Natural Gas Liquids and Liquefied Petroleum Gas Emergency Response Guide

Good Practice Guide for Natural Gas Liquids and Liquefied Petroleum Gas Emergency Response Tactics

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1 General

1.1 Purpose

This guide includes a high-level overview for response and safety strategies to respond to an incident involving natural gas liquids (NGL) and liquefied petroleum gases (LPG), both of which are highly volatile liquids (HVL). NGL and LPG are unique in the fact that they are often transported as a liquid under pressure, but are vapors under most atmospheric conditions. The purpose of this report is to highlight the unique nature of NGL and LPG releases and their consequences. This guide is to be used by first responders and terminal personnel to give an overview of product characteristics, as well as firefighting and other response techniques with regard to NGL and LPG release events.

Natural gas production within the United States has more than doubled from 2010 to 2020. Because NGLs are by-products of drilling for natural gas, NGL production has increased similarly. Now that NGLs are prominent throughout the oil and gas industry, they are being shipped, transferred, and used throughout the United States. The increased supply of these products has increased the likelihood of a severe fire or explosion event associated with them. This guide provides an overview of the special hazards associated with these products that can be found as either a gas or liquid.

1.2 Scope

The scope of this guide includes a review of product characteristics, response safety, site evaluation and control, defensive and offensive strategies for response, vapor cloud control, isolation methods, logistical considerations (water, pumping, resources, etc.), pipeline incidents, facility/storage events, air monitoring, etc., as well as a review of the most all-encompassing response scenarios. Specifically, this guide has been developed to consider the initial response to an incident utilizing industry best practices, and will stress the importance of safety considerations for responders and nearby communities. Emergency response scenarios included in the guide will focus on NGL and LPG, and hydrocarbon products including ethane, propane, butane, and pentanes.

2 Referenced Publications

The most recent editions of each of the following codes, standards, and publications are referenced in this guide as useful sources of additional information.

American Petroleum Institute (API)

API Recommended Practice 2001, *Fire Protection in Refineries*

API Recommended Practice 2218, *Fireproofing Practices in Petroleum and Petrochemical Processing Facilities*

API Standard 2510, *Design and Construction of LPG Installations*

API Recommended Practice 2030, *Application of Fixed Water Spray Systems for Fire Protection in the Petroleum and Petrochemical Industries*

Center for Chemical Process Safety (CCPS)

Guidelines for Fire Protection in Chemical, Petrochemical, and Hydrocarbon Processing Facilities

National Fire Protection Association (NFPA)

NFPA 1, *Fire Code*

NFPA 15, *Standard for Water Spray Fixed Systems for Fire Protection*

NFPA 30, *Flammable and Combustible Liquids Code*

NFPA 58, *Liquefied Petroleum Gas Code*

NFPA 329, *Recommended Practice for Handling Releases of Flammable and Combustible Liquids and Gases*

NFPA 600, *Standard on Facility Fire Brigades*

NFPA 704, *Standard System for the Identification of the Hazards of Materials for Emergency Response*

NFPA 1561, *Standard on Emergency Services Incident Management System and Command Safety*

NFPA 1620, *Standard for Pre-Incident Planning*

NFPA 1901, *Standard for Automotive Fire Apparatus*

3 Terms, Definitions, Abbreviations, and Conversions

3.1 Terms and Definitions

3.1.1
ambient atmospheric pressure
The pressure at sea level within the atmosphere of the Earth, defined as 101.325 kPa, 14.7 psi, or 1 atm.

3.1.2
autoignition temperature
The minimum temperature at which a material will ignite with self-sustained combustion without an external source of ignition (such as a spark or flame).

3.1.3
boiling liquid expanding vapor explosion
BLEVE
An explosion caused by the rupture of a vessel containing a pressurized liquid that has reached temperatures above its boiling point. Because the boiling point of a liquid rises with pressure, the contents of the pressurized vessel can remain liquid so long as the vessel is intact. If the vessel's integrity is compromised, the loss of pressure and dropping boiling point can cause the liquid to rapidly convert to gas and expand extremely rapidly. If the gas is combustible, as well, as is the case of LPG and NGL, further damage can be caused by an ensuing fire.

3.1.4
bonding
The joining of metal parts to form an electrically conductive path that will ensure electrical continuity and the capacity to safely conduct any current likely to be generated.

3.1.5
cementitious fireproofing
A spray-applied coating, made from a cement-like material, that limits the reduction in the strength of steel at elevated temperatures, increasing the time before significant failure of the steel.

3.1.6
combustible gas detector
An instrument used to sample the atmosphere and indicate if any flammable (combustible) vapors or gases are present and, if so, indicate the amount of vapor or gas present in the atmosphere as a percentage of the lower explosive (flammable) limit. Detectors can be fixed and monitored by a detections system or portable monitor.

3.1.7
combustible liquid
A liquid having a closed cup flash point equal to or greater than 100 °F (38 °C).

3.1.8
confinement
A measure of enclosure or partial enclosure areas where vapor clouds or liquid pools may become contained.

3.1.9
congestion
A measure of the physical layout, spacing, and obstructions within a facility that promote the development of a vapor cloud or liquid pool (e.g., confinement within an enclosure).

3.1.10
deflagration
A combustion wave that propagates subsonically (as measured at the pressure and temperature of the flame front) by the transfer of heat and active chemical species to the unburned gas ahead of the flame front.

3.1.11
degassing
The process of collecting or treating vapors removed from a tank or vessel so as to prevent or reduce the amount of organic volatile compounds released into the atmosphere during vapor and gas freeing operations.

3.1.12
detonation
A reaction in a combustion wave propagating at sonic or supersonic velocity (as measured at the pressure and temperature of the flame front).

3.1.13
explosion
A rapid release of energy (such as burning) that produces a pressure wave.

3.1.14
explosive (flammable) range
The range of concentrations of flammable vapor-in-air (gas-in-air), between the lower explosive limit and the upper explosive limit that will propagate flame if ignited.

3.1.15
flammable liquid
A liquid having a closed cup flash point below 100 °F (38 °C).

3.1.16
flash fire
A flash fire is the rapid burning of a gas cloud in such a way that it does not produce blast overpressures. A flash fire does not produce much radiant heat because the flame only lasts a few seconds, but contact with the flame can cause serious burns.

3.1.17
flash point
The temperature at which a particular organic compound gives off sufficient vapor to ignite in air.

3.1.18
hazard
An inherent physical or chemical characteristic (e.g., flammability, toxicity, corrosivity) or set of conditions that has the potential to cause harm to people, property, or the environment.

3.1.19
highly volatile liquid (HVL)
A hazardous liquid that will form a vapor cloud when released to the atmosphere and that has a vapor pressure exceeding 40 psi at 100 °F (38 °C).

3.1.20
hot work
Any work that has the potential to produce enough energy to be an ignition source in an area where the potential exists for a flammable vapor-in-air (gas-in-air) atmosphere in the explosive (flammable) range to occur.

3.1.21
hot work permit
The employer's (owner/operator and contractor) written authorization to perform hot work operations or use equipment (including but not limited to welding, cutting, grinding, burning, heating, use of internal combustion engines, and non-explosion-proof electric motors) capable of producing a source of ignition.

3.1.22
immediately dangerous to life or health (IDLH)
Any condition that poses an immediate or delayed threat to life or that would cause irreversible adverse health effects.

3.1.23
inert gas
A gas that is noncombustible, noncontaminating, and nonreactive.

3.1.24
inerting
The displacement of oxygen (air), hydrocarbon gas, and/or vapors to eliminate the possibility of a potentially flammable atmosphere in a permit-required confined space. This is accomplished by using an inert gas that is noncombustible, noncontaminating, and nonreactive (e.g., nitrogen) or a gas containing an insufficient amount of oxygen to support combustion (e.g., flue gas), to such an extent that the resultant atmosphere is noncombustible or nonreactive.

3.1.25
intumescent coating
A thin material that is spray-applied to steel to provide protection from elevated temperatures. As the thin layer is exposed to elevated temperatures, the coating expands. With the increased volume and decreased density, the coating slows the heating of steel to prolong the time before failure of the steel.

3.1.26
liquefied petroleum gas (LPG)
Any material having a vapor pressure not exceeding that allowed for commercial propane that is composed predominantly of the following hydrocarbons, either by themselves (except propylene) or as mixtures: propane, propylene, butane (normal butane or isobutane), and butylenes.

3.1.27
lower explosive (flammable) limit (LEL)
The minimum concentration (expressed as a volume percentage) of a vapor-in-air (gas-in-air) below which propagation of flame does not occur on contact with an ignition source; generally considered to be “too lean to burn.”

3.1.28
natural gas liquids (NGL)
Petroleum products that are removed from natural gas at natural gas processing plants as a combined stream. This combined stream is then fractionated to produce raw products including ethane, propane, butane, and pentanes (natural gasoline) for sale or use within the petrochemical industry. NGLs are derived from vapor, but are kept in a liquid state for storage, shipping, and consumption.

3.1.29
oxygen-deficient atmosphere
An atmosphere containing less than 19.5 percent oxygen by volume.

3.1.30
oxygen-enriched atmosphere
An atmosphere containing more than 23.5 percent oxygen by volume.

3.1.31
risk
A combination of the probability of an exposure to a hazard that could result in harm to personnel, the environment, or general public, and the magnitude of the injury or loss should the exposure occur.

