LP-GAS BLEVES RESULT IN FIRE FIGHTER FATALITIES

National Fire Protection Association Fire Investigations
Albert City, Iowa / Burnside, Illinois / Ste. Elisabeth de Warwick, Quebec, Canada
http://ncsp.tamu.edu/reports/NFPA/vapor_explosion.htm

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(See last page for information on an excellent Canadian first-responder training film/manual.)

On April 9, 1998 an Boiling Liquid Expanding Vapor Explosion (BLEVE) involving an 18,000-gallon LP-Gas tank on a turkey farm outside of Albert City, Iowa resulted in the death of two fire fighters. Since 1993, at least two other similar incidents, involving LP-Gas in a farm setting resulted in the death of six fire fighters. The first incident in Ste. Elisabeth de Warwick, Quebec, Canada, on June 27, 1993, resulted in the death of four fire fighters. The other BLEVE occurred in Burnside, Illinois, which resulted in two fatalities on October 2, 1997.

This bulletin summarizes the Albert City, Burnside, and Ste. Elisabeth de Warwick incidents and presents lessons learned from the incidents and those topics that should be revisited. This bulletin was prepared for the members of the fire service and others in order to raise their awareness of hazards present when an LP-Gas tank is involved in or exposed by fire. It is not the intention of this bulletin to pass judgement on, or fix liability for, the loss of life or property resulting from the incidents reviewed.

Albert City, Iowa (April 9, 1998)

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 teenagers riding an all terrain vehicle (ATV) struck two pipelines carrying liquid propane from an 18,000 gallon (68,220 L) capacity tank to two vaporizer units. The ensuing cloud of vapor was ignited by a near-by ignition source. The teens were able to escape the area prior to ignition and went to a near-by farmhouse to phone 911.

The LP tank was located between three buildings; an office and storage building 60 ft (18 m). to the west, a large turkey coop 100 ft. (30.5 m) to the east and another storage building 45 ft. (12 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 ft. (19.8 m) south of the LP tank.

The fire department arrived at 11:21 p.m. The initial report given upon arrival was that there was fire below the propane tank and the tank was venting from the relief vents at the top of the vessel.

The fire department began to set up operations to protect the exposed buildings with hose lines. There was no water supply in the area so a tanker shuttle operation was established, with a portable tank left at the scene.

After transferring a load of water, the department's tanker unit drove the two miles to town to refill. The remaining two engines and a rescue unit set up on the north side of the LP 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 LP tank. The fire chief joined them there to monitor conditions from that vantage point. This group was approximately 100 ft. (30.5 m) from the LP tank.

Another group of two 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 ft. (27.4 m) north from the LP tank.

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

As this strategy was being implemented at approximately 11:28 p.m. a tremendous explosion occurred, sending large sections of the LP tank flying in four different directions (see Figure 1 -- [Diagram: http://ncsp.tamu.edu/reports/NFPA/bleve-2.jpg]).

The largest portion of the LP tank, a piece approximately 24 ft. (7.3 m) long, was hurtled over 300 ft. (91.4 m) into the large coop east of the LP tank (see Photo 1). Another piece was propelled directly north, narrowly missing the two fire fighters positioned north of the LP tank.

An NFPA Fire Investigator traveled to the scene to document the incident. 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 firefighter deaths:

* Lack of protection around the LP tank installation and associated equipment that allowed the ATV to strike the piping.
* The impingement of flame on the propane tank, causing the tank shell to weaken and eventually 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 sufficient hose streams to be rapidly placed in service to cool the LP-Gas tanks that was being impinged upon by flames from the broken pipes
* The decision to protect the exposed buildings and not relocate all personnel to a safe location given the fire impinging directly on the LP-Gas tank and the lack of a life hazard exposure.

This piece went through the north building and was stopped by a silo over 150 ft. (45.7 m) from the LP 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 re-joined the others.

The third large piece traveled northwest from the LP 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 fire fighters instantly. This piece also narrowly missed the fire chief as he stood near the two men that were killed. He was burned badly by the blast.

