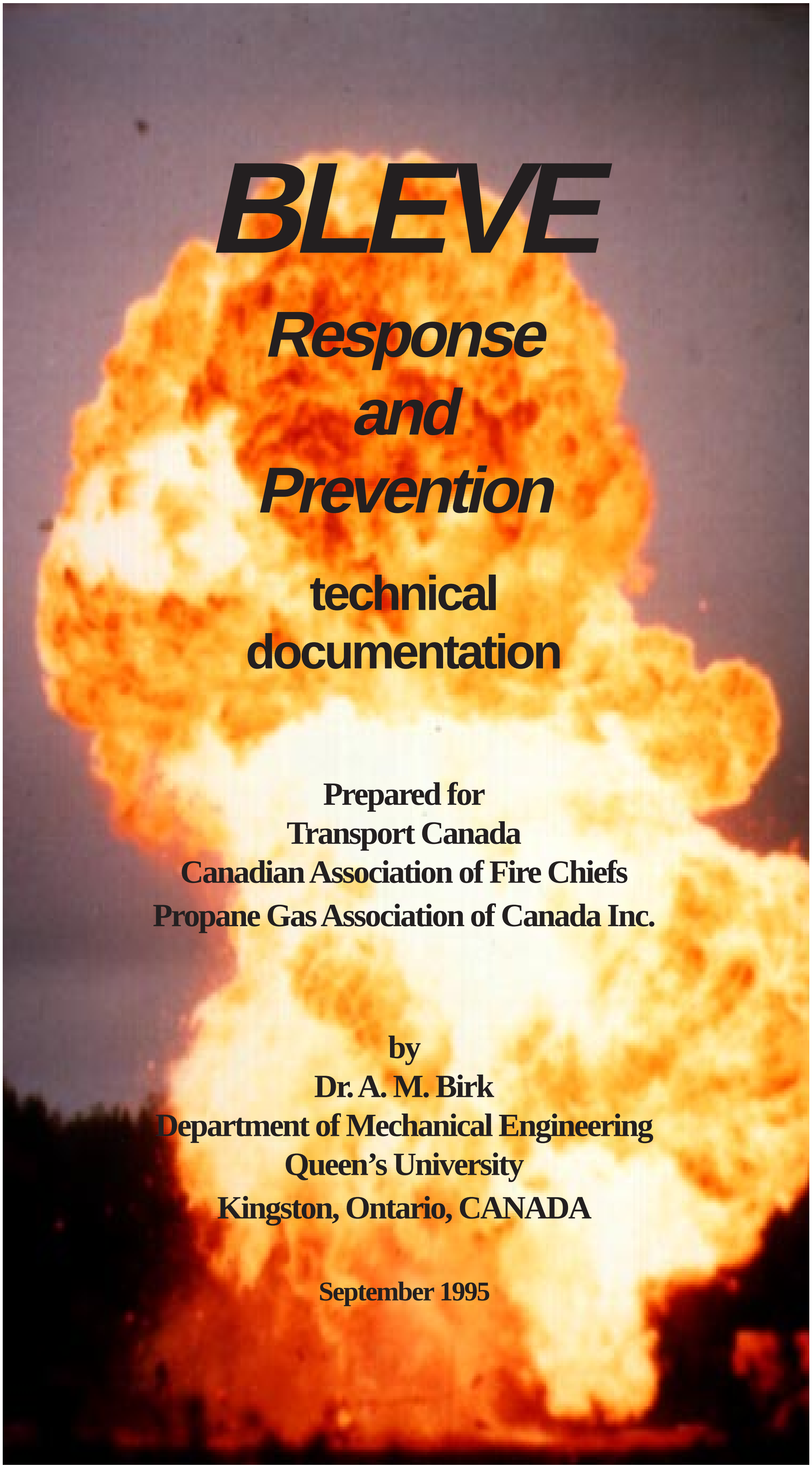

BLEVE

Response and Prevention

technical documentation

Prepared for
Transport Canada
Canadian Association of Fire Chiefs
Propane Gas Association of Canada Inc.