3.1.32
safety data sheet (SDS)
Written or printed material concerning hazardous chemicals that is prepared in accordance with applicable regulations and standards. SDSs provide physical properties, safety, personal protection, health, and fire prevention and protection data.

3.1.33
toxic substances
Any material or substance whose properties are such that they can cause injury to a biological system, depending on the exposure concentration, time of exposure, and means of exposure.

3.1.34
upper explosive (flammable) limit (UEL)
The maximum concentration (expressed as a volume percentage) of a vapor-in-air (gas-in-air) above which propagation of flame does not occur upon contact with an ignition source; generally considered “too rich to burn.”

3.1.35
vapor cloud
A gathering of flammable vapors into a particular area that can become explosive if the proper ratio of air to vapor is met.

3.1.36
vapor cloud explosion (VCE)
An explosion in air of a cloud of flammable material.

3.1.37
vapor collection system
A piping system to which vessels are connected, that collects vapor from these vessels and directs them to environmental control equipment such as flares, incinerators, scrubbers, and activated carbon adsorbers.

3.1.38
vapor pressure
The point at which equilibrium pressure is reached, in a closed container, between molecules leaving the liquid phase and going into the gaseous phase and molecules leaving the gaseous phase and entering the liquid phase.

3.2 Abbreviations

API	American Petroleum Institute
ATM	atmospheric
BLEVE	boiling liquid expanding vapor explosion
DCS	distributed control system
FLIR	Forward Looking Infrared
GPM	gallons per minute
HMI	human machine interface
HVL	highly volatile liquid
IDLH	immediately dangerous to life and health
LEL	lower explosive limit
LFL	low flammability limit
LNG	liquefied natural gas
LPG	liquefied petroleum gas
SDS	safety data sheet
NGL	natural gas liquid
NIOSH	National Institute for Occupational Safety and Health
PID	photoionization detector
PLC	programmable logic controller
PPE	personal protective equipment
PSI	pounds per square inch
SCBA	Self-Contained Breathing Apparatus
SIS	safety instrumented system

TLV threshold limit value

UEF upper explosive limit

UFL upper flammability limit

USCG CHRIS United States Coast Guard Chemical Hazard Response Information System

VCE vapor cloud explosion

VOC volatile organic compound

3.3 Unit Conversions

	Converting From	Converting To	Multiply By*
Length	meter (m)	feet (ft)	3.281
	feet (ft)	inch (in)	12
	mile (mi)	feet (ft)	5,280
	kilometer (km)	mile (mi)	0.621
Area	square meter (m^2)	square feet (ft^2)	10.764
	square feet (ft^2)	square inch (in^2)	144
	square mile (mi^2)	square feet (ft^2)	27,878,000
Volume	m^3	ft^3	35.315
	ft^3	in^3	1,728
	gallon	ft^3	0.134
	gallon	fluid ounce (oz)	128
Volume Flow	cubic meters per second (m^3/s)	cubic feet per second (ft^3/s)	35.315
	gal/min	ft3/s	0.00228
Mass—Weight	kilogram (kg)	pounds (lbs)	2.205
Pressure	kilopascal (kPa)	pounds per square inch (PSI)	0.145
	atmospheres (atm)	pounds per square inch (PSI)	14.696
	inches of water (in-H_2O)	pounds per square inch (PSI)	0.036
	inches of mercury (in-Hg)	pounds per square inch (PSI)	0.491
	millimeters of mercury (mm-Hg)	pounds per square inch (PSI)	0.019
Temperature	Celsius	Fahrenheit	(1.8 x °C) + 32

* To convert units in the reverse direction of this table, divide by the number in the “multiply by” column.

4 Product Characteristics

Natural gas produced from wells contains several petrochemicals. Once the natural gas (methane) is fractioned off, the remaining products are ethane, propane, butane, and pentanes, a mixture classified as an NGL; LPG is a subsection of this grouping of hydrocarbons that includes propane, butane, and isobutane. This section will define the characteristics of these petrochemicals pertinent to life safety of first responders and surrounding communities, including flammability data, heat release, vapor pressure, flash point, and boiling point.

4.1 Chemical Properties

NGLs are a group of hydrocarbons having between two carbon atoms (ethane) to five carbon atoms (pentane), that are removed from natural gas through condensation during the refining process. Figure 1 shows each group of hydrocarbons with its chemical formula and classification.

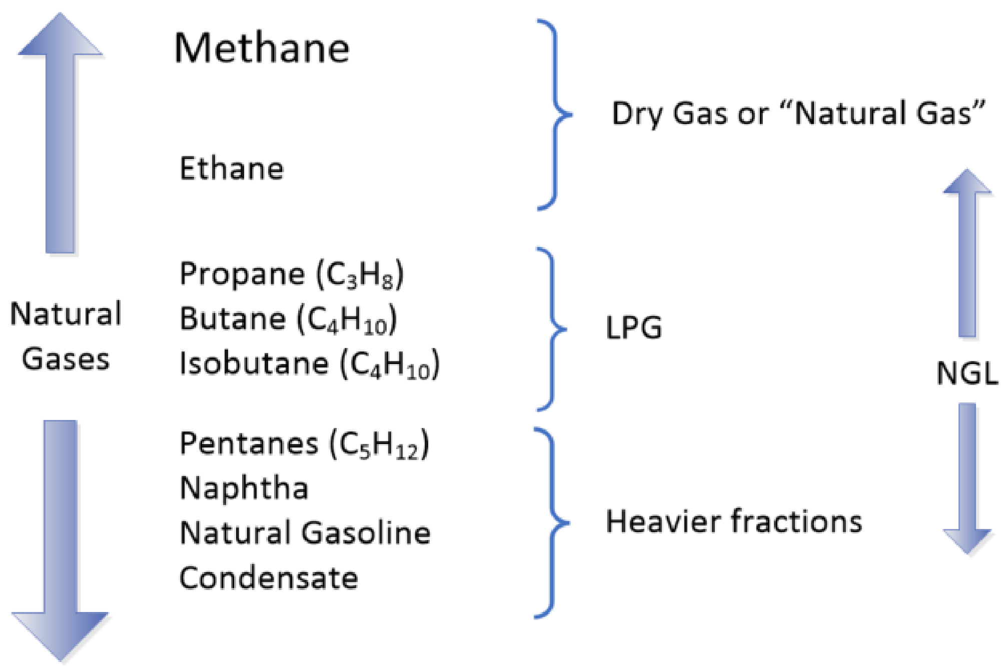

Figure 1—Natural Gas Group

The components of LPG and NGL are all vapors that are heavier than air at typical ambient temperatures, and therefore normally settle to ground level, move toward low-lying places, and accumulate in depressions. LPG and NGL storage and transport is almost always in liquid form. These gases are turned into liquid by increasing the pressure, with or without reducing the temperature.

This means that vessels, tankers, and pipelines containing these materials are under pressure, and a leak would result in the pressure within the vessel rapidly dropping. This pressure drop may cause a portion of the liquid to vaporize (turn to gas form), which is considered two-phase flow (both liquid and gas discharge simultaneously). If the ambient temperature is warm, it is likely that the discharge will be all gas. Some of the discharging gas may also return to liquid form depending on the storage pressure and ambient temperature; the liquid would pool near the discharge point. The higher the internal pressure in the storage or transport vessel, the faster the gas will escape, and the further gases may travel. Higher storage or transport pressure will also significantly decrease the product temperature with a release to ambient pressure; the resulting product temperature may be well below the vapor pressure of the product, resulting in a liquid release rather than a vapor.