Other pieces of the LP tank were scattered in the open field across the street from the tank. Some traveled almost 250 ft. (76.2 m) from the site of the blast. A piece of one of the vent pipes was found embedded over 3 ft. (0.9 m) deep into a gravel driveway over 200 ft. (61 m) west of the LP tank's original location (see Photo 2).

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

Two fire fighters were killed, and the fire chief, five fire fighters and a sheriff's deputy were injured in the blast. The chief was badly burned along with three others. The remaining fire fighters and the deputy were treated and released from area hospitals.

Burnside, Illinois, October 2, 1997

Two volunteer fire fighters were killed and another two seriously injured as a 1,000 gallon (3785 L) LP-Gas tank BLEVE'd when it became exposed to a fire in a nearby grain dryer. The LP tank was reported to be venting upon arrival of the fire units.

Fire fighters took shelter behind a storage building 60-80 ft. (18.3-24.4 m) from

the LP tank while applying water to the tank in an attempt to cool the exposed tank. Within minutes of the fire department's arrival the LP tank exploded sending large pieces in all directions. Pieces of the LP tank and near-by structures struck several fire fighters and a fire engine. A large piece of the LP tank went through the storage building striking two fire fighters.

Ste. Elisabeth de Warwick, Quebec, Canada

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 they arrived at approximately 9:12 a.m. the fire department found a large cattle barn ablaze. During the size-up phase, a 4000 litre (1055 gallon) propane tank was found close to the involved barn. The relief vents were operating on the tank shooting flames over five meters (16 ft.) into the air.

Fire fighters began to apply water to the exposed LP tank in an effort to cool it. Suddenly, the tank BLEVE'd and split into two large pieces. The blast sent one of the pieces into an open field, while the other piece traveled over 45 meters (150 ft.), and struck a fire engine, and continued another 230 meters (754 ft.) where it struck a vehicle parked on the road trapping an occupant

Three fire fighters were killed when the piece struck the engine, where they were donning protective equipment and preparing hoselines. The fourth fire fighter was killed when he was thrown approximately 45 meters (150 ft.) as the LP tank part slammed into the engine.

The blast also injured three fire fighters as well as four civilians, including an occupant in the

vehicle on the road.

ANALYSIS

BLEVE

The phenomenon known as a Boiling Liquid Expanding Vapor Explosion (BLEVE) is the result of a liquid within a container reaching a temperature well above its boiling point at atmospheric temperature, causing the vessel to rupture into two or more pieces. A BLEVE can occur when fire impinges on the LP tank shell at a point or points above the liquid level of the contents of the LP tank. This impingement causes the metal to weaken and fail from the internal pressure.

BLEVEs can result from mechanical damage to a tank, as well. This damage can be the result of a train derailment, traffic accident, or other physical shock. When a BLEVE occurs, debris may travel hundreds of feet, with tremendous force, and the escaping fuel can ignite causing an expanding fireball.

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. In one instance, however, a 30,000 gal (113.5 m3) tank car of LP-Gas was only severely weakened by impact during derailment and did not BLEVE until more than 40 hours later. The tank car had been lifted and moved without incident in the interim. At the time of failure, however, the internal pressure was increasing as the ambient temperature was rising.

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.

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 and any damage dome to the tank. Uninsulated containers located aboveground can BLEVE in the absence of water cooling in a matter of a very few minutes.

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. 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 the dangers of these, the fire officer or fire fighter can make decisions based on the potential danger present (risk vs. benefit).

Operations: When controlling an LP-Gas leak and/or fire the following three methods of control should be utilized:

1. If there is a leak with no fire present, the flow of gas should be slowed or stopped. 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.

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

3. Applying water to exposed containers and equipment to cool them and prevent failures and BLEVEs from occurring. The major consideration for this method is the availability of an adequate 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 and its location.

