Fire Investigation Summary

Fire Fighter Fatalities

Albert City, Iowa
April 9, 1998

A Boiling Liquid Expanding Vapor Explosion (BLEVE) resulted in the death of 2 fire fighters. Fire fighter training plays a key role in preventing such tragedies. Fire fighters should be made aware of the dangers posed by leaking LP-Gas or by flame impingement to tank containers.

National Fire Protection Association
Fire Investigations Department
At approximately 11:10 p.m. on Thursday, April 9, 1998, a fire was reported at a large turkey farm near Albert City, Iowa. The fire began when an all-terrain vehicle (ATV) driven by teenagers struck two pipelines carrying liquid propane from an 18,000 gallon (68,220 L) capacity LP-Gas tank to two vaporizer units, creating a leak. The ensuing cloud of vapor was ignited by a nearby ignition source. The teens were able to escape the area prior to ignition and went to a nearby farmhouse to phone 911.

The tank was located between three buildings: an office and storage building 60 feet (18 m) to the west, a large turkey coop 100 feet (30.5 m) to the east, and another storage building 90 feet (27.4 m) to the north. The buildings were of wood-frame construction with a combination of metal and wood exterior siding. A gravel road was located approximately 65 feet (19.8 m) south of the tank. The propane fuel was utilized in heater units located in the farm buildings.

The fire department arrived at approximately 11:21 p.m. The initial report given upon arrival stated that there was fire involving the propane tank and that the tank was venting from the relief vents at the top of the vessel. Fire was noted to be below the tank, as well.

The fire department began to set up operations to protect the exposed buildings with hose lines. Because there was no water supply in the area a tanker shuttle operation was implemented, with a portable tank left at the scene. The department’s tanker unit returned to town to refill after transferring its load of water to the portable tank. The remaining two engines and a rescue unit were set up on the northern side of the tank and began operations.

Two fire fighters advanced a hose line from the engine set up northwest of the LP tank. They positioned themselves at the west corner of the storage building immediately north of the tank. The fire chief joined them to monitor conditions from that vantage point. This group was approximately 100 feet (30.5 m) from the tank.

Two additional fire fighters advanced a hose line from the engine staged northeast of the LP tank between the building north of the tank and the large coop east of the tank. These men were approximately 90 feet (27.4 m) north of the tank.

The gas venting from the pressure relief valves on the tank created a loud noise similar to a jet engine, making communications on the fireground difficult. The fire chief indicated that the plan was to allow the tank to burn itself out and to protect exposures.

As this plan was being implemented, at approximately 11:28 p.m. a tremendous explosion occurred, sending large sections of the tank flying in four different directions.

The largest portion of the tank, a piece 24 feet (7.3 m) long, was hurled over 300 feet (91.4 m) into the large coop east of the tank. Another piece was propelled directly north, narrowly missing the two fire fighters positioned north of the tank. This piece went through the north building and was stopped by a silo more than 150 feet (45.7 m) from the tank’s original location. The force of this piece passing by the two fire fighters carried one of the men into the building and up against the far wall. He crawled out of the wreckage and rejoined the others.

The third large piece was thrown northwest from the tank’s location and...
struck the two fire fighters operating the hose line at the west corner of the north building. The impact killed the two men instantly. This piece narrowly missed the fire chief as he stood near the two men who were killed. However, he was badly burned by the blast.

Other pieces of the tank were scattered in the open field across the road from the tank. Some traveled almost 250 feet (76.2 m) from the site of the blast. A piece of one of the vent pipes was found embedded over three feet deep into a gravel driveway over 200 feet (61 m) west of the tank’s original location.

The fire was extinguished by the blast, leaving only several small hot spots that were promptly extinguished by fire fighters.

The fire chief, five fire fighters, and a sheriff’s deputy were injured in the blast. Three of the injured, two fire fighters and the chief were badly burned. The remaining two fire fighters and the deputy were treated and released from area hospitals.

On the basis of the fire investigation and analysis, the NFPA has determined that the following significant factors directly contributed to the explosion and the fire fighter deaths:

- Lack of protection around the LP tank installation and associated equipment. This lack of protection allowed the ATV to strike the vaporizer piping.
- The impingement of flame on the propane tank (in the vapor space), causing the tank shell to weaken and fail.
- The close proximity of fire department operations to the LP tank while the tank was being exposed to direct flame contact.
- The lack of an adequate and reliable water supply in close proximity to the site to allow for hose streams to be rapidly placed in service to cool the LP-Gas tank that was being impinged upon by flames from the broken pipes.
- The decision, given the lack of an adequate water supply, to protect the exposed buildings and not to relocate all personnel to a safe location.

*Fig. 1 - Location of personnel and apparatus at the time of the BLEVE*
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The National Fire Protection Association’s Fire Investigations Department documents some of the most significant fires and incidents throughout the world. The objective of these investigations is to determine what lessons can be learned from these incidents. The information is then made available to the fire safety community to be used in developing future codes and standards. A complete listing of reports is available, either upon request or can be viewed on our web page.

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FIRE FIGHTER FATALITIES
ALBERT CITY, IOWA
APRIL 9, 1998
LP-GAS BLEVE

ALBERT CITY, IOWA
APRIL 9, 1998

TWO FIRE FIGHTER FATALITIES

Prepared by

Robert Duval
Fire Investigator
National Fire Protection Association
ABSTRACT

At approximately 11:10 p.m. on Thursday, April 9, 1998, a fire was reported at a large turkey farm near Albert City, Iowa. The fire began when an all-terrain vehicle (ATV) driven by teenagers struck two pipelines carrying liquid propane from an 18,000 gallon (68m³) capacity LP-Gas tank to two vaporizer units, creating a leak. The ensuing cloud of vapor was ignited by a nearby ignition source. The teens were able to escape the area prior to ignition and went to a nearby farmhouse to phone 911.