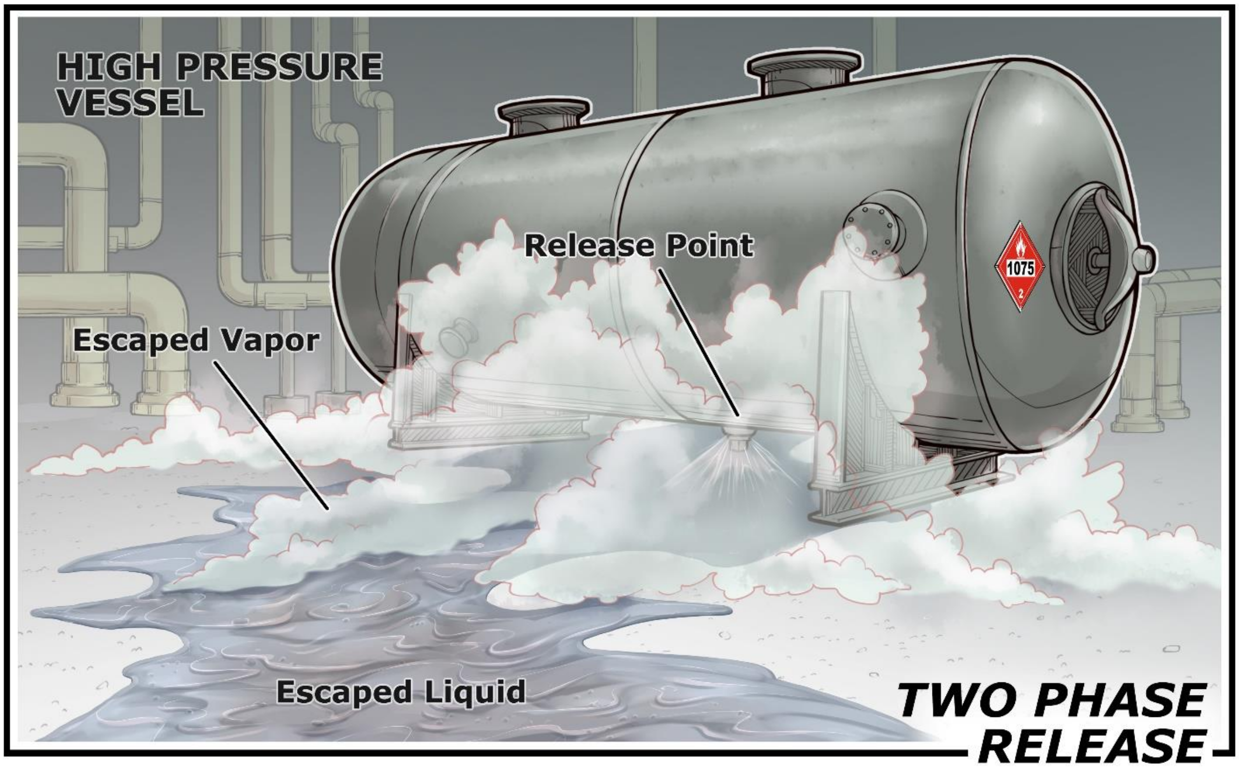

Figure 2—Two-phase Release

The weather conditions into which the LPG or NGL is released play an important part in the behavior of the material. If it is windy, the gases will be more quickly transported in the direction of the wind. Temperature also plays an important role; the warmer the ambient environment, the more the gas will tend to vaporize, creating a vapor cloud. If it is very cold, the gases may condense into liquid. If the ambient temperature is lower than the boiling point, the release product will tend to stay in liquid form. The approximate boiling points of common chemicals within NGL at atmospheric pressure are as follows:

— ethane: -128 °F

— propane: -44 °F

— butane: 31 °F

— pentane: 97 °F

Additionally, the physical terrain largely affects the behavior of the material. Since the gases are heavier than air, they tend to “flow” downhill and concentrate in lower areas, such as depressions or ditches.

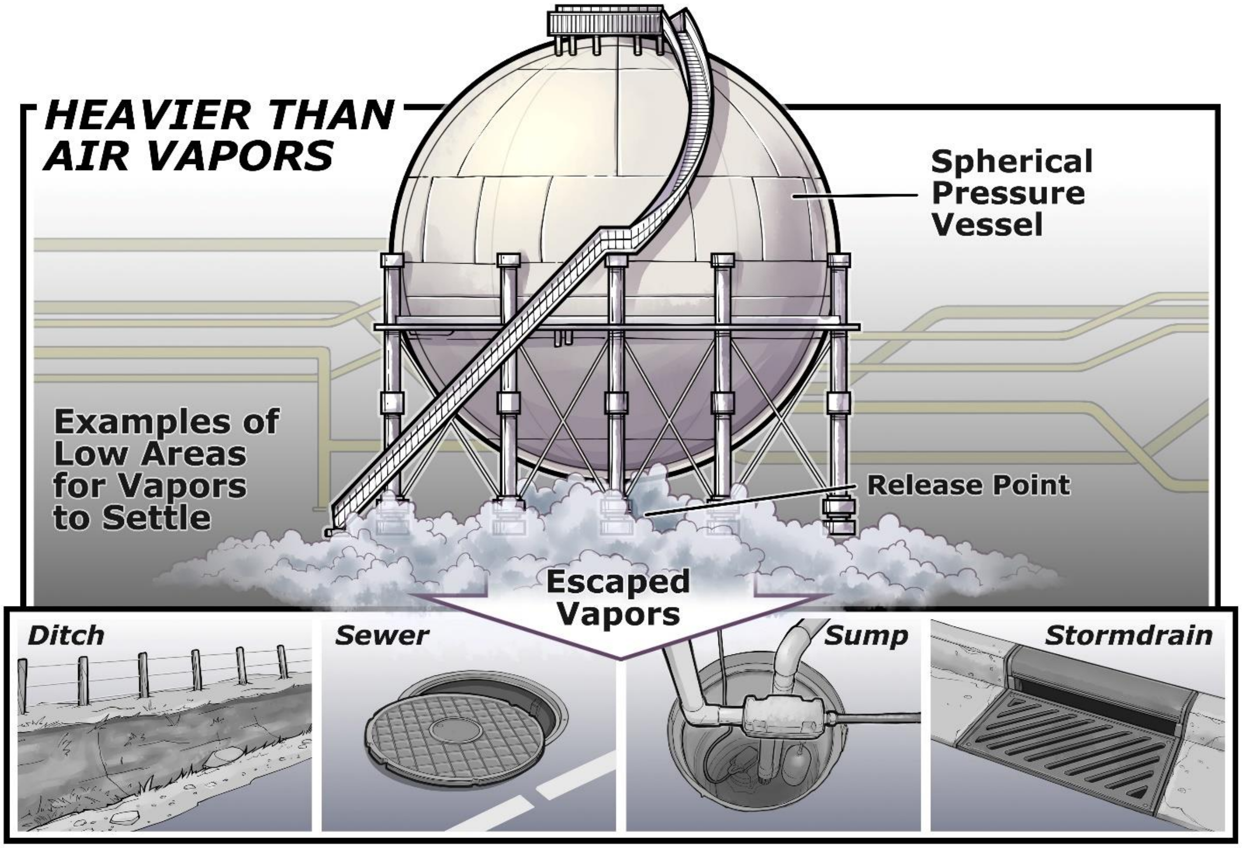

Figure 1—Heavier-than-air Vapors

4.2 Chemical Properties Related to Firefighting

There are various chemical properties that are important to know with regard to first response or firefighting of NGL or LPG fires or releases. Table 1 provides specific information for the individual products that make up mixtures of NGL or LPG. Because there is no limit to the number and quantity of mixtures, the exact product data must be determined from SDS sheets; however, the table provides a good baseline of information.

Table 1—Chemical Properties Regarding Firefighting

Chemical name	Flash point °F	Flammable Limits in Air %	Auto Ignition Temperature °F	Burning Rate in/min	Health Hazard Classification	Flammability Hazard Classification	Instability Hazard Classfication
Ethane	-211	2.9 to 13.0	940	0.29	1	4	0
Propane	-156	2.1 to 9.5	842	0.32	1	4	0
Butane	-76	1.8 to 8.4	550	0.31	1	4	0
Pentane	-57	1.4 to 8.3	500	0.34	1	4	0
NOTE All data taken from the USCG CHRIS database.							

All of the products have relatively low flash points and relatively high auto ignition temperatures, meaning that a release would require an external ignition source to ignite in most ambient conditions. However, it should always be assumed that ignition will occur as there are numerous examples of such releases igniting without an ignition source being identified. The flammable limits in air define the mixture percentage that must be present to support combustion. Where the concentration of the gas present is less than the flammable limits, the mixture is considered “too lean to ignite.” Where the concentration of the gas is above the flammable limits, the mixture is considered “too rich to ignite.”

The health, flammability, and instability hazard classifications are as defined by NFPA 704. Each of these classifications are ranked numerically between 0 and 4, where 0 represents the least hazardous and 4 represents the most hazardous. All NGL products are classified as having low health hazard consistent with minor irritation from exposure, high flammability hazard having a flash point less than 73 ºF, and no instability hazard.

5 Control Devices

As previously discussed, NGL products are most typically transferred and stored as a liquid, which requires high pressure and/or low temperature. With the pressurization or refrigeration of any transport or storage method, product control is required in accordance with NFPA 58 and API 2510, both of which cover LPG installation. It is noted that there is no NFPA or API document dedicated to NGL product control.

5.1 Pressure Relief

A basic premise of safety for all transportation methods is pressure relief. As required by NFPA and API, redundant pressure-relief devices are required on all vessels and tankers. High pressure is required to ensure the LPG/NGL products remain a liquid, but it is critical to ensure the elevated pressure does not exceed that of the maximum working pressure of the storage or transport method, which can rupture the vessel and cause catastrophic failure and large-scale product release. Pressure-relief devices are designed to have a specific set point to open that is less than the rated pressure of the vessel. Should the internal pressure reach the set pressure, the pressure-relief device will vent vapor to atmosphere, or to flare where provided, to reduce the internal pressure of the vessel. Though the release from the pressure-relief device is intentional, there is potential for formation of a flammable gas cloud to develop near the affected vessel or transport vehicle. Spring-loaded pressure-relief valves are resetting; therefore, upon reduction of pressure below the set point, the pressure-relief valve will close, stopping the release of vapor.

Additional pressure relief is often designed into vessels by a rupture disc. Rupture discs are safety devices constructed with a lower failure pressure compared to the rest of the vessel or tanker. Should the pressure increase beyond the set point of the pressure-relief valve and continue to increase, the rupture disc would fail prior to failure of the entire vessel. Rupture discs are not resettable; once they are ruptured, the entire vapor contents of the vessel will be discharged to atmosphere.

