinct, unreliable, or missing entirely.

6.6.3.2.3 When the vessel is protected with a manual-start, fixed firewater system, check the following:

a. How severe is the fire and how long has it been burning?
b. Are the manual-start valves in a safe location, or is overhead water protection needed from a hand line?

Also, refer to the questions listed in 6.6.3.2.2 for an automatic, fixed water-application system.

6.6.3.2.4 When the vessel is protected with fixed monitors for cooling, check the following conditions:

a. How severe is the fire and how long has it been burning?
b. Should monitor operators be protected with an umbrella of spray from hand lines while starting and adjusting the monitor streams?
c. Do the monitor streams remain fixed on their target or do they tend to drift off target?
d. Is the wind changeable or opposing so that it is difficult to direct the monitor streams at their target?
e. Is there a need to utilize a person at another vantage point to be a spotter to give instructions to the person positioning a firewater monitor for the most effective cooling?

6.6.3.2.5 When the vessel has neither a fixed system nor fixed monitors, consider the following:

a. Assess the situation promptly and determine if there is a safe strategy to follow. The supervisor is confronted with a number of serious problems and questions that must be solved without delay.
b. How long has the fire been burning? Where is the liquid level in the vessel? How extensive is the flame impingement on the vessel shell above the liquid level at the most severely exposed area? Have the relief valves started venting with force? A large, general ground fire may not be as serious as an intense, smaller fire against the shell at a spot above the liquid level. A large fire may obscure a jet fire that is within the general fire.
c. Is it safe to bring up shorter-range hand lines for cooling the vessel shell where it needs cooling while waiting for the monitor streams to start and personnel may retreat to a safe cover? Sometimes fire crews can arrive early enough to safely set up cooling streams if the exposure fire is small. However, remember that with an early, severe exposure fire, the radius of a massive blast can greatly exceed the longest range of a monitor stream and overwhelm any hand-held fire hose spray streams used for personnel protection.
d. As a safety contingency, is there any operating equipment that can serve as a shelter for hand-line and monitor operators, assuming that overhead spray streams can be used to protect emergency personnel from the radiant heat of a fireball should the vessel rupture before adequate cooling is established?
e. Have prefire training and tests shown the best places, perpendicular to the axes of horizontal vessels, for location of portable monitors with allowances for wind conditions, best protection of monitor operators, and adequate reach of monitor streams? Be aware that fragments from horizontal vessels do not always rocket endwise.
f. Have prefire tests shown the best type of monitor nozzle to use and the appropriate tip size for the flowing water pressure at the nozzle?

6.6.4 UNINSULATED PIPELINE FAILURES CAUSING VESSEL RUPTURES

6.6.4.1 Uninsulated pipelines containing LPG also are subject to failure from flame contact. In turn, the jet fire from the pipeline failure can cause adjoining unfireproofed pressure vessels to rupture soon afterward.

6.6.4.2 Quickly assess the fire and establish the proper short-time control tactics similar to those for an unfireproofed vessel. Consider, also, the following factors:

a. Possible lack of a fixed firewater application system for the piping.
b. Difficulty of reaching the pipeline with water streams because of interfering equipment.
c. Difficulty of identifying the critical pipe because of congestion, smoke, and so forth.
d. Inability to depressurize the line promptly because it is connected to a large pressurized vessel and there is no safe access to the vessel shutoff valve.
e. Possible difficulty with operating controls because of damage to automatic or remote-manual control facilities and instrumentation that occurred earlier in the fire.
f. Complications of fighting the existing fire along with the need to prevent failure of a dry or blocked-in pipeline exposed to the fire.

6.6.5 USING WATER PRUDENTLY TO PROTECT EXPOSURES

6.6.5.1 Assume a severe ground fire is exposing one storage vessel to direct flame contact while adjoining vessels are exposed only to radiant heat, as illustrated in Figure 5.