The tank was located between three buildings: an office and storage building 60 feet (18 m) to the west, a large turkey coop 100 feet (30.5 m) to the east, and another storage building 90 feet (27.4 m) to the north. The buildings were of wood-frame construction with a combination of metal and wood exterior siding. A gravel road was located approximately 65 feet (19.8 m) south of the tank. The propane fuel was utilized in heater units located in the farm buildings.

The fire department arrived at approximately 11:21 p.m. The initial report given upon arrival stated that there was fire involving the LP-Gas tank and that the tank was venting from the relief vents at the top of the vessel. Fire was noted to be below the tank, as well.

The fire department began to set up operations to protect the exposed buildings with hose lines. Because there was no water supply in the area a tanker shuttle operation was implemented, with a portable tank left at the scene. The department’s tanker unit returned to town to refill after transferring its load of water to the portable tank. The remaining two engines and a rescue unit were set up on the northern side of the tank and began operations.

Two fire fighters advanced a hose line from the engine set up northwest of the LP-Gas tank. They positioned themselves at the west corner of the storage building immediately north of the tank. The fire chief joined them to monitor conditions from that vantage point. This group was approximately 100 feet (30.5 m) from the tank.

Two additional fire fighters advanced a hose line from the engine staged northeast of the LP-Gas tank between the building north of the tank and the large coop east of the tank. These men were approximately 90 feet (27.4 m) north of the tank.

The gas venting from the pressure relief valves on the tank created a loud noise similar to a jet engine, making communications on the fireground difficult. The fire chief indicated that the plan was to allow the tank to burn itself out and to protect exposures.

As this plan was being implemented, at approximately 11:28 p.m. a large explosion occurred, sending large sections of the tank flying in four different directions.
The largest portion of the tank, a piece 24 feet (7.3 m) long, was hurled over 300 feet (91.4 m) into the large coop east of the tank. Another piece was propelled directly north, narrowly missing the two fire fighters positioned north of the tank. This piece went through the north building and was stopped by a silo more than 150 feet (45.7 m) from the tank’s original location. The force of this piece passing by the two fire fighters carried one of the men into the building and up against the far wall. He crawled out of the wreckage and rejoined the others.

The third large piece was thrown northwest from the tank’s location and struck the two fire fighters operating the hose line at the west corner of the north building. The impact killed the two men instantly. This piece narrowly missed the fire chief as he stood near the two men who were killed. However he was badly burned by the blast.

Other pieces of the tank were scattered in the open field across the road from the tank. Some traveled almost 250 feet (76.2 m) from the site of the blast. A piece of one of the vent pipes was found embedded over three feet deep into a gravel driveway over 200 feet (61 m) west of the tank’s original location.

The fire was extinguished by the blast, leaving only several small hot spots that were promptly extinguished by fire fighters.

The fire chief, five fire fighters, and a sheriff’s deputy were injured in the blast. Three of the injured, fire fighters and the chief were badly burned. The remaining two fire fighters and the deputy were treated and released from area hospitals.

On the basis of the fire investigation and analysis, the NFPA has determined that the following significant factors directly contributed to the explosion and the fire fighter deaths:

- Lack of protection around the LP-Gas tank installation and associated equipment
- This lack of protection allowed the ATV to strike the vaporizer piping
- The impingement of flame on the propane tank (in the vapor space), causing the tank shell to weaken and fail
- The close proximity of fire department operations to the LP-Gas tank while the tank was being exposed to direct flame contact
- The lack of an adequate and reliable water supply in close proximity to the site to allow for hose streams to be rapidly placed in service to cool the LP-Gas tank that was being impinged upon by flames from the broken pipes
- The decision, given the lack of an adequate water supply, to protect the exposed buildings and not to relocate all personnel to a safe location
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Introduction

The National Fire Protection Association (NFPA) investigated the Albert City LP-Gas explosion in order to document and analyze significant factors that resulted in two fatalities.

The study was conducted by the NFPA as part of an ongoing program to investigate technically significant incidents. The NFPA’s Fire Investigations Department documents and analyzes incident details so that it can report lessons learned for life safety and property loss purposes.

The NFPA became aware of the Albert City incident the day after it occurred. NFPA Fire Investigator Robert Duval traveled to Iowa to meet with investigators from the State Fire Marshal’s Office and the local Sheriff’s Department and to view the scene and perform an on-site study of the incident. The information gathered during the on-site activities and subsequent analysis of that information are the basis for this report. Entry to the fire scene and access to the investigation reports were made possible through the cooperation of the Iowa State Fire Marshal’s Office and the Buena Vista County Sheriff’s Department.

This report is another of NFPA’s studies of fires having particularly important educational or technical interest. All information and details regarding fire safety conditions are based on the best available data and observations made during the on-site data collection phase and on any additional information provided during the report development process. It is not NFPA’s intention that this report pass judgment on or fix liability for the loss of life and property resulting from the Albert City explosion. Rather, the NFPA intends that its report present the findings of the NFPA data collection and analysis effort and highlight factors that contributed to the loss of life and property.