    * The water supply must be of sufficient volume for the prolonged application of water streams. The supply must also be reliable.
    * If the supply is a water source such as a pond, lake or river, determine if the supply available in cold weather. Is the supply available on-site or near-by?
    * Estimate the amount of time it is going to take to establish the water supply based on the distance from the site.

If a container is being exposed to fire or flames, water should be applied directly to the vessel. The larger the container, the larger the potential BLEVE hazard. The cooling water should be applied at a minimum rate of 500 gpm, at each point of flame impingement, by unmanned master streams, as not to expose fire fighters to any further danger.

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 ten minutes of intense flame impingement on a dry portion of the outer surface. This time frame can encompass the time it takes the fire department to arrive, size-up the scene, and begin to place sufficient hose streams in operation. In other words, there is no safe time period in which operations can be established. In the case of the Albert City incident, the BLEVE occurred approximately 18 minutes from the time the fire department was notified, and within eight minutes of the time the apparatus had arrived.

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

Physical Protection of Tank Installation

In the Albert City, Iowa incident the tank and vaporizer installation location was not protected against physical damage. The tanks and associated equipment were located on a section of grass, approximately 100 ft. x 100 ft. 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 (1995 edition) states that where physical damage to LP-Gas containers, or systems 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 (i.e. fencing, concrete bollards, etc.)

Conclusion

Training programs warning the fire service of the potential dangers of BLEVEs, should be re-emphasized. It is recommended that the lessons learned from these incidents be used to help develop operational plans and procedures to guard against similar incidents.

In each of these incidents, the relief valves were operating upon arrival of fire department. The weakened tank shells ruptured sending tank pieces in all directions striking near-by buildings, equipment and personnel. Therefore, it should not be assumed that because the relief vents are operating, a BLEVE would not occur. When flames are impinging on an LP tank, there is no safe side or end to approach. In a BLEVE, sections are thrown in all directions. 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, when venting through relief valves is not adequate to relieve the pressure build-up. Since it is difficult to detect if the venting is adequate 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 is to apply large quantities of water to the effected tanks, to cool the vessel. This evolution requires that large amounts of water be readily available and 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 safely, 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.

Canadian First Responder BLEVE Instructional Video

Produced by

Transport Canada
Canadian Association of Fire Chiefs
Fire Protection Canada

Based on research done at Queens University in Canada:
http://me.queensu.ca/People/Birk/Research/ThermalHazards/bleve/

Description (from Transport Canada) -- The video concentrates on addressing critical safety issues affecting emergency responders by providing answers to common questions regarding accidents involving fire impingement of pressure liquefied gas tanks and BLEVEs (Boiling Liquid Vapor Explosion). Typical questions addressed include:

What is a BLEVE and its hazards?
What is a safe distance for emergency responders when a fire is close to a pressure tank?
How much water is required to keep a tank cool?
Does there have to be a fire for a BLEVE to occur?

The video sequences include 3-D animation and film footage of complete BLEVE scenarios, followed by more detailed examination of specific parameters using animated graphics.

Purchase DVD ($9 Canadian):
http://shop.tc.gc.ca/TChtml/ibeCCtpItmDspRte.jsp?item=66083&language=US
Download (wmv format, 21MB, 21:50)
http://download.isiglobal.ca/transport/BLEVE/BLEVEE-WMV128kbps.wmv
Full brochure (29pp, charts and diagrams)
http://www.tc.gc.ca/Publications/en/TP13649/PDF/HR/TP13649E.pdf
View online:
Part 1: http://www.youtube.com/watch?v=btmy5JblMOg
Part 2: http://www.youtube.com/watch?v=UHRoRM-flgA
Part 3: https://www.youtube.com/watch?v=9KJdXyIHnJE

The importance of all this for first responders is underlined by the events described at

http://ncsp.tamu.edu/reports/NFPA/vapor_explosion.htm

Excellent example of a BLEVE with a visible blast wave (Toronto, 2008):

http://www.youtube.com/watch?v=__1Ym_F94CE

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