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Contents

Introduction

This document is intended to go with the video of the same title, and will provide the viewer with additional technical information to support the content of the video. It is recommended that the video be viewed first, then this document should be read and discussed.

This video and technical document have been prepared for emergency responders who may be called to a scene where a tank holding a pressure liquefied gas has been **severely damaged** by impact or by fire exposure. In this case a severe explosion is possible and the hazards can be far reaching.

This document is not suggesting that all tanks in fires or other accidents will BLEVE. Tanks designed to carry pressure liquefied gases are very strong and safe. In recent experiments conducted to study the BLEVE it was very difficult to make the tanks BLEVE even though strong torch fires were applied to the tank vapour space wall area. However, if a fire is severe enough and long lasting enough, or if a tank has been weakened by impact or corrosion then a BLEVE can happen. The objective of this video is to provide some guidance as to the hazards involved ***if a BLEVE takes place.*** Suggestions are made regarding tactics so that responders are not exposing themselves to unnecessary danger.

This document in the format of questions and answers, and is organized in the following order:

i) general information about pressure liquefied gases
ii) what, why and hows of BLEVEs
iii) brief description of common safety devices
iv) hazards from BLEVEs
v) response tactics
vi) sample problems

Pressure Liquefied Gases

What is a pressure liquefied gas ?

A pressure liquefied gas (PLG) is a substance that is transported and stored as a liquid under pressure. In other words, the substance has been liquefied by increasing the pressure. Some gases are liquefied by cooling, such as liquefied natural gas (LNG).

Common examples of PLG's are:

Anhydrous Ammonia	LPG (liquefied Petroleum gas)
Propane	Isobutane
Butane	Vinyl Chloride
Chlorine	Propylene

This document and the video will concentrate on propane or LPG because they are the most common, flammable pressure liquefied gases.

What are the properties of a PLG?

The physical and chemical properties of PLG's vary widely and cannot be given here in any detail. The reader should seek other references to find out more about the specific properties of PLG's (for example, Handbook of Compressed Gases , from the Compressed Gas Association Inc. Arlington Virginia, ISBN 0-442-21881-8). Some important properties to look for are:

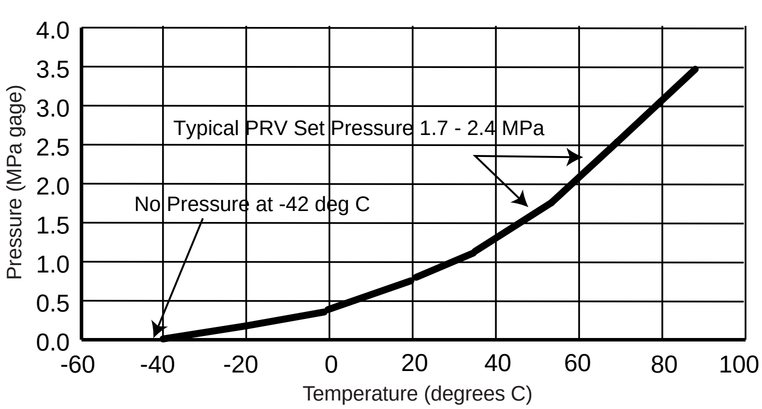
- pressure vs temperature
- toxicity
- expansion ratio
- specific gravity of gas at 1 atmosphere pressure (14.7 psia, or 0.101 MPa)
- flammability limits
- boiling point

Let us consider propane as an example of a very commonly used PLG.

Figure 1 shows how the pressure required to hold propane as a liquid increases with the temperature of the propane. At -42 degrees C, propane can be held as a liquid in an open container. At 25 C the pressure needed to hold propane as a liquid is 0.95 MPa (138 psia).

If 1 litre of propane liquid at 25 degrees C is released it will expand to 270 l of propane vapour. This is called the expansion ratio and is an important factor to remember if liquid propane is accidentally released.

Figure 1: **Pressure vs Temperature for Propane**



The flammability range for propane in air is 2.2-9.5% by volume.

Propane is non-toxic but it does have an anesthetic effect when inhaled in high concentration. Propane will also act as an asphyxiant.