5.2 Internal Flow Control Valves

Internal flow control valves are widely used to meet the installation requirements of NFPA 58 for LPG vessels with water capacities of greater than 4,000 gallons. The basic design premise is to stop all flow and LPG transfer in the event of an emergency. Internal control valves are installed in the liquid supply and discharge outlets of vessels to control the flow of product into and out of the vessel. Internal valves are unique in that they bolt to the outside of the vessel, but the flow control portion of the valve is inside the tank. This installation allows for the valve to stop flow even with pipe or flange failure near the connection to the tank, limiting the quantity of product lost.

To meet the requirements of NFPA 58 and API 2510, most of the flow control valves use pneumatic pressure to open and control the positions of the valves, which are spring-loaded to fail closed. The pneumatic pressure may be supplied by a dedicated air compressor, the site-wide instrument air system, a nitrogen system, or any other inert gas supply, but for the purposes of this description, it will just be considered compressed air. When pneumatic pressure to the valve position control is lost, the valve will automatically close. Typically, the pneumatic tubing supplying the air to control the valve is designed to fail at 250 ºF. Should there be a fire or excess temperature near the discharge or supply of the vessel, the pneumatic tubing will fail, the air supply will be released, and the valve will close, stopping the transfer of product. Although there are other design arrangements permitted, the arrangement previously described is very common in the industry. Other arrangements may include check valves rather than internal flow control valves, electrical valve control rather than pneumatic, and fusible link valve closure rather than pneumatic tubing with a specific melting point.

5.3 Emergency Shutdown

NFPA 58 and API 2510 require product transfer emergency shutdown capabilities for all transfer locations. Emergency shutdown is typically installed at rail and truck load racks by way of automated valves that can be manually or automatically controlled. Manual operation of emergency shutdown is completed by an operator using a push button located adjacent to the transfer location. Automatic shutdown is completed by site automation controls and can be initiated by flame detectors, gas detectors, or upset process conditions. The intent is to stop the flow of an uncontrolled release to limit the size of the resulting gas cloud, reducing the likelihood of the gas cloud finding an ignition source leading to a flash fire or explosion. Many sites are equipped with vapor collection systems. Upon release from pressure-relief valve (or other type of safety valve), the vapors are transferred to a flare, combustion unit, or safe atmospheric location. Upon an emergency, it may also be possible to tap into a pipeline to relieve pressure, provided the vapors can be collected or distributed safety. In some remote instances, it may be possible to ignite released vapors to prevent flammable vapors from spreading; however, this method is generally not recommended as it is possible to escalate the event from the radiant heat generated by a potential jet fire at the point of the leak.

Transport vehicles are equipped with control valves at the connections, but there is no way to stop a release from a damaged tanker or rail car.

5.4 Drainage and Containment

Drainage and containment around large storage vessels (greater than 4,000 gallons) handling LPG/NGL is critical to prevent event escalation. Many storage areas are designed with bund walls surrounding the vessels that will capture a large-scale product release and drain the liquid into a remote basin, where it can vaporize in a location separated from the vessels such that radiant heat within the basin would not affect the vessels; however, remote impoundment may not always be provided. The purpose of the drainage to a remote area is to ensure there will not be a pool fire below large vessels leading to a BLEVE, which is described in detail in 8.2. Smaller residential and commercial LPG installations are not specifically required to have drainage or containment, but it is recommended to have no containment around the vessel to ensure any liquid leak will drain away from a vessel.

6 Site-specific Protection Methods Against Local Hazards

In addition to control methods, all process plants, storage terminals, and other LPG/NGL facilities may be equipped with release detection, passive and active fire protection systems, and/or process safety systems to control or isolate a release.

6.1 Release Detection

Combustible gas detection for LPG/NGL leaks is most reliable with fixed on-site monitoring equipment; this may include point combustible gas detectors or open path combustible gas detectors. Because LPG/NGL products have only a faint odor and potentially do not have added mercaptans (odorizer added to LPG that smells similar to sulfur), leaks of gas may not be detectable by sense of smell; therefore, gas detectors are very useful tools for release detection. Gas detectors are typically located throughout large process facilities, storage terminals, transfer locations, and production sites; however, due to the minimal detection ranges, they are not typically installed to monitor long pipelines, small facilities, or at smaller commercial installations. Locations of combustible hydrocarbon gas detectors are to be determined by an engineer based on site conditions and specific safety objectives.

Combustible gas detectors may operate using a catalytic bead, infrared light, or acoustic sound measurement. The catalytic bead detectors use electrically charged wiring to detect combustible gas. Infrared detectors measure the optical change in the wavelength of light associated with the presence of a hydrocarbon gas. Open path gas detectors operate similarly to infrared gas detectors; however, they consist of a transmitter and receiver that can be spaced up to hundreds of feet apart. Acoustic gas detectors consist of a microphone and a processor that listen for a high-pitch distinct sound level associated with a high-pressure gas leak. Acoustic gas detectors are capable of covering large areas compared to point gas detectors; however, they are not capable of distinguishing between flammable and nonflammable gases. All detectors are required to be monitored by a site PLC system, such as a DCS, SIS, or fire alarm panel.

With either detection method, there are generally two alarm set points, 5 %–25 % LEL and 10 %–50 % LEL depending on site, location, applicable codes, and company standards. The lower threshold typically initiates a high alarm signal and the higher threshold typically initiates a high-high signal. Generally, the high alarm threshold will only alert operators of an issue, while the high-high signal may initiate automatic shutdown or product isolation.

Because it is impractical to install fixed gas detectors along hundreds or even thousands of miles of pipeline, release detection can also be achieved via pipeline pressure and flow equipment. Pressure sensors are designed to initiate an alert to operators upon detection of a sudden drop in pressure in a pipeline, indicative of pipe failure. Similarly, flow monitoring is provided to measure the liquid flow rate from one end of a pipeline to the other. Any difference in flow rates would indicate a loss of product from a pipe failure.

6.2 Air Monitoring

With regard to a suspected release in a facility or along a pipeline, it is critical to identify the release location. Due to the change in pressure from a pipeline to ambient conditions, there may be a visible gas cloud; however, this may not always be the case. Without the presence of hydrocarbon leak detectors, a FLIR camera provides adequate air monitoring. FLIR cameras are relatively expensive and not easily accessible, but they provide an optical view of hydrocarbon gas release that cannot be seen by the human eye. FLIR cameras are to be used by plant personnel or first responders to pinpoint a leak in an open area where detection is not practically installed. FLIR cameras cannot be calibrated to detect specific concentrations of LPG/NGL, but will detect a mixture of hydrocarbons.

Figure 2—Air Monitoring

Additionally, personal gas detection monitoring equipment is often used by plant personnel and first responders. Photoionization detectors (PIDs) are gas detectors used to measure volatile organic compounds (VOCs). PIDs are often used to monitor potential VOC exposure for personnel and detect dangerous conditions. PIDs can be used for the detection of a wide variety of gases; however, in order to quantify a large number of chemicals using a single calibration gas, a correction factor must be used to obtain the measured concentration of the gas of interest. It is to be noted that the correction factor will vary based on the calibration of the detector and the gas of interest (i.e., if the detector is calibrated for methane, a correction factor is required to detect butane).

6.3 Isolation Methods

Product isolation is critical with regard to LPG/NGL releases, specifically high-pressure jet fires. Within plants and process facilities, various control valves are installed throughout piping networks, including at each vessel, at the suction and discharge of pumps and compressors, and various other locations. As such, a process facility has the capability to close specific valves to limit a release to a relatively small volume of product, which is the volume between isolation valves.

Similarly, pipelines are equipped with isolation valves; however, these valves are located much further apart, allowing for a significantly greater volume of product to be released due to the volume of piping between the isolation valves.

Isolation and valve closure is possible through various methods. The most common method is through plant automation. Should an upset condition be sensed by process controls or combustible gas detectors, isolation valves are automatically closed, limiting the quantity of product released.

6.4 Active Fire Protection

Active fire protection systems for LPG/NGL facilities typically include deluge water spray systems. Deluge water spray systems are designed to apply cooling water to structural supports and/or adjacent storage vessels. The water application flow rate is based on providing a specific application density in gallons per minute per square foot (gpm/sf), as defined by NFPA 15 or API 2030, which provide nearly identical application rates. Vessels are recommended to be cooled using 0.25 gpm/sf over the entire surface area of the vessel. Steel structures are recommended to be applied with 0.10 gpm/sf over the surface area of the protected structural steel. Pumps are recommended to be cooled using 0.50 gpm/sf over the surface of the protected pump.

The two most likely fires associated with LPG/NGL are high-pressure jet fires and liquid pool fires. It is not recommended to extinguish a jet fire, as this will result in a combustible gas cloud. Additionally, water is not recommended to extinguish a pool fire because the added water will heat the LPG/NGL, increasing the vaporization rate and essentially feeding the fire.

Therefore, active fire protection systems at LPG/NGL facilities are generally designed to apply cooling water to structural members to prevent further damage and event escalation. Water applied to adjacent vessels is designed to cool the vessels to prevent a BLEVE, which has the potential to cause significant damage to the affected plant and the surrounding area.