Current NFPA codes and standards were used as criteria for this analysis so that conditions at the scene of the explosion could be compared with state-of-the-art fire protection practices. It is recognized, however, that these codes and standards may not have been in effect during installation of the LP-Gas storage tank and associated equipment. The NFPA has not analyzed this event regarding the compliance with the codes and standards that were in existence when the tank and equipment were installed or during its operation.

The cooperation and assistance of the Iowa State Fire Marshal’s Office and Buena Vista County Sheriff’s Department are greatly appreciated.
BACKGROUND

INSTALLATION

The LP-Gas tank involved in this incident was located on a turkey farm situated approximately 2-1/2 miles (4.0 km) north of Albert City, Iowa.

The tank had a capacity of 18,000 gallons (68 m³) of liquid. The tank measured 42 feet 2 inches (12.8 m) in length and had an inside diameter of 106 inches (2.7 m). According to information from the nameplate on the tank, the tank walls had a thickness of 0.4576 inch (11.6 mm) at the head of the tank and a shell thickness of 0.770 inch (19.6 mm). The maximum working pressure was identified as 250 lbs. The maximum temperature was identified as 115°F (46.1°C).

The installation was equipped with three excess flow valves and three pressure relief valves with associated venting stacks. Two 1-inch diameter liquid lines were located approximately 26 inches (660 mm) above the ground and ran 37 feet (11.3 m) north between the tank and the two vaporizer units. These lines were supported by vertical metal pipe stands.

The tank was installed on the present site in 1987. The vessel was situated between two driveways and the gravel road. Trees of varying sizes were scattered around the tank.

The installation was equipped with two vaporizers (east and west). The vaporizers turn liquid propane into gaseous propane, which can then be utilized as fuel for heating or other equipment.

The LP-Gas was used in building unit heaters in each coop and other occupied areas. The tank and vaporizer installations were not protected with a fence or other forms of protection against physical damage.

The structures on the farm included several large turkey coops. Each coop [(300 feet x 75 feet) (91.4 m x 22.9 m)] housed turkeys being raised for sale. Other buildings included a storage building [(200 feet x 75 feet)(61 m x 22.9 m)] that was located 90 feet (27.4 m) directly north of the tank and a combination office and storage building located approximately 60 feet (18 m) northwest of the tank. The buildings were constructed of wood frame with corrugated metal or wood panel exterior siding and had concrete slab floors.
Figure 1 – Layout of Farm showing proximity of tank to surrounding buildings.

FIRE PROTECTION

No automatic fire protection equipment or alarms were in place in the buildings on the farm. Manual fire extinguishers were installed in the office, storage, and coop buildings.

FIRE DEPARTMENT

The Albert City Fire Department is an all-volunteer department of 25 members, providing service to a population of 850. The department maintains a single station and covers a response area of 100 square miles (259 square km).

New fire fighters receive a 24-hour course of basic fire fighting skills and safety. Topics include fire behavior, ventilation, fire streams, ladders, and breathing apparatus, among others.

WEATHER

The temperature at the time of the incident was 39° F (4°C). The relative humidity was 79 percent. The wind was 5 mph (8 km/h) from the southeast.
THE FIRE

DISCOVERY AND NOTIFICATION

On the evening of April 9, 1998, at approximately 10:30 p.m., a group of youths gathered at the farm approximately 2-1/2 miles (4.0 km) north of Albert City. Some of the youths knew that an all-terrain vehicle (ATV) was stored in the storage building on the property. One of them removed the ATV from the equipment shed and began riding the vehicle around the property. The youths took turns taking rides on the vehicle. At one point one youth drove off of the gravel driveway and through the grass south of the equipment building that was located north of the LP-Gas tank. The ATV was driven between the tank and building.

The ATV then struck the liquid lines that ran from the tank to the two vaporizers. This collision damaged the lines and caused liquid propane to leak and vaporize, creating a large white vapor cloud. The impact of the ATV’s striking the pipes caused a youth riding on the rear of the vehicle to be thrown off and into the vapor cloud. Another youth, witnessing the accident, ran to help the fallen youth, running into the vapor cloud as well. The driver of the vehicle turned the ATV around and again drove through the cloud to retrieve the fallen youth. They then drove the ATV several hundred feet to the storage barn and parked the vehicle inside. At this point the leaking gas had not ignited, but was still creating a white cloud near the tank.

The youths decided to drive to a nearby home to report the accident and to call 911. As they exited the property, in a car, one of them noticed that the gas had ignited and flames were now visible around the bottom of the tank.

Arriving at the home of one of the owners of the turkey farm approximately one-half mile (0.8 km) from the farm, the youths informed the owner of what had happened. The owner went out on the front steps of the home and could see flames from burning gas showing above the buildings. He then placed a call to the Buena Vista County 911 center located in Storm Lake. This initial 911 call was received at the center at approximately 11:10 p.m.

FIRE DEPARTMENT OPERATIONS

The Albert City Fire Department was dispatched to a reported fire at the turkey farm at 11:11 p.m. While en route, assistance was requested from the Marathon Fire Department at 11:19 p.m. because of the apparent magnitude of the fire.

The Sheriff’s Department notified the deputies on patrol in the area of Albert City at 11:11 p.m. and two patrol units responded. One deputy, responding from the south, reported seeing a glow in the sky from 4 to 5 miles (6.5 to 8.0 km) away. The
deputies conferred by radio while en route and decided to assist the fire department by blocking traffic at intersections east and west of the scene.