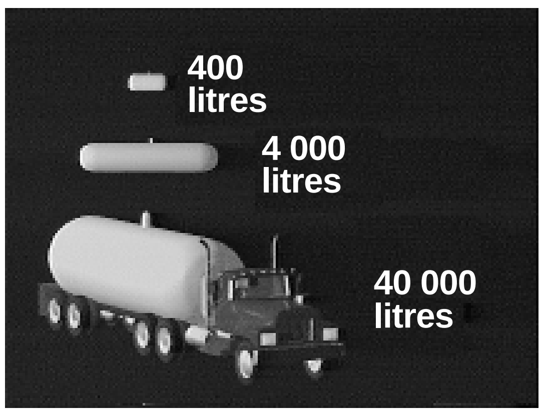
The specific gravity of propane at 21 degrees C is 1.52 (air is 1.0). This means that propane vapours are 1.52 times as heavy as air and therefore will tend to sink and find low areas.

Propane has an atmospheric boiling point of -42 degrees C. If skin comes in contact with the cold liquid then rapid freezing can result. The low boiling temperature also suggests that if pressure liquefied propane is suddenly released it will boil violently because of the large difference between the boiling point and the ambient containment temperature.

How are PLG's stored and transported?

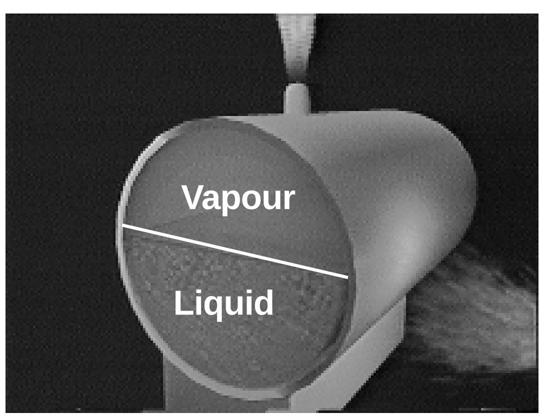
PLG's are stored and transported in pressure vessels of various sizes and shapes (see Figure 2). These vessels are built to strict standards such as the ASME Pressure Vessel Code. Under normal operating conditions these tanks are very tough and very safe. However, under severe fire exposure these vessels can fail violently.

Figure 2: **A Variety of Compressed Gas Cylinder Types**



PLG tanks are not filled full with liquid so that there is space for the liquid to expand if there is a temperature increase. The space not filled with liquid forms a vapour space in the top of the tank as shown in Figure 3.

Figure 3: **Liquid and Vapour Space in PLG Tank**



How can you tell if a tank is a pressure tank?

Pressure tanks or cylinders can usually be recognized by the cylindrical shape with round or elliptical ends. Tanks holding pressure liquefied gases tend to have squat proportions (i.e. the tank length is generally less than 6 times the diameter). This is in contrast to high pressure gas cylinders that are usually long and slender.

Pressure tanks normally do not have flat ends. However, some cylinders made to stand vertically have a foot-ring which allows the tank to stand up. This foot-ring may make the tank look like it has a flat bottom.

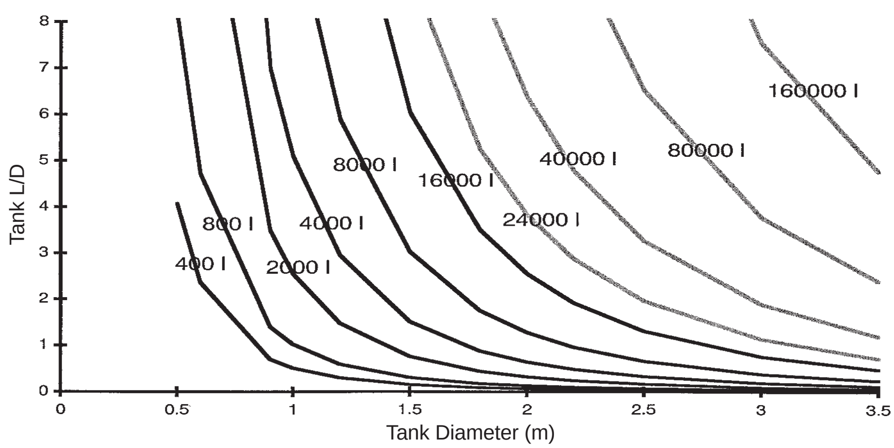
When in doubt — assume a tank is pressurized until you are sure.