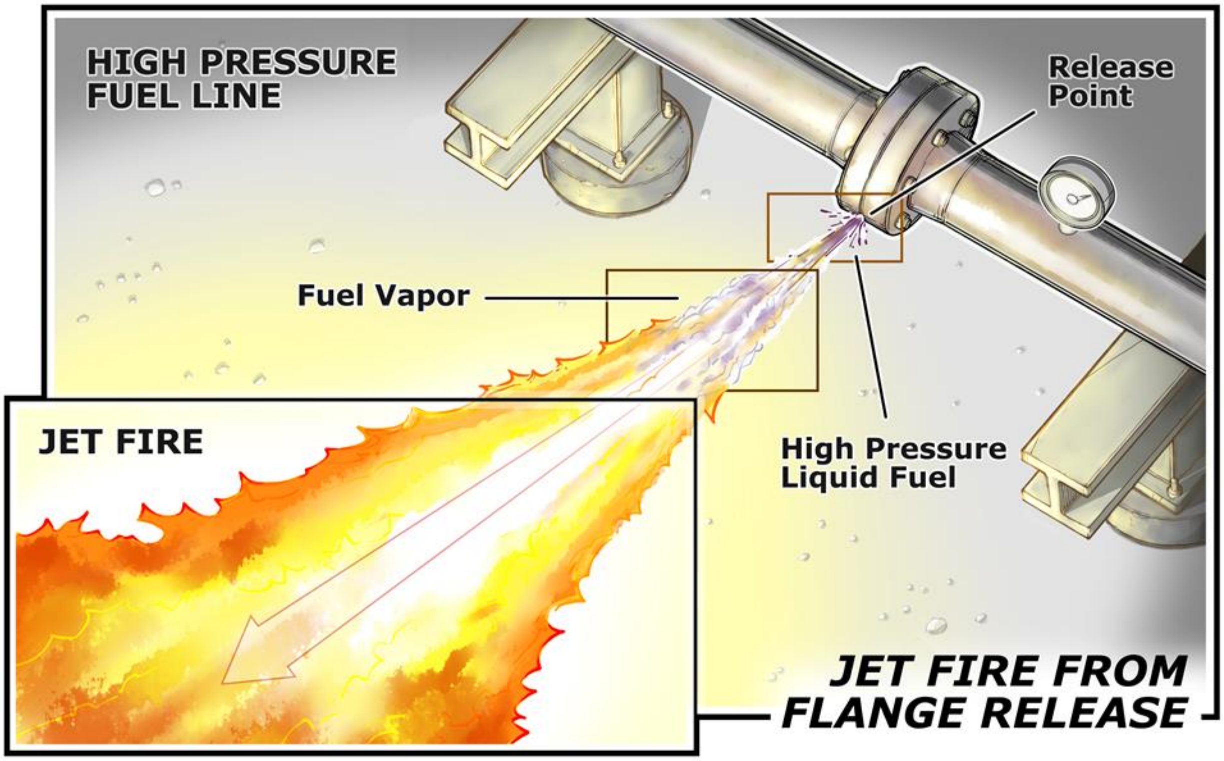

Figure 3—Jet Fire From Flange Release

6.5 Passive Fire Protection

Similar to active fire protection systems, the design intent of passive fire protection is to protect adjacent structures and/or vessels to prevent escalation of a fire event. The two most common passive fire protection materials are cementitious and intumescent coatings. Cementitious coatings are concrete-like materials that are applied to insulate steel, slowing the temperature increase of the steel when exposed to elevated temperatures. Cementitious coatings vary in thickness, as required by the manufacturer, but are generally about 2 inches thick. Intumescent coatings are applied to steel similarly; however, the coatings are much thinner compared to cementitious coatings. When the intumescent coating is exposed to increased temperatures, the coating expands, increasing its volume and decreasing its density. With the expansion, the temperature increase of the steel is then reduced. The two coating materials provide similar protection, but cementitious coatings are much thicker and heavier when compared to intumescent coatings; intumescent coatings are much more expensive.

Where firewater is not readily available, or there is high congestion within a plant, passive fire protection may be applied to specific structural members or vessels to prolong the time before failure of steel with elevated temperatures associated with fire. Passive fire protection is required on many vessel saddles and sphere supports in accordance with NFPA 58 and API 2510. Process-related structural members or pipe racks that are to be protected using passive fire protection are determined through a detailed design review as described in API 2218. Passive fire protection may also be applied to entire vessels where cooling water used for exposure protection is not available.

7 Event Evaluation and Responses

Most major events with LPG/NGL are initiated from a leak, vapor, or potentially liquid, creating a gas cloud that migrates to an ignition source, leading to flash fire, jet fire, liquid pool fire, or vapor cloud explosion. Upon arrival by any first responder, the event is to be evaluated by completing a “scene size up” by the incident commander as defined by the incident command structure. Further guidance on the creation of incident command structure is described in NFPA 1561.

The scene size up is to identify several items, first of which is to determine immediate hazards associated with the event; this may be radiant heat impingement from a fire or gas cloud formation from a product leak. Based on the immediate hazards, the incident commander is to further evaluate the scenario, determining the products involved, ambient temperature, wind direction, and wind speed. With this information, a safe command post can be established, and an incident action plan can be implemented. At all times during the event response, the safety of nearby residents, operators, and first responders shall be the primary concern.

7.1 LPG/NGL Release Scene Evaluation and Response

A gas release scene is to be evaluated first to determine the hazards associated with the material being released. Important information with regard to flammability, toxicity, and stability of the product is available in the SDS sheets. When responding to a release known to involve LPG/NGL, if the SDS sheets are not available, as might be the case with a pipeline, tanker, or small installation incident, it is assumed that the release will vaporize relatively quickly; it may create liquid pools with cold ambient temperatures; the vapors are heavier than air and will collect in low-lying areas; and the vapors are flammable with an outside ignition source. It is important to recognize the ambient air temperature during the release, since any NGL release will vaporize relatively quickly in warm conditions; however, cold weather may allow some NGL products to pool and vaporize slowly.

All personnel are to be notified and evacuated from the area, including plant personnel and/or neighboring areas. All ignition sources that can be safely accessed shall be removed from the affected area and gas monitoring equipment is to be used to determine the extent of the leak and dispersion of the gas cloud. A release in warm weather with rapid vaporization will create a large vapor cloud near the leak; however, as the vapor warms, the visible cloud will disperse, but the flammable region of the release may include areas that extend beyond the visible vapor cloud. Collection of a release in cold weather may create pooling of a clear liquid.

Whether at a pipeline or process facility, an LPG/NGL leak is to be isolated using control valves. Because isolation will not immediately stop the flow of product, the scene is to remain secure to ensure there are no ignition sources, specifically downwind of a release. Wind direction and speed are critical with regard to vapor dispersion. The wind direction is indicative of the expected vapor dispersion locations and the wind speed will indicate if a collection of vapors is possible. Because LPG/NGL vapors are heavier than air, they have the capability to collect in low-lying areas. However, this is less likely with greater wind speeds as the wind will disperse the vapor a greater distance and reduce the vapor concentration.

Due to the chemical properties of LPG/NGL, a release from a pipeline or vessel may be liquid, especially during cold weather. It is important to note that liquid spills will vaporize, and it is not recommended to apply water to the spill to increase vaporization. Doing so will increase the size of the vapor cloud and dispersion, thus increasing the potential for vapor migration finding an ignition source. However, where only vapor is present, water spray in a fog pattern may be utilized to “scrub” LPG/NGL vapors from the air to protect specific locations such as a residential area, roadway, or known ignition source. The water spray is to use any available water source to supply a fixed monitor or hand hose line to create a fog pattern where the gas dispersion is expected.

Toxic exposure from LPG/NGL is low and primarily only an inhalation hazard for first responders. It is never recommended for first responders to enter a confined space, or in areas where vapors from a release have collected, without proper protective gear, including an SCBA.

7.2 Fire Scene Evaluation and Response

After completing the scene size up and establishing a safe boundary around the affected equipment or area, an incident action plan can be initiated. All LPG/NGL product fire suppression efforts are to begin with product isolation and system shutdown. Until isolation has occurred, any firefighting strategies are to be geared toward a defensive action, protecting adjacent equipment and/or structures from the thermal effects of the elevated heat of a pool fire or jet fire.

When available, water is to be applied to structures or adjacent vessels to reduce the heat impact, preventing fire escalation. Water application may be from hydrants, hoses, fixed monitors, portable monitors, or even fixed water spray deluge systems. Water is to be applied only to the heated equipment and never at the source of the flame, as this may extinguish the fire, leading to a large, combustible gas cloud.

It may be possible to extinguish a small-scale liquid pool fire of LPG/NGL liquids; however, this is only possible with the application of a dry chemical extinguishing agent. The dry chemical agent "Purple K," in particular, is most effective at extinguishing these types of pool fires. It is noted that foam should never be used to suppress an LPG/NGL fire.

8 Offsite/Nearby Community Safety Considerations

In the event of an LPG or NGL release, the safety of personnel and property outside the boundaries of the facility (offsite) must be a primary concern. A release can result in fires that produce flames and intense heat (thermal radiation), explosions that cause overpressure (a shock wave over and above normal atmospheric pressure), and/or toxic cloud dispersion. The potential threat to nearby communities will be a function of the quantity and type of release, and proximity to the nearby communities.