The first deputy arrived at approximately 11:18 p.m. and parked his patrol car in the driveway entrance east of the tank. He then conferred with one of the owners, who had just arrived, and asked how full the tank was and was informed that it was nearly full. The deputy then spoke to the fire chief, who arrived soon after. The chief informed the deputy that the fire department’s plan was to allow the gas to continue to burn while the department protected the exposed buildings. The fire chief asked the deputy to notify the local electrical utility of the incident because the fire potentially exposed power lines running on the south side of the tank. As he returned to his patrol car, the deputy noted flames under the west end of the tank, as well as the flames venting from the relief vents at the top of the tank.

The fire department units began arriving at 11:21 p.m. The chief had parked his vehicle at the east end of the building, located north of the LP-Gas tank. The first engine to arrive was positioned west of the north building [approximately 160-feet (48.8 m) northwest of the tank], between the north building and the office/shop building. The second engine was positioned east and slightly north of the tank near the east end of the north building [approximately 100-feet (30.5 m) northeast of the tank]. The Albert City tanker unit arrived and set up a portable tank behind the second engine, filled the portable tank, and then left to refill the apparatus from a hydrant about two miles (3.2 km) from the farm. The department rescue unit was positioned north of the second engine, immediately east of the north building. At this time there were 18 fire fighters at the scene.

Upon arrival of fire units, it was reported that fire was showing at the relief vents at the top of the tank and that flames were shooting north of the tank from the broken liquid lines. The noise from the operating vents was reported to be so loud that radio communication was very difficult. Fire officers interviewed by the State Fire Marshal’s office and the Sheriff’s Department reported that flames were also visible beneath the west end of the tank.

A 1-3/4 inch (45-mm) diameter hose line was deployed from the first engine to the west end of the north building. Two fire fighters began applying water to the corner of this building from a point approximately 100-feet (30.5 m) from the west-end of the tank. Another 1-3/4 inch (45 mm) hoseline was deployed from the second engine to the center of the exposed wall (south) of the north building. Two fire fighters began applying water to this wall from a point 87-feet (26.5 m) north of the center of the tank.

The first arriving sheriff’s deputy had returned to his patrol car to notify the electric utility of the fire. At this time he also relocated the car to a point several hundred feet southwest of the burning tank. While standing outside of the patrol car and talking on the radio, he noticed a change in the flames at the tank. He reported that it appeared that the tank had “swelled” in the center after which there was a tremendous
explosion. The deputy was thrown into a ditch beside the patrol car. After recovering from the fall into the ditch, he returned to the car and radioed for additional fire and rescue personnel to respond to the scene.

The second responding deputy was delayed when he took a wrong turn while en-route. He was just turning onto the road from the west when he heard the explosion. As he continued to the scene he met up with the first arriving deputy and began to survey the damage. Both deputies noted that the fire had gone out and that several small spot fires were burning on the ground and in the surrounding buildings.

When the BLEVE occurred, the tank broke into numerous pieces. The largest piece of the tank, measuring 24 feet (7.3 m) in length, was launched over 300 feet (91.4 m), landing 205 feet (62.5m) into the 300 feet (91.4 m) long turkey coop east of the tank. Another large piece of the tank flew directly north into and through the north building, coming to rest against a silo north of the building, having traveled more than 200 feet (61m) from the tank location. The third large tank piece rocketed northwest of the tank and hit the northeast corner of the office/shop building, before coming to rest 83 feet (25.3 m) from the rear of the building, more than 230 feet (70 m) from the tank location.

Photo 1 - Large section of tank shell that struck the two fire fighters northwest of tank’s original location. (Courtesy of the Iowa State Fire Marshal’s Office)
Several smaller pieces were scattered south of the tank’s original location, in the open field across the road from the tank. The farthest any of these pieces was found was 248 feet (75.6 m) from the tank location. A section of vent pipe was found driven over three feet (1 meter) into a gravel driveway west of the tank location.

Photo 2 - Section of vent piping embedded in gravel driveway several hundred feet west of the tank’s location. (Courtesy of the Iowa State Fire Marshal’s Office)

The Marathon Fire Department arrived shortly after the blast and completed extinguishment of the remaining spot fires. They also provided lighting to assist investigators until daylight.

CASUALTIES

In the moments following the explosion, attempts were made to take a head count to determine the number of injured and missing. Fire department members, with assistance from the two sheriff’s deputies and the former Albert City fire chief (who was staffing the ambulance) began accounting for the injured and dead.

The fire chief, standing approximately 100-feet (30.5 m) northwest of the west end of the tank when the BLEVE occurred, was badly burned by the fireball. The chief’s protective clothing was burned along the back surface of the turnout coat and the rear and sides of the bunker pants. An assistant chief and another fire fighter, who were standing approximately 150-feet (45.7 m) northwest of the tank, were thrown to the
ground by the blast. The assistant chief suffered burns to his face while the other fire fighter suffered multiple injuries. A third fire fighter, standing along the east side of the office/shop building, approximately 100 feet (30.5 m) west of the tank location, was thrown to the ground by the blast and suffered minor injuries.

Figure 2- Aerial view of the aftermath showing locations of units and personnel at the time of the blast. (Numbered circles indicate location of personnel at the time of the blast. Lettered rectangles indicate the location of apparatus.)