How can you tell what the tank capacity is?

Tanks come in various sizes and shapes and it may be very difficult to know what the capacity is without actually reading it off the tank itself (all tanks are marked with this kind of information). You need to know the capacity so that you can estimate the size of the danger zone.

Figure 4 gives a summary of approximate tank capacities based on the tank diameter and the tank length to diameter ratio. To use this figure you must estimate the dimensions of the tank. First estimate the diameter by comparing it to nearby objects and then estimate the length by comparing it to the tank diameter. For example, if a tank has a diameter of 1 m and the tank is about 6 diameters long then from Figure 4, the tank capacity is approximately 5000 litres (approx. 1250 USgal).

Figure 4: **Approximate Tank Dimensions and Capacities (based on ASME Code Tanks)**



You should learn to recognize standard cylinder sizes for propane. The most common are 1, 4, 11, 20, 30, 40, 60, 100, 200, 300 and 420 lb. Sizes larger than this can be estimated from the above figure.

What happens if the tank is punctured?

If the containment vessel is punctured in the vapour space the vapour will leak out and the liquid will boil off to replace the lost vapour. Depending on the properties of the liquefied gas and the size of the hole in the vapour space, the boiling can be slow or it can be explosive. If a pin hole forms in a tank then the vapour will leak out slowly and the boiling will be very gradual. If the tank is suddenly completely broken open, the release will be explosive — i.e. a BLEVE.

If the tank is punctured in the liquid space then liquid will leak out and it will boil off rapidly outside of the tank. Once again, the violence of the process will depend on the size of the puncture and on the properties of the released substance.

Will the tank empty itself if there is a puncture or leak?

Yes, but it may take quite a while, depending on if there is a fire, how large the hole is, where the hole is and the tank size and its fill level. As mentioned above if the hole forms in the liquid space the tank can empty quickly. If the hole is in the vapour space then the liquid must boil off to leave the tank as a vapour.

The liquid needs heat energy to convert from liquid to vapour (i.e. boil). If a fire is present the heat energy will come from the fire and in this case the punctured tank can empty fairly quickly.

If there is no fire, or if the fire has been put out, then the heat energy for boiling must come from the liquid itself, and in this case the boiling will cool the liquid. As it cools, its vapour pressure will decrease until eventually the liquid will reach its atmospheric boiling point temperature (this is autorefrigeration). At this temperature the boiling will almost stop. This means that if a tank is punctured and there is no fire, then the tank will not boil empty immediately. You may see this if a tank has a puncture in the vapour space — the bottom of the tank may ice over telling you that the tank is still partly full of very cold liquid. This liquid will now boil off very slowly as heat from the surrounding air enters the tank and liquid. The pressure in the tank is now gone but there is still a hazard. If something or someone causes this liquid to be spilled on the ground, then a very hazardous situation can result. The cold spilled liquid will contact the warm ground and it will boil rapidly, and cause a vapour cloud.

For propane starting at 20 degrees C, up to 60% of the original liquid can remain in the tank after a puncture in the vapour space.

BLEVE

Exactly what is a BLEVE and what are the hazards?

A *boiling liquid expanding vapour explosion* or BLEVE happens if a container holding a pressure liquefied gas fails catastrophically. Catastrophic failure of the vessel is followed by the explosive release of boiling liquid and expanding vapour.

The BLEVE is a physical explosion where the hazards are blast and projectiles. It should be noted that a commodity does not have to be flammable to suffer a BLEVE.

If the commodity happens to be flammable, then a fireball may happen after the BLEVE if the released cloud is immediately ignited. This is usually the case if the tank failure is caused by fire impingement. If a flammable cloud is not ignited immediately then delayed ignition could lead to other fires, explosions, etc. If the cloud is toxic then this too becomes a possible threat.

What could cause a tank to fail catastrophically?