6.6.5.2 Close the valves on product lines of adjacent vessels. Use adequate cooling water on storage vessel areas that are exposed to direct flame contact and avoid wasting water on areas that are exposed only to radiant heat. See 5.2.6.1 for guidance on cooling requirements for radiant heat. Conservation of water is very important.

6.6.5.3 Prefire training enables accurate assessment of the situation at the start of fire-control operations, which helps to avoid problems. However, one typical problem is using excess water. This can reduce pressure and volume of water available to cool the exposed vessel shell areas adequately, where cooling is needed the most. There is also a tendency to use all of the cooling-water available even if it is not needed.

6.6.5.4 Radiant heat exposure of bare vessels can increase the vessel pressure, open relief valves, and produce large, vertical, noisy jet flames from relief-valve stacks. As long as these flames do not contact exposed metal, there is no need for immediate cooling of the top of the vessel. For prolonged releases, application of water to the top of the vessel is advisable (see 2.10.2.2).

6.6.6 VESSELS WITHOUT COOLING WATER PROTECTION

6.6.6.1 The most serious firefighting problem is a vessel without cooling water protection that is exposed to direct flame contact, for it may rupture at any time.

6.6.6.2 Is it safe to make an attack? Conventional firefighting objectives often are advance and extinguish. Seldom considered are the options of not advancing or retreating. The average supervisor may decide to attempt an attack only after a time-consuming assessment because of initial uncertainty about how to proceed.