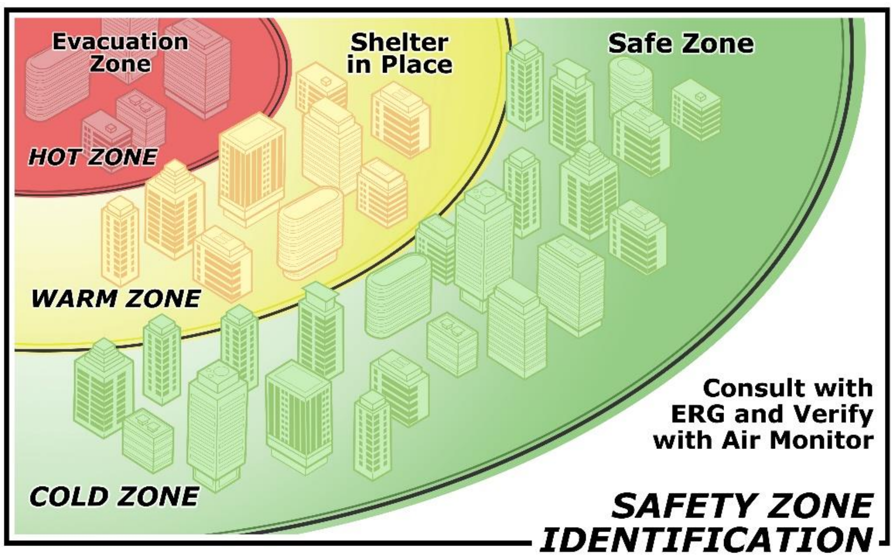

Figure 4—Safety Zone Identification

8.1 Fire Risks to Nearby Communities

Damage and injury from a fire resulting from an accidental release of LPG/NGL results from direct flame contact and radiant heat. The type of fire that occurs in a particular situation depends on several factors, including the nature of the material released, the pressure and temperature of the storage vessel or pipeline from which the material is released, the degree of mixing between the material and air, the location of any ignition source, and the ambient temperature, humidity, and wind conditions. The reach of the radiant heat is a function of the size of the fire, where a larger release with greater surface area will result in greater radiant heat exposure. A hypothetical example of radiant heat release from a catastrophic rupture of a rail car is shown in Figure 7.

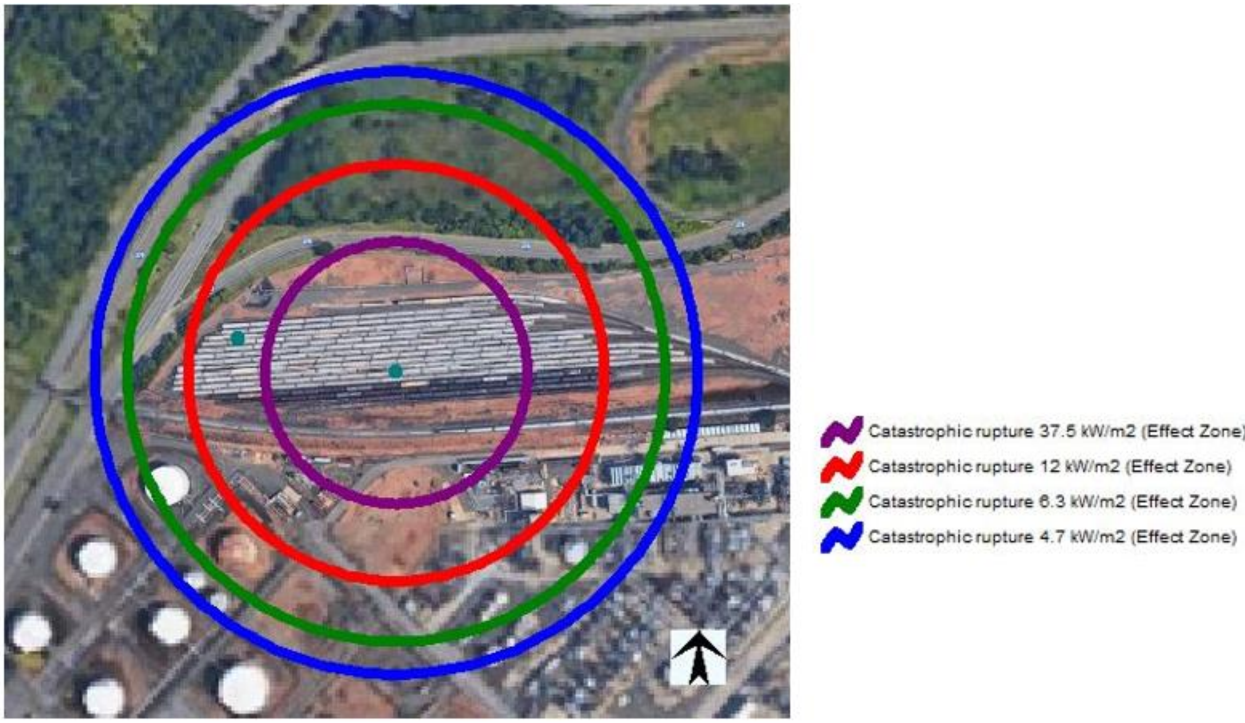

Figure 7—Radiant Heat Example

The rings indicate a range of radiant heat intensities—4.7 kW/m^2 is the maximum radiant heat intensity allowing emergency actions lasting 2 to 3 minutes by personnel without shielding but with appropriate clothing, and 37.5 kW/m^2 will cause structure failure of steel within minutes. Exposure to elevated radiant heat intensity leading to structural failure will result in weakening and bending of the steel prior to failure.

In general, nearby offsite communities have limited risk from an on-site fire unless they are very close to the site. However, if a flammable gas cloud forms from the release that is carried off site and encounters an ignition source, and if, upon ignition, there is not sufficient turbulence or confinement to accelerate the flame and produce a blast wave, a "flash fire" results. A flash fire is the rapid burning of a gas cloud but in such a way that it does not produce blast overpressures. While a flash fire also does not produce much radiant heat because the flame only lasts a few seconds, contact with the flame can cause serious burns.

8.2 BLEVE Risk to Nearby Communities

While on-site fires represent only limited risk to nearby offsite communities, a more significant danger results from the fact that the on-site fire can heat nearby storage vessels and lead to what is called a boiling liquid expanding vapor explosion, or BLEVE. If a nearby vessel is heated, the contents of the vessel are also heated. If the vessel contains a liquid stored under pressure and above its normal boiling point (such as LPG or NGL), the additional heat causes more liquid to evaporate (boiling liquid) and significantly increases the pressure inside the vessel due to the expanding vapor. If pressure increases faster than can be released by the pressure-relief devices, the vessel can fail catastrophically. When the vessel fails, the pressure immediately drops to atmospheric, and the remaining hot liquid rapidly boils, generating a large quantity of vapor. Significant damage is caused by the pressure wave from rapid expansion of the released vapor, ignition of a large fireball, and from flying pieces of the vessel and piping. A BLEVE is the most damaging event associated with the storage and transport of LPG/NGL. Though BLEVEs are most commonly associated with storage vessels, the hazard is also present with pressurized rail and truck tankers.

BLEVE blast overpressures can travel a great distance and depend greatly on the volume of the vessel. Table lists four different-size propane tanks typically used for residential or small commercial uses and the maximum distance that overpressure waves of 1, 5, and 10 psi travel should the tank experience a BLEVE. Note that at 1 psi, there would be partial demolition of houses, making them uninhabitable. At 5 psi, there is permanent damage to hearing, and significant damage to any building or infrastructure. At 10 psi overpressure, there is total building destruction and fatalities.

Table 2—Overpressure Impacts from the BLEVE of Small Propane Tanks

Tank Size (gallons)	Typical Uses	Predicted Overpressure Radius Resulting from BLEVE (ft)		
		1 psi	5 psi	10 psi
5 gallons	Home grills and patio heaters.	33.4	11.6	7.8
25 gallons	Home fireplaces, dryers, and grills.	68.4	23.5	15.3
100 gallons	Home heating, hot water, dryers, fireplaces, generators, and pool heaters.	94.4	32.9	22.3
500 gallons	Whole home heating systems, generators, and pool heaters.	165.1	56.1	36.2

For vessels greater than 500 gallons, the effects from a BLEVE are proportional to the size of the vessel. For large storage sites, overpressure effects from a BLEVE could be in excess of a mile. A hypothetical example of the blast overpressure from a BLEVE of a tanker is shown in Figure 8. Although an overpressure of 0.3 psi, shown in blue, would not cause structural instability, that pressure does have the capability to cause minimal damage to an area extending offsite.