Containers holding pressure liquefied gases are pressure vessels. Internal pressure puts the container wall under stress. If the container is weakened the internal pressure may exceed the tank strength resulting in tank failure. Tanks can be weakened by:

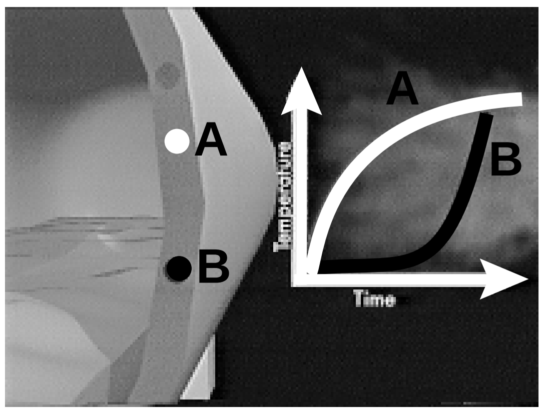
- severe corrosion
- severe mechanical damage from impacts, scraping, etc.
- very high temperatures as from fires

How can fires cause BLEVEs ?

The heat from a nearby or impinging fire causes increases in exposed tank wall temperature. As shown in Figure 5 the largest temperature increase is seen in the wall area in contact with vapour in the tank. This is at the top of the tank since gravity will make the liquid settle to the bottom of the tank.

As the wall temperature increases to high levels, the strength of the wall steel decreases. As the steel strength decreases the stresses in the tank wall (due mostly to pressure in the tank) result in the wall stretching and thinning, and this leads to higher stresses and more stretching. Eventually, the wall may become so thin in the affected area that a crack or tear forms. This crack may stop growing and in this case the outcome is a jet release. If the crack continues to grow then the tank will fail catastrophically and a BLEVE will happen.

Figure 5: **Pressure vs Temperature for Propane**



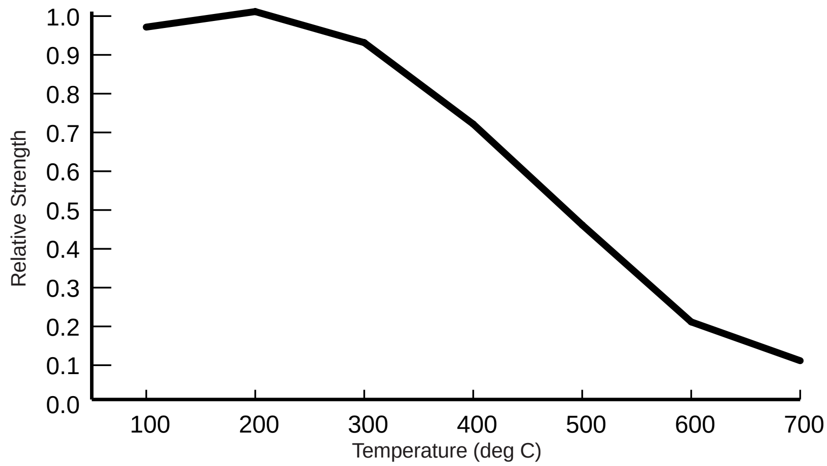
Another possible mechanism for tank failure is when the top half of the tank is heated to high temperature by fire exposure. This causes the top half of the tank to expand. However, the bottom of the tank is cool since it is cooled by liquid. This cool half of the tank does not expand and resists the expansion of the tank top. This adds to the tension in the tank caused by the internal pressure. This differential expansion also makes the tank bend (i.e. the top is longer than the bottom) and this too adds to the stress in the tank wall. Eventually the aggravated stress condition may initiate a failure that propagates along the length of the tank.

In any event, tank mechanical damage from accidental impacts may cause additional weakening and as a result less fire heating may be needed for tank failure. Other mechanical damage such as corrosion can also weaken a tank making it even more susceptible to fire induced failure.

At what temperature does steel weaken?

Normal steels start to weaken significantly above 300 degrees C. If the fire exposure is severe, it only takes a few minutes to reach these temperatures in the vapour space region of the tank. Figure 6 shows how steel strength drops with increasing temperature.

Figure 6: **Strength of Carbon Steel vs Temperature**



If the fire is only contacting the bottom can we relax?