One of the two fire fighters operating the hose line north of the tank was thrown to the ground by the blast. The second fire fighter on this hoseline was thrown through the north building, coming to rest against the north wall, inside the building. After getting his bearings, the second fire fighter returned to the front of the building to check on the first fire fighter. The fire fighter who was thrown into the building found the first fire fighter and others frantically searching for him in a crater along the
south side of the building. The crater was created when the large tank piece hit the ground prior to traveling through the building.

The first arriving sheriff’s deputy suffered numerous bruises and scrapes when he was thrown into the ditch.

All injured personnel were transported to local hospitals. Those suffering burn injuries were transferred to a burn center in Sioux City.

The two fire fighters who were on the hose line at the southwest corner of the north building were killed instantly as a large piece of the tank traveled through the spot where they were standing at the time of the blast. The subsequent medical examiner’s report stated the cause of death as massive blunt trauma to all body systems.
DAMAGE

The tank, concrete supports, and associated piping were completely destroyed in the blast. The two vaporizers were badly damaged as well.

The office/shop building suffered severe structural damage to the northeast corner of the building, as the tank piece traveled through the building. The force of the part hitting the building scattered debris and equipment from inside the building for several feet north of the building.

The building north of the tank location was cut nearly in half by the tank piece that slammed into the structure. Portions of both the north and south exterior walls of the building were torn open, and lightweight wood roof trusses in the central portion of the building were badly damaged.

The coop building east of the tank location was severely damaged when the large section of the tank was thrown into the building by the blast. The entire west wall of this building was destroyed, as were several lightweight wood trusses within the building.

Photo 4 - View showing tank’s original location looking north. Damage to the building was from tank shell section being thrown through the structure. - NFPA
Photo 5 - Largest section of tank shell, [24 feet (7.3 m)] in length, thrown east over 300 feet into a coop building. (Courtesy of the Iowa State Fire Marshal’s Office)

The first arriving engine, which was positioned by the office/shop building was badly damaged by flying debris. The windshield and other front surfaces of the engine were scratched, dented, and marred by this debris.
**Time Line**

11:10 p.m. 911 calls received reporting a fire on the farm on 490th Street.

11:11 p.m. Albert City Fire Department and Buena Vista Sheriff's Department dispatched to a possible building fire at farm on 490th Street.

11:15 p.m. Flames reported visible by fire officers and sheriffs en route.

11:16 p.m. Another 911 call reports the fire to be in an LP-Gas tank at the 490th Street address.

11:16 p.m. Marathon Fire Department requested to respond as well.

11:18 p.m. Propane tank involvement confirmed by arriving sheriff. Reports that no were buildings involved yet.

11:21 p.m. Fire Department units begin to arrive.

11:24 p.m. Fire Department begins operation of protecting exposures.

11:24 p.m. Sheriff reports that a “big LP tank” is involved.

11:27 p.m. Sheriff relays request from fire chief to have power company respond to the scene due to the proximity of the fire to power lines.

11:28 p.m. Sheriff reports “very large explosion” There are no injury estimates. EMS units requested to the scene.

11:28 p.m. Albert City and Buena Vista Ambulances dispatched.

11:30 – 11:36 p.m. Reports of several serious injuries.

11:39 p.m. Sheriff reports at least two fatalities. State Fire Marshal requested.

11:44 p.m. Two fatalities confirmed. Fire Department conducting head count.
Analysis

ORIGIN AND CAUSE

The damage caused by the ATV striking the liquid lines from the tank to the vaporizers caused liquid propane to escape, forming a vapor cloud, which eventually found an ignition source and ignited. Eventually, the flames from the vapor lines impinged upon the tank shell, weakening the steel and resulting in a Boiling Liquid Expanding Vapor Explosion (BLEVE).

Investigators from the State of Iowa Fire Marshal’s Office and the Buena Vista County Sheriff’s Department have not determined the source of ignition of the escaping liquid vapor. The most likely ignition factor would be the two vaporizers located within 37 feet of the tank.

BLEVE

The phenomenon known as a Boiling Liquid Expanding Vapor Explosion (BLEVE) can occur when fire impinges on the tank shell above the liquid level of the contents of the tank. This impingement causes the metal to weaken and fail from the increased internal pressure causing the vessel to rupture into two or more pieces.

BLEVEs can result from mechanical damage to a tank, as well. Such damage can be the result of a train derailment, traffic accident, or other physical shock. When a BLEVE occurs, the vessel (or portions thereof) can travel hundreds of feet, with tremendous force, and the escaping fuel will ignite and cause an expanding fireball.

The following is an excerpt from Section 4, Chapter 7, of the NFPA Fire Protection Handbook (18th edition) on the Liquefied Gas BLEVE:

All liquefied gases are stored in containers at temperatures above their boiling points at NTP and remain under pressure only so long as the container remains closed to the atmosphere. This pressure ranges from less than 1 psi (6.9 kPa) for some cryogenic gas containers to several hundred psi for noncryogenic liquefied gas containers at normal storage temperatures. If the pressure is reduced to atmospheric, such as through container failure, the substantial heat that is in effect “stored” in the liquid causes very rapid vaporization of a portion of the liquid, to a degree directly proportional to the temperature difference between that of the liquid at the instant of container failure and the normal boiling point of the liquid. For many liquefied flammable gases, this temperature difference at normal
atmospheric temperatures can result in vaporization of about one third of the liquid in the container.