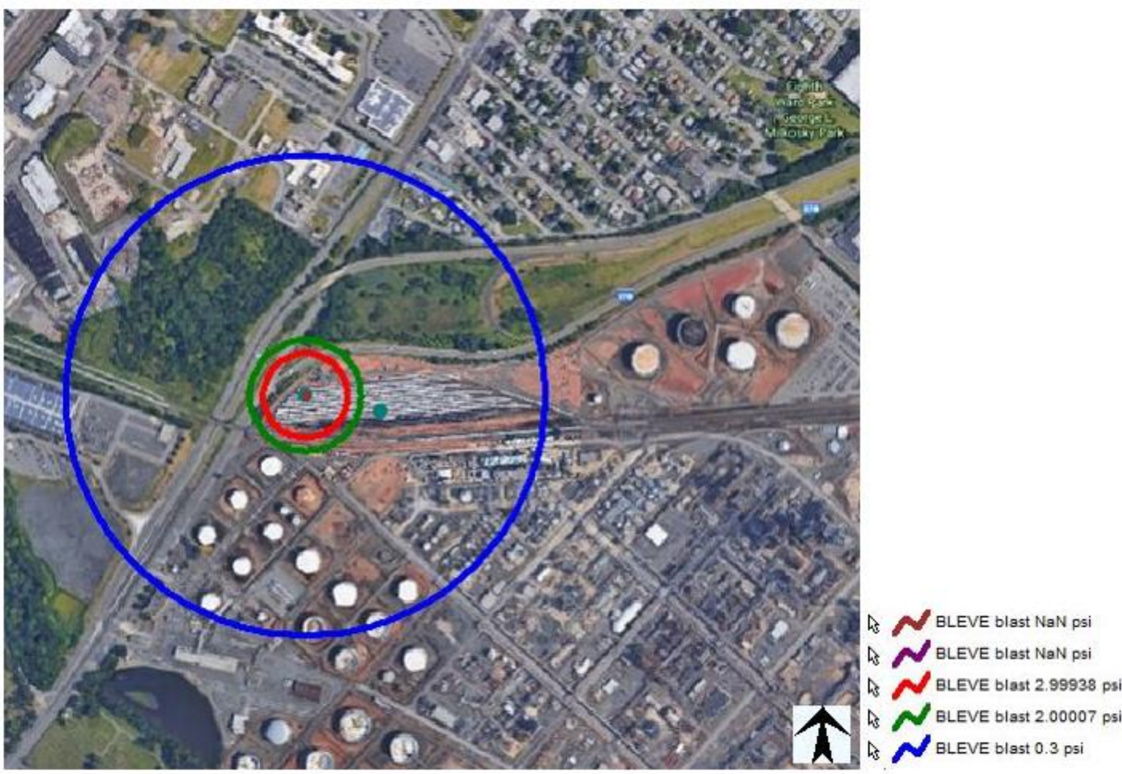

Figure 8—Blast Overpressure Example

It is important to cool the vessel to prevent BLEVE; this may include cooling water application from fixed monitors. Portable monitors may be used where fixed monitors are not available. When there is the risk of BLEVE, the area surrounding the vessel is to be evacuated immediately; this may include evacuating emergency responders and using unattended monitors to continue to apply cooling water to the affected vessel.

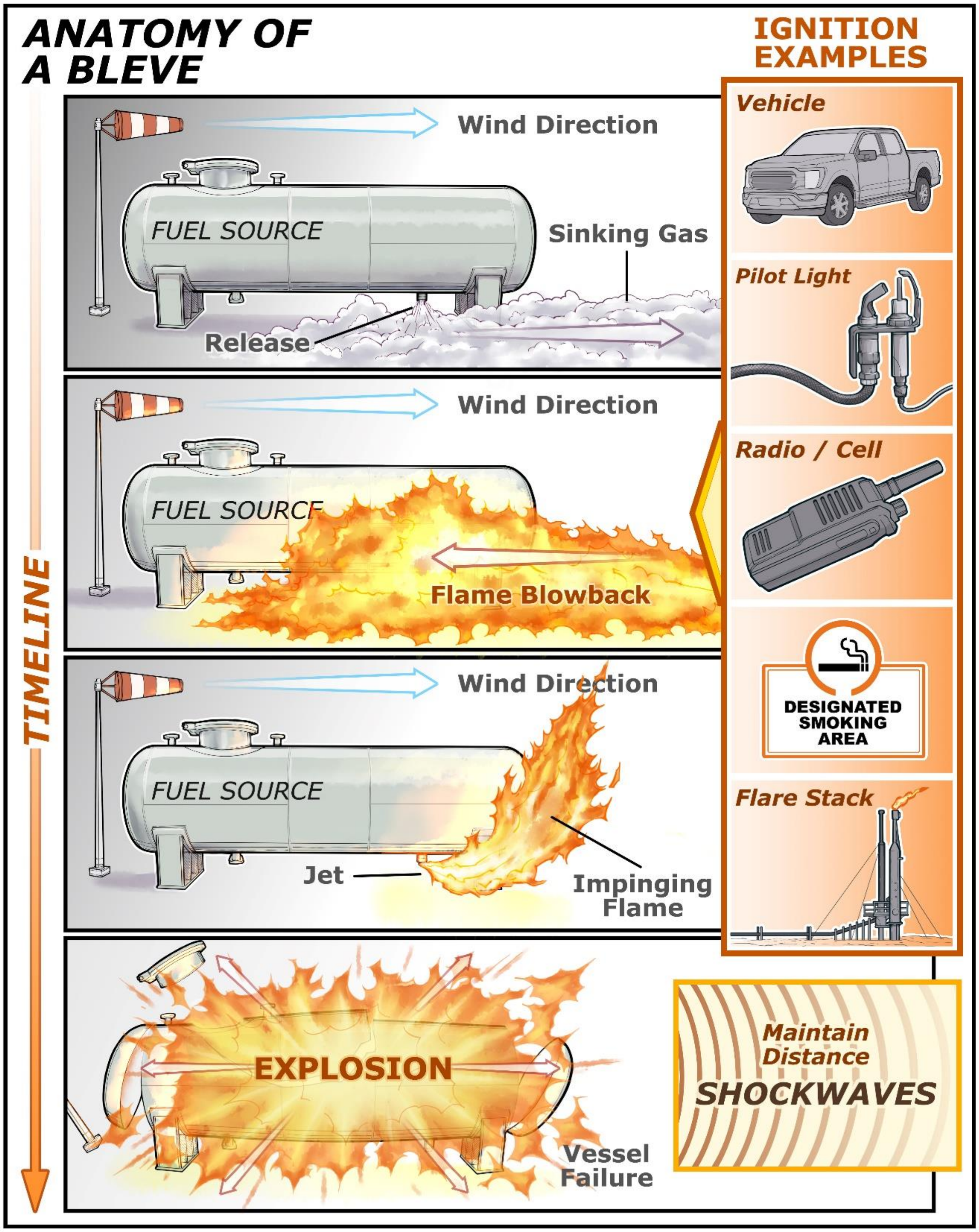

Figure 5—Anatomy of a BLEVE

8.3 Explosion Risk to Nearby Communities

An explosion may be defined as a phenomenon where a blast (pressure or shock) wave is generated in air by a rapid release of energy. To be considered explosive, the release of energy must be rapid enough and concentrated enough to produce a pressure wave that can be heard. The resulting blast wave is what is largely responsible for any offsite damage to structures and injury to people. In addition, indirect effects such as missile generation, crater formation, ground shock, and fires resulting from damage and releases caused by the blast wave (e.g., ruptured gas lines near homes) can cause additional serious damage, injury, or deaths. Table 3 provides estimates of the types of impacts on structures and people experienced at increasing overpressure levels.

Table 2—Overpressure Levels and Consequences

Overpressure (psi)	Effect	Overpressure (psi)	Effect
0.15	Typical pressure for glass failure.	2.5	50 % destruction of home brickwork.
0.3	“Safe distance” (95 % probability no serious damage below this level).	3	Steel frame buildings distorted and pulled away from foundation.
0.4	Limited minor structural damage.	4	Rupture of storage tanks.
0.50–1.0	Windows usually shattered; some window frame damage.	5	Wooden utility poles snapped. Eardrums ruptured.
0.7	Minor damage to house structures.	5.0–7.0	Nearly complete destruction of houses.
1	Partial demolition of houses; made uninhabitable.	7	Loaded train cars overturned.
1.0–2.0	Corrugated metal panels fail and buckle. Housing wood panels blown in. Cars overturned.	8	Fatal head Injuries.
1.0–8.0	Range for slight to serious laceration injuries from flying glass and other missiles.	9	Loaded train box cars demolished.
2	Partial collapse of walls and roofs of houses.	10	Probable total building destruction.
2.0–3.0	Non-reinforced concrete or cinder block walls shattered.	11	Fatal internal organ injuries.

These are peak pressures formed in excess of normal atmospheric pressure by blast and shock waves excerpted from multiple sources. For example:

Chang and Young, "Probabilistic Estimates of Vulnerability to Explosive Overpressures and Impulses,” *Journal of Physical Security* 4(2), 2010, pp.10-29.

Lees, Frank, *Loss* Prevention in the Process Industries, Vol. 1., London and Boston, 1980, Butterworths.

Glasstone, Samuel, *The Effects of Nuclear Weapons*. U.S. Atomic Energy Commission, 1964, Washington, D.C.

Generally, as the blast wave travels farther away from the center of the explosion, it loses energy, so the magnitude of overpressure and other effects experienced from the blast wave decreases as the distance from the explosion source increases.

8.3.1 Vapor Cloud Explosion Impacts

A vapor cloud explosion (VCE) results from the ignition of a flammable mixture of vapor, gas, aerosol, or mist, in which flame speeds accelerate to sufficiently high velocities to produce significant overpressure). VCEs are generally associated with the release of a sufficient quantity of flammable gas or liquid that vaporizes from a storage tank, process or transport vessel, or piping system. In general, five conditions must be met before a VCE with damaging overpressure can occur:

— The released material must be flammable and at suitable conditions to form a vapor cloud. Some portion of the resulting cloud must mix with air such that concentrations are within the flammable range for the material.

— An ignition source is needed to initiate the explosion. The presence of an ignition source should always be assumed because explosions and fires have occurred where no obvious ignition source could be identified.