It was previously stated that fire exposure above the liquid level can cause rapid temperature increases and tank failure. However, this does not mean that fire exposure below the liquid level is a safe condition. Bottom fire contact may mean you have more time to act, but beware:

- you may not know where the liquid level is
- when the PRV opens the liquid level will drop and eventually even bottom contact becomes very dangerous
- the tank may be damaged (corrosion, mechanical impact)

Is there some high risk time for a tank when it is most likely to BLEVE?

Yes — but you don't have enough information to figure it out at an accident. The timing and severity of a BLEVE depend on many factors including:

- commodity
- fill level
- type of fire contact (torch or engulfing), location (vapour space or liquid space) and coverage of the fire exposure
- PRV setting and flow capacity

For tanks there is an optimum time for a very powerful BLEVE when the tank fails when the liquid is hot and tank is near full of liquid. However, even if the tank is near empty of liquid when it fails the explosion can still be devastating.

Tanks can BLEVE in just a few minutes if the fire is severe enough. Small tanks can fail in less than 5 minutes if the fire is severe. Large tanks will take longer but under the worst possible conditions a large tank could fail in less than 10 minutes. However, tanks can BLEVE much later than this if the fire contact begins below the liquid level and PRV action slowly drops the liquid level.

As liquid is removed from the tank, the severity of the BLEVE decreases — but even a reduced strength BLEVE is a major hazard. When the tank is empty of liquid the BLEVE hazard is gone — but you can still have a compressed gas explosion (CGE) which is also very dangerous (i.e. blast, projectiles, fireball, etc.).

The problem is that you rarely know when the fire start time was, and how much liquid is in the tank. Tank mechanical damage reduces the time to failure — this is another very important unknown.

In other words, don't try to guess when a BLEVE will happen. If a tank is exposed to severe fire then assume the worst and stay back.

What tanks are easier to BLEVE large or small?

Small tanks empty faster through the PRV (i.e. wall is quickly exposed to vapour — poor cooling effect, etc.). Small tanks have thinner walls and these can heat up faster and fail more quickly than larger tanks with thick walls (**with severe torch fire** impingement tanks with 3 mm wall thickness can fail in less than 2 minutes, tanks with 6 mm wall can fail in about 4-5 minutes, larger tanks with wall thickness 12 - 18 mm may take 8 - 10 min or less to fail).

Obviously large tanks give more powerful explosions, larger fireballs and tank fragments can go further. However, don't be fooled by small tanks, small tanks are also very dangerous because they can make very good rockets.

Does there have to be a fire for a BLEVE to occur?

NO. There have been reported BLEVEs where no fire was involved. These are usually due to some structural problem with the tank (i.e. corrosion, fatigue, impact damage, etc.).

Anything that leads to a sudden catastrophic failure (i.e. tank splits open completely) will result in a BLEVE.

With no fire present the resulting cloud will drift downwind and into low lying areas (sewers, ditches, etc.). For large releases toxic concentrations or flammable mixtures may last for considerable distances from the source.

When is the danger of a BLEVE over?

For a severely weakened tank, the danger of a BLEVE is gone only when the pressure in the tank is gone.

You can only be sure the pressure is gone if there is a reliable pressure reading from the tank or if there is a hole in the tank and nothing is coming out. Even if the pressure is gone you can still have vapours and liquid in the tank (if there is liquid and no pressure the liquid has refrigerated itself — for example, propane at -42 degrees C has a pressure of 1 atmosphere).

If the fire is out, stay away from the tank. Call in experts to evaluate the tank condition. It is very dangerous to approach a tank after it has been weakened by fire exposure.

Safety Devices

What are examples of safety devices?

The following are examples of safety devices that may be found on tanks to protect them from accidental fire impingement:

- pressure relief valves
- thermal barriers (i.e. thermal insulation)
- water spray systems

All pressure tanks in North America have pressure relief valves (PRV) that open if the tank pressure exceeds some predetermined level. PRVs are designed to close again when the pressure in the tank is reduced slightly below the PRV opening pressure. This is an important point to remember — PRVs do not reduce the pressure in the tank all the way down to zero! For propane tanks PRVs are normally set at pressures between 1.7 and 2.6 MPa (250 - 380 psi).