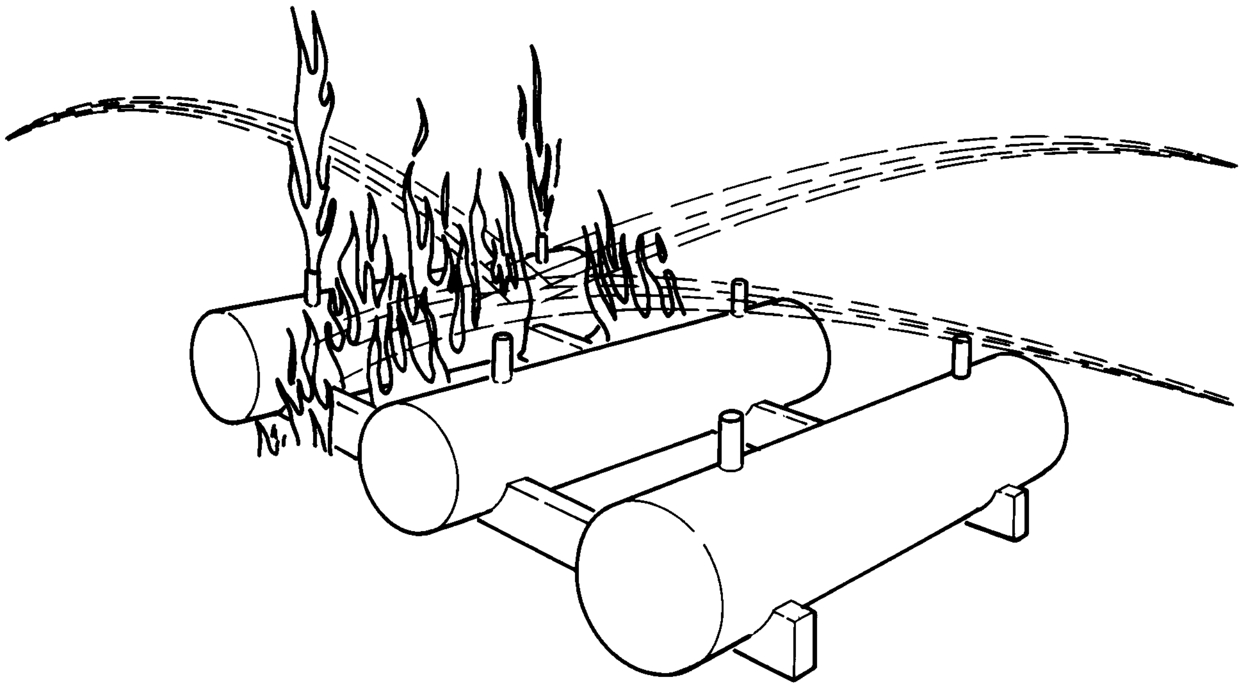


Figure 5—Directing Cooling Water to Flame-Exposed Metal

6.6.6.3 It is possible to assess the problem quickly and competently if the supervisor has participated actively in sufficient prefire plan studies and drills that have simulated realistic problems for the tanks involved. A basic decision-making process is presented in 6.6.3.2.5. Inexperience in such situations can lead to tragic consequences. Good prefire planning may determine that doing nothing other than shutting-in and isolating fuel sources is the best response to a fire in a remote, unmanned facility.

6.6.7 LEAK CONTROL

6.6.7.1 Water Injection

Because LPG is less dense than water, it can be displaced by water injection. For example, if a leak occurs at a weld on a vessel nozzle, the leak cannot be stopped in the normal manner, since the leak is upstream of the first valve. Injecting water into the attached piping or through a separate pipe into the tank will effectively displace the LPG so that the leaking fluid will be water rather than LPG. Water injection systems may be either hard-piped systems, or systems that rely on fire hose connections. In either case, water pressure must exceed the LPG system pressure; and backflow check valves and a quick-change blind should be installed on the water lines to prevent LPG from flowing back into the water system. Care must be taken in designing this type of system to prevent vessel overfilling, since this might result in LPG liquid being expelled from the pressure relief valves. Since normal liquid withdrawal systems will remove only water that has accumulated at the bottom of the vessel, another method must be used to empty the vessel of LPG.

6.6.7.2 High-Velocity Water Streams

High-velocity water streams aimed directly into a leak source are not effective in stopping LPG release, though they may reduce the leak rate. This is only a stopgap measure, since the leak will resume its initial rate if the water stream is stopped. The water stream may increase the liquid vaporization rate, but will offset this effect by diluting and dispersing the released vapor.

6.6.7.3 Vessel Depressurizing

An LPG vessel can be depressed by venting it through a large-diameter pipe to a blowdown system. The drop in pressure may reduce the leak rate for a leak source in the vessel or its attached piping. As liquid vaporizes in an effort to maintain the pressure within the vessel, the liquid autorefrigerates, which can result in the temperature of the remaining liquid dropping to its boiling point, and its vapor pressure decreasing. When considering depressurizing, be sure that the construction materials are suitable for use at the low temperatures that can result. Vapor depressurizing is described in 2.11.

6.6.7.4 Vessel Pump-Out

Liquid can be transferred from a leaking vessel to another vessel or vessels. Depending on line sizes and pumping arrangements, liquid transfer can require considerable time. For example, 30,000 gallons of liquid pumped at a rate of 300 gallons per minute would require 100 minutes. Also, the decline in liquid level creates more unwetted tank shell that could weaken and fail if exposed to flame contact. Therefore, transferring liquid from a tank that is involved in a fire may not be advantageous and may significantly increase the risk of a vessel rupture and rapid escalation of the fire emergency. An exception where rapid pump-out of a vessel may be advantageous is when the supply of fire-fighting water is limited, or may soon be exhausted, and the fire cannot be controlled and extinguished. Under these conditions, when fire-fighting water is exhausted, vessel rupture may not be preventable. Evacuating the area and pumping out the vessel as rapidly as possible prior to vessel failure will reduce the size of the resulting fire ball, depending on the amount of inventory reduced.

6.6.7.5 Manual Methods

Under some conditions it may appear to be worthwhile to try to stop leak sources by manually tightening a leaking flange, installing a tapered plug in a hole or open pipe end, or closing a leaking valve. Such efforts expose personnel to high concentrations of LPG vapor and the consequent risk of severe burn injuries if ignition of the vapor cloud occurs while repair attempts are underway. As a general rule, manual methods should never be attempted unless adequate personnel protection is provided.

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