Because overpressure relief devices are set to discharge at pressures corresponding to liquid temperatures above normal atmospheric temperatures (to prevent premature operation), the liquid temperature is higher than this if container failure occurs when a relief device is functioning. Therefore, more liquid is vaporized under these conditions—often over one half of the liquid in the container. This is the usual situation when a container fails from fire exposure. The remaining liquid unvaporized is cooled by the “self-extraction” of heat when the pressure is reduced to atmospheric and is cooled to near its normal boiling point.

Liquid vaporization is accompanied by a large liquid-to-vapor expansion. It is this expansion process that provides the energy for propagation of cracks in the container structure, propulsion of pieces of the container, rapid mixing of the vapor and air resulting in the characteristic fireball upon ignition by the fire which caused the BLEVE, and atomization of the remaining cold liquid. Many of the atomized droplets burn as they fly through the air. However, it is not uncommon for the cold liquid to be propelled from the fire zone too quickly for ignition to occur and fall to Earth still in liquid form. In one case, dissolved spots in asphalt paving were noted up to 1/2 mile (0.8 km) from the site of an LP-Gas BLEVE. In other BLEVEs, fire fighters have been cooled by cold liquid passing in their vicinity.

Reduction of internal pressure to atmospheric level in a container results from structural failure of the container. Failure is most often due to weakening of the container metal from flame contact; however, this will happen if the container is punctured or fails for any other reason.

It is also known that the entirely satisfactory performance of a spring-loaded relief valve to design parameters cannot prevent a BLEVE. By its nature, such a valve cannot reduce the pressure to atmospheric but only to a point somewhat below its start-to-discharge pressure. Therefore, the liquid will always be at a temperature above its normal boiling point, pressure will remain inside the container, and the container structure will be stressed in tension.

It is extremely difficult to significantly heat the container metal where it is in contact with liquid because the liquid conducts the heat away from the metal and acts as a heat absorber. For example, when the relief valve cited in this example is the discharging propane liquid
stays in the 120 to 140°F (49 to 60°C) range. As a result, the metal temperature is well within safe limits. This situation does not exist for the metal in the vapor space of the container, as vapor is relatively nonheat conductive and has little heat-absorbing capacity.

In most BLEVEs that have been studied where the failure was due to metal overheating, it originated in the metal of the vapor space and was characterized by both the metal stretching and thinning out and the appearance of a longitudinal tear which progressively got larger until a critical length was reached. At this time, the failure became brittle in nature and propagated at sonic velocity through the metal in both longitudinal and circumferential directions. As a result, the container came apart in two or more pieces.

**Magnitude of a BLEVE**

Although most liquefied gas BLEVEs that involve container failure result from fire exposure, a few BLEVEs have occurred due to container failures from other causes, such as corrosion or impact from an outside force. Impact failures are particularly noticeable in transportation accidents involving railcars and cargo vehicles. In these cases, the BLEVE generally occurs simultaneously with impact.

The size of a BLEVE depends upon the weight of the container pieces and upon how much liquid vaporizes when the container fails. This is analogous in many respects to the performance of rockets, as far as propulsion of container parts is concerned. Most liquefied gas BLEVEs occur when containers are from slightly less than 1/2 to about 3/4 full of liquid. The liquid vaporization-expansion-energy to container-piece weight ratio is such that pieces are propelled for distances up to approximately 1/2 mile (0.8 km). Deaths from such missiles have occurred up to 800 ft (244 m) from larger containers. Fireballs several hundred feet in diameter are not uncommon, and deaths from burns have occurred to persons as much as 250 ft (76 m) from the larger containers.

**Time intervals for fire-caused BLEVEs**

The time between initiation of flame contact and a BLEVE varies because it depends upon such widely varying factors as the size and nature of the fire as well as the container itself. Uninsulated containers located aboveground can BLEVE in the absence of water cooling in a matter of a very few minutes in the case of small containers to a few hours for very large containers. Data on insulated containers is meager because only cryogenic containers and some reactive-gas containers are usually insulated. However, there is no
doubt that insulation designed for fire-exposure conditions can delay BLEVE times significantly. In one case involving an insulated LP-Gas railroad tank car, the BLEVE did not occur until 20 1/2 hr of fire exposure—undoubtedly an extreme example. In comparison, using fire tests on LP-Gas railroad tank cars, a BLEVE occurred in 93 min in the insulated case, as opposed to 25 min for the uninsulated tank.¹

Ignition of the escaping liquid vapor in this instance was reported by the youths, who were leaving the scene to report the accident at approximately 11:05 p.m. The fire was reported to the fire department at 11:10 p.m. Fire department units arrived at approximately 11:21 p.m. The explosion occurred at approximately 11:28 p.m., 18 minutes from the time of first notification.

PROTECTION OF TANK INSTALLATION

The tank and vaporizer installation at this location was not protected against physical damage by fences or other physical barriers. The tanks and associated equipment were located on a section of grass, approximately 100 feet x 100 feet (30.5 x 30.5 m) in size. This area was bordered on three sides by a roadway and two gravel driveways.

Paragraph 3-2.4.1 of NFPA 58, Standard for the Storage and Handling of Liquefied Petroleum Gases (1998 edition), states “where physical damage to LP-Gas containers, or systems of which they are a part, from vehicles is a possibility, precautions shall be taken against such damage”. The type of traffic encountered in the area determines the type of protection (e.g., fencing, concrete bollards).

Had this installation been protected against vehicular traffic, the liquid lines would not have been damaged by the ATV, which began the tragic chain of events that led up to the death of two fire fighters.

FIRE DEPARTMENT OPERATIONS

In responding to incidents involving LP-Gas, fire departments have many factors to consider.