— Ignition of the flammable vapor cloud is delayed until a cloud of sufficient size has formed. If ignition occurs as the flammable material is escaping, a large fire, jet flame, or fireball might occur, but a VCE is unlikely.

— Turbulence is required for the flame front to accelerate to the speeds required for a VCE; otherwise, a flash fire will result. In the absence of turbulence, under laminar or near-laminar conditions, flame speeds are too low to produce significant blast overpressure. In such a case, the cloud will merely burn as a flash fire.

— Confinement of the cloud by obstacles can result in rapid increases in pressure during combustion. Unconfined clouds usually do not generate sufficient flame speeds to result in overpressure effects.

The overpressure effects of VCEs vary greatly depending on the five factors listed above, but because the explosion can occur offsite, it represents a significant hazard for nearby, offsite communities. Upon response to a VCE, it is important not to enter structures due to instability. Severe structural damage may not be immediately evident and is to be determined by an expert prior to entry.

8.4 Toxic Cloud Risks to Nearby Communities

In general, the toxic effects of LPG and NGL are low. Table 4 shows various concentration levels for the major components of LPG and NGL and the potential acute response if exposure occurs.

Table 4—Toxicity Levels and Effects of Major Components of LPG and NGL

Material	IDLH*	Effects
Ethane	No data available	Exposure may aggravate pre-existing eye, skin, or respiratory conditions.
Propane	2,100 ppm	No effects were noted during a 10-minute exposure to propane at 10,000 ppm, but distinct vertigo was reported by volunteers exposed at 100,000 ppm for 2 minutes. The IDLH is set at 10 % of the lower explosive limit of propane in air based strictly on safety considerations.
Butanes	1,600 ppm	Drowsiness following exposure to 10,000 ppm for 10 minutes. High concentrations > 100,000 ppm) have shown health effects including ventricular fibrillation, encephalopathy, pulmonary distress, and death. The IDLH is set at 10 % of the lower explosive limit of butane in air based strictly on safety considerations.
Pentanes	1,500 ppm	A 10-minute exposure to 5,000 ppm did not cause mucous membrane irritation or other symptoms. The odor of n-pentane at this concentration is readily detectable. The revised IDLH is set at 10 % of the lower explosive limit of pentane in air based strictly on safety considerations.
* IDLH set by the National Institute for Occupational Safety and Health.		

Because the IDLH is 10 % of the LEL, a toxic cloud can extend much further downwind than a flammable cloud. Although health effects are minimal, downwind exposure of people to an accidental release of LPG or NGL, either outside or inside buildings, can cause public concern.

9 Local Responder Capabilities

It is important to understand the capabilities of the local first responders that may respond to an on-site incident, whether it be an LPG/NGL process plant, storage terminal, or small commercial installation of LPG.

Many large plants may train operators for emergency response or even hire a full-time fire brigade; however, small plants or commercial LPG installations will rely on local fire departments to respond to emergencies.

Whether the first responders work on-site or for a municipal fire department, all responders are to understand the hazards associated with the products on-site, including the presence of flammable vapors, potential for liquid pool fires, and the understanding that extinguishing an LPG/NGL fire may not always be the best option. Where a site is equipped with an on-site fire brigade, the local first responders are to be familiar with the equipment on-site and the capabilities of that fire brigade to ensure the brigades can work together during an event.

At a minimum, first responders are to be equipped with the following for a response to an incident involving LPG/NGL products:

— a fully functional fire truck with pumping capabilities;

— additional support vehicles depending on the size of the event;

— water tenders or tankers where water is not readily available;

— several lengths and diameters of hose, including 2½”, 5”, and 6”;

— portable monitors;

— trailer-mounted monitors;

— trained firefighters fully equipped with proper bunker gear;

— portable fire extinguishers;

— portable combustible gas monitors;

— visual gas monitoring equipment, such as a FLIR.

10 Historical Events

Throughout the history of the petrochemical industry, there have been many releases and catastrophic fire events. From these events, future plant, pipeline, and process facilities are improved to reduce the likelihood of repeating similar events. The following details several release events associated with NGL products and LPG within the United States over the past 60 years.

Baton Rouge, Louisiana, November 22, 2016—Isobutane Vapor Cloud Explosion

During maintenance activities at an Exxon-Mobil refinery, workers were attempting to open a plug valve. The plug valve was attached to a gearbox and handwheel, but when the workers spun the handwheel, the gearbox was malfunctioning. Standard practices at the refinery allowed the removal of the gearbox to use a pipe wrench directly on the valve. The workers removed four bolts that held the gearbox onto the plug valve via a bracket. Those same four bolts were also the bolts sealing the valve in the pipeline. When the workers attempted to open the valve using a pipe wrench, the seal broke, releasing isobutane into the refinery, where it found an ignition source and exploded. The United States Chemical Safety Board (CSB) investigated and found the particular plug valve, gearbox, and bracket were of a 30-year-old design and were being replaced by an updated design where the bracket was not bolted using the four pipeline sealing bolts. The CSB also found that while the workers were trained on hard-to-operate valves, the training did not include the removal of an inoperable gearbox. **This incident highlights the value of engineering controls, as the updated bracket design would have prevented this incident. This incident also highlights the importance of detailed written procedures for workers conducting hazardous work that specifically detail different configurations of equipment and specific training in hazard awareness.**

Ghent, West Virginia, January 30, 2007—Propane Tank Lean and Explosion

Propane gas was being transferred from an old tank to a new tank. The procedure required partially unscrewing a safety plug on the old tank to check that the tank's liquid withdrawal valve was properly sealed shut. If gas came through a small hole on the side of the plug, called a "tell-tale," it meant the tank's liquid withdrawal valve was malfunctioning and stuck in the open position, which meant the technician should shut the safety plug. On January 30, 2007, a junior technician was left to conduct the procedure unsupervised and without training. Instead of partially unscrewing the safety plug, the technician fully removed the plug, unleashing a stream of propane gas into the air. The stream was too strong for the technician to re-insert the safety plug, so the junior technician called the senior technician for guidance. The senior technician said to call 911. A Ghent Volunteer Fire Department captain arrived, and ordered the store to close to customers, but did not order an evacuation. The captain's evacuation order came several minutes later, but the store exploded within only a few seconds. Two propane technicians, the volunteer fire department captain, and an emergency medical technician lost their lives in the explosion. Several others survived with severe burns and other injuries. The United States Chemical Safety Board (CSB) investigated and found the junior technician had no training in a propane transfer, the propane tank was installed in an unsafe location too close to the store, and while the volunteer fire department captain had training in propane leak response, he had no continuing education for nine years leading up to the explosion. **This incident highlights the importance of technical training, supervision, continuing education, and emergency response planning.**

Sacramento, California, July 20, 2003—Coordinated Cleanup

Multiple explosions at a large industrial gas retail facility triggered a succession of fires that engulfed 12 large fleet trucks and blasted the roof off a building. The cause of the fire was possibly an accidental release of propane or propylene. Three hazardous materials fire crews and one engine company oversaw the clean-up, which was handled by the facility's employees. **This incident highlights the importance of coordinated remediation and mitigation efforts between industry personnel and local safety officials.**

Potterville, Michigan, May 28, 2002—Town Evacuated due to Large Derailment

Thirty-five of 58 train cars derailed in the town of Potterville about 12 miles southwest of Lansing, Michigan. The town's residents were ordered to evacuate because nine of the derailed cars contained liquid propane and two contained sulfuric acid. One car was spewing propane, one had a steady leak, and a third was punctured. All roads leading into the city were shut down and electrical power was cut off to most of the town to reduce the chance of any lingering gas finding an ignition source. **This incident shows a fortunate outcome due to rapid response by police and fire departments who took proper actions to evacuate the area, remove potential ignition sources, and secure the hazardous material.**

North Manheim Township, Pennsylvania, January 26, 1997—Car Hits a Propane Tank

A light-duty vehicle struck a pair of propane tanks at a service station, causing a release of gas into the air that formed an explosive gas cloud. Police quickly evacuated the area and firefighters from different regional fire departments flooded the air with water spray. The nearby roadway was closed for three hours as a precaution. **This incident is an example of how rapid police and fire response can contribute to a safe outcome after an LPG release.**

Kemp, Texas, August 26, 1996—Truck Ignition Triggers Fireball

Local 911 centers received a flurry of calls complaining of strong gas fumes. A liquid butane pipeline was leaking. Two teenagers started their pickup and ignited the butane-air gas mixture, causing a massive fireball and between 15 and 20 other fires. **This incident shows how combustible gas clouds can form and be ignited by simple sources.**

St. Louis, Missouri, August 7, 1993—Flooded Propane Tank Farm

St. Louis saw the greatest flood in its history, which knocked 51 propane tanks from their saddles at the Phillips Petroleum Co. tank farm. The tank farm was located next to the Des Peres River, less than 2,000 feet from where it meets the Mississippi River. The floating propane tanks presented an explosion hazard, and 12,000 residents were asked to evacuate. Plans to remove the approximately 90,000 gallons of propane were drawn. One of the plans was to vent the propane to the air in a high-density water fog. That plan was not chosen due to the risk of propane and air forming a combustible gas cloud. The chosen solution was to pump the propane from the floating tanks into underground gas mains, which was a routine practice for the gas utilities during wintertime to increase volume. **This incident highlights the importance of geographic location in hazardous chemical storage and engineering controls to mitigate risk should a natural disaster occur.**

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