Training: Fire fighters should be familiar with the basic properties of LP-Gas (e.g., vapor density). Knowledge of these properties allows fire fighters to make decisions regarding exposures and evacuations.

Fire fighters should be aware of the dangers posed by leaking LP-Gas or by flame impingement to a tank container. By reviewing these dangers, the fire officer or fire fighter can make decisions based on the potential danger present (Risk vs. Benefit evaluation).

¹ Fire Protection Handbook 18th Edition (NFPA 1997), 4-74 – 4-75
Operations: When controlling an LP-Gas leak and/or fire the following three methods of control should be utilized:


1) Slow or stop the flow of gas, if there is a leak with no fire present. This action is appropriate when the flow can be controlled through intact valves or control devices and by personnel that are trained in the operation of the control devices are present.

2) Dissipate gas vapors through ventilation or the application of water streams to prevent the vapors from reaching a flammable mixture within the flammable range.

3) Apply water to exposed containers and equipment to keep these items cool and prevent failures and BLEVEs from occurring.

The major consideration for the water application method is the availability of an adequate and reliable water source for the constant and long-term application of water to the exposed equipment. The amount of water required is dependent on the size of the leak or fire, the size and location of the tank, and the amount of fuel in the tank.

The water supply must be of sufficient quantity for the prolonged application of water streams. The supply must also be reliable.

If the supply is a natural water source (i.e., pond, lake, or river), the supply should be available in cold weather. The available supply should be on-site or nearby.

The amount of time required to establish the water supply due to its distance from the site or other factors should be considered.

Upon arrival, the fire department could find burning LP-Gas or a cloud of unignited gas. With the unignited gas, the dissipation of the vapors can be accomplished by the application of water fog streams.

If a container is being exposed to fire or if flames are impinging on the container, water should be applied directly to the vessel. The larger the container, the larger the potential BLEVE hazard. A “rule of thumb” regarding the rate of application of cooling water is that water should be applied at a rate of 500 gpm (1892 L/min) for each point of flame impingement (the point where flames come in contact with the tank shell).

When confronted with a container that is being impinged upon by flames, time is the most important factor to consider. Containers can be in serious danger of
experiencing a BLEVE after less than 10 minutes of intense flame impingement on an unwetted portion of the outer surface. This time frame can encompass the time it takes for the fire to be reported, and for the fire department to arrive, size-up the scene, and begin to place sufficient hose streams in operation. The hose streams should be operated from a safe distance from the container as well, so as not to expose fire fighters to any further danger. The operation of unattended monitors would also limit exposure to personnel.

In the case of the Albert City incident, the BLEVE occurred approximately 18 minutes from the time the fire department was notified, and within 8 minutes of the time the apparatus had arrived.

A final objective the fire officer or fire fighter has to consider is whether to attempt to control vapors (when unignited gas is present), to apply water to the container being exposed to flame, or to establish a safe evacuation area and allow the gas to burn off or the BLEVE to occur.

The decision to remove fire units to a safe location and evacuate any civilians in danger can be a difficult one for fire fighters. The first instinct of fire fighters may be to attempt to attack the fire or attempt to control escaping gas vapors. The officer or fire fighter must weigh the information available with the potential outcomes and perform a risk vs. benefit analysis of the situation. In many cases the better course of action may be to retreat to safe location and monitor the situation from a distance.
CONCLUSION

Over the past 25 years, there have been several incidents where fire fighters were killed after being exposed to Boiling Liquid Expanding Vapor Explosions. Included in these incidents is the BLEVE that occurred in 1973 in Kingman, Arizona. This blast involved rail cars and resulted in the death of 12 fire fighters. An incident in 1974 at a St. Paul, Minnesota, housing development resulted in three fire fighter fatalities.

After these and other tragedies, training programs warning the fire service of the potential dangers of BLEVEs were developed. It was recommended that the lessons learned from these incidents be used to help develop operational plans and procedures to guard against similar incidents.

Recently, several more fire fighters have been killed in BLEVE incidents occurring in farm settings:

- Ste. Elisabeth de Warwick, Quebec, Canada (6/27/93) – Four fatalities
- Burnside, Illinois (10/2/97) – Two fatalities

In each of these cases the relief valves were operating upon arrival of fire units. However, flame impingement in each case resulted in sufficient weakening of the involved tanks. The weakened tank shells ruptured and tank pieces were propelled in all directions, striking nearby buildings, equipment, and personnel. Therefore, it should not be assumed that because the relief vents are operating, a BLEVE would not occur. The potential for a BLEVE should be considered any time there is direct flame impingement on a LP-Gas vessel at the vapor space of the vessel. Since it is difficult to detect whether the flame impingement is above or below the liquid level in an emergency situation, the potential of a BLEVE should always be given the utmost consideration.

The most effective way to reduce the potential of a BLEVE in tanks exposed to fire is to apply large quantities of water to the affected tanks in order to cool the vessels. This process requires that large amounts of water be readily available for extended time periods. Unattended hose stream or monitor devices should be utilized to complete this task. Use of these devices limits the exposure to fire fighters from an explosion.

If a sufficient amount of water cannot be applied to the tank without exposing personnel, then fire fighters should be withdrawn to a safe remote location, and fire should be allowed to burn. In the case of train derailments or other large scale
incidents, a large “hot zone” should be established to reduce the exposure to fire forces and civilian population.

Differing from most modes of fire attack, where an aggressive approach is recommended, fires involving LP-Gas tanks should be approached with extreme caution. Incident commanders should not be hesitant to order a withdrawal of forces to safe positions and to allow the fire to burn out or the tanks to fail and result in a BLEVE.
Synopsis of Burnside, Illinois, LP-Gas explosion
(10-2-97)

Two volunteer fire fighters were killed and another two seriously injured when a 1000 gallon (3,785 L) LP-Gas tank exploded after it was exposed to a fire in a nearby grain dryer. Upon arrival of the fire units, the tank was reported to be venting. Fire fighters took shelter behind a storage building while applying water to the tank in an attempt to cool the exposed surface. Within minutes of the fire department’s arrival, the tank exploded, sending large pieces in all directions. Pieces of the tank and nearby structures struck several fire fighters and a fire engine.

Synopsis of Warwick, Province of Quebec, LP-Gas explosion (6-27-93)

On the morning of June 27, 1993, at 9:02 a.m., the Warwick Volunteer Fire Department responded to a report of a barn fire. When fire department units arrived at approximately 9:12 a.m., they found a large cattle barn ablaze. During the size-up phase, a 4000 litre (1,056 gallon) propane tank was found close to the involved barn. The relief vents were operating on the tank, shooting flames over 15 feet (4.5 m) into the air.

Fire fighters began to apply water to the exposed tank in an effort to cool it. Suddenly, the tank exploded and split into two large pieces. The blast sent one of the pieces into an open field nearby, while the other piece traveled over 150 feet (45 m), glancing off of a fire engine, before travelling another 750 feet (230 m) where it struck a vehicle parked on the road and trapped the occupant.

The explosion killed four fire fighters and injured three others as well as four civilians, including the occupant in the vehicle on the road.
The following is a list of the NFPA documents that contain information relating to
fire department operations at incidents involving hazardous materials.

<table>
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<th>NFPA DOCUMENTS</th>
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<tr>
<td><strong>NFPA 471, Recommended Practice for Responding to Hazardous Materials Incidents</strong></td>
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| This recommended practice applies to all organizations that respond to hazardous materials incidents and recommends standard operating guidelines for responding to such incidents. Planning procedures, policies, and application of procedures for incident levels, personal protective equipment, decontamination, safety, and communication are specifically covered in this document.

The purpose of this document is to outline the minimum requirements that should be considered when dealing with responses to hazardous materials incidents and to specify operating guidelines for responding to hazardous materials incidents. It is not the intent of this recommended practice to restrict any jurisdiction from using more stringent guidelines.

The recommendations contained in this document should be followed by organizations that respond to hazardous materials incidents and by incident commanders responsible for managing hazardous materials incidents. |

| NFPA 472, Standard for Professional Competence of Responders to Hazardous Materials Incidents |
| This standard identifies the levels of competence required of responders to hazardous materials incidents. It specifically covers the competencies for first responders at the awareness level, first responders at the operational level, hazardous materials technicians, incident commanders, hazardous materials branch officers, hazardous materials branch safety officers, and other specialist employees. |
The purpose of this standard is to specify minimum competencies for those who will respond to hazardous materials incidents. It is not the intent of this standard to restrict any jurisdiction from exceeding these minimum requirements.

One purpose of the competencies contained in this standard is to reduce the numbers of accidents, injuries, and illnesses during response to hazardous materials incidents and to help prevent exposure to hazardous materials in order to reduce the possibility of fatalities, illness, and disabilities among emergency response personnel.

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<th>NFPA 1500, <strong>Standard on Fire Department Occupational Safety and Health Program</strong></th>
<th>The purpose of this standard is to specify the minimum requirements for an occupational safety and health program for a fire department and to specify safety guidelines for those members involved in rescue, fire suppression, emergency medical services, hazardous materials, operations, special operations, and related activities.</th>
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<tr>
<td><strong>NFPA 1561, Standard on Fire Department Incident Management System</strong></td>
<td>This standard establishes minimum performance requirements for an incident management system based on concerns for the safety and health of fire department personnel. The benefits of an incident management system extend far beyond this single concern, but personnel health and safety is considered to be the most important reason to implement an incident management system. This standard can also be permitted to be used for guidance in meeting the requirements for an incident command system as outlined in other NFPA documents, including NFPA 471, Recommended Practice for Responding to Hazardous Materials Incidents, and NFPA 472, Standard for Professional Competence of Responders to Hazardous Materials Incidents.</td>
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The incident commander has the ultimate responsibility for the safety of all fire department personnel operating at an incident and for any and all other persons whose safety is affected by fire department operations. Risk management provided a basis for the following:

(a) Standard evaluation of the situation  
(b) Strategic decision making  
(c) Tactical planning  
(d) Plan evaluation and revision  
(e) Operational command and control.

Many of the requirements of this standard could be satisfied by adopting a “model” system (such as the Incident Command System) that is intended to provide for a uniform approach to incident management while providing for some variations to meet local requirements.

An incident management system is intended to provide a standard approach to the management of emergency incidents. The primary objective is always to manage the incident, not to fully implement and utilize the incident management system. The command officer should be able to apply the incident management system in a manner that supports effective and efficient management of the incident. The use of the system should not create an additional challenge for the incident commander.

The following document relates to the installation of LP-Gas storage tanks and distribution equipment:

**NFPA 58, Liquefied Petroleum Gas Code**

This standard establishes minimum requirements for the installation, storage, transportation, and use of LP-Gas storage containers, systems, and equipment.