Most tanks are not equipped with thermal barriers or water spray. Some transportation tanks such as rail tank-cars have thermal barriers. Some large stationary facilities have thermal barriers or water spray systems. Both of these systems act to limit the heating effects of fire on the tanks and this tends to make more time available to get the situation under control.

Thermal barriers and water spray systems are not perfect and tanks can still BLEVE if for some reason the water spray or thermal barrier has been damaged. However, they are much less likely to BLEVE if they are equipped with these systems.

Is the situation under control if the pressure relief valve (PRV) is working?

A pressure relief valve or PRV by itself cannot stop a BLEVE. PRVs are only designed to keep the pressure in the tank below some set pressure — tanks can and do fail even though the PRV is working properly.

Recent fire tests of tanks have shown that you can't always rely on a PRV to open at the set pressure (test results show first opening pressures may be well above the normal set pressure).

Keep in mind that PRVs don't do anything to keep the tank strong. As the tank weakens due to high wall temperature even perfect operation of the PRV may not be enough to save a tank. If the PRV is open take this as a warning that something may happen. In very rare cases the PRV may not open at all, due to a malfunction.

Is the tank more likely to BLEVE when the PRV is open or closed ?

Tanks can BLEVE with the PRV open or closed if the tank has been severely weakened by mechanical damage or fire exposure. An open or cycling PRV should be taken as a warning that something is heating the tank and therefore the situation is serious.

Does the operation of the relief valve tell us anything?

As stated above PRV operation should be taken as a warning. When the PRV first opens it will usually cycle a few times (open, close, open, close, etc.) and then it may remain open continuously. This valve behavior depends on the severity and location of the fire contact. If valve is cycling open and closed for an extended period this suggests that there is not enough heat being added to the tank contents by the fire to maintain the pressure to hold the PRV open — this could mean the fire impingement is minor or it could mean the fire is impinging on the vapour space and this is very bad.

A PRV that is open continuously suggests a very bad situation — stay clear. A long duration with the PRV open suggests that the tank is emptying and more of the tank wall is not cooled by the internal liquid — if fire is impinging the vapour space wall then a BLEVE may be imminent.

Look for signs such as increased PRV noise, or increased length of PRV flare — these suggest the pressure is rising and this could be very bad. But beware that it may be very difficult to notice these effects in an accident. Don't expect to get some clear warning that something is about to happen. Table 1 gives a brief summary of signs to look for.

Table 1: **Summary of PRV Signs**

Fire Condition	PRV Condition	Comments
no fire	PRV closed	- has tank been weakened by impact?
no fire	PRV open	- is it due to solar heating? - has PRV been damaged? - may not be PRV — may be broken fitting/pipe
fire	no PRV action	- fire should open PRV within few minutes (unless tank is thermally protected)
fire	cycling PRV	- common PRV mode - could mean fire contact on vapour space — very dangerous - liquid level is dropping
fire	continuous open PRV	- severe heating of tank — very dangerous - liquid level is dropping - tank is probably getting weaker
fire out	PRV closes	- tank may have been weakened - tank may still have pressure and therefore is still dangerous to approach

Does it matter if the tank is rolled over on its side?

YES — this means that liquid will be coming out of the PRV when it opens. If the fire is severe and the PRV is venting liquid, pressure may still be increasing in the tank even though the PRV is open. If liquid is coming out of the PRV then the tank can empty very quickly — thus exposing more wall to severe heating and weakening.

When liquid is coming out of the PRV then the toxic and fire hazards are larger than if vapour was coming out (remember when liquid expands to vapour there is a large increase in volume — this is the expansion ratio).

When the liquid drops below the location of the PRV intake the PRV will begin to vent vapour once again.

If the relief valve closes and remains closed does that mean the tank is empty?

NO — there is probably pressure in the tank and if the wall has been weakened by fire it could still burst and there could be an explosion (compressed gas explosion if all the liquid is gone). There is also a small chance that the valve may be stuck (filled with crud, etc.)

If the fire is out and the PRV is closed then stay back and let the tank cool down. Call in the experts to assess the condition of the tank and its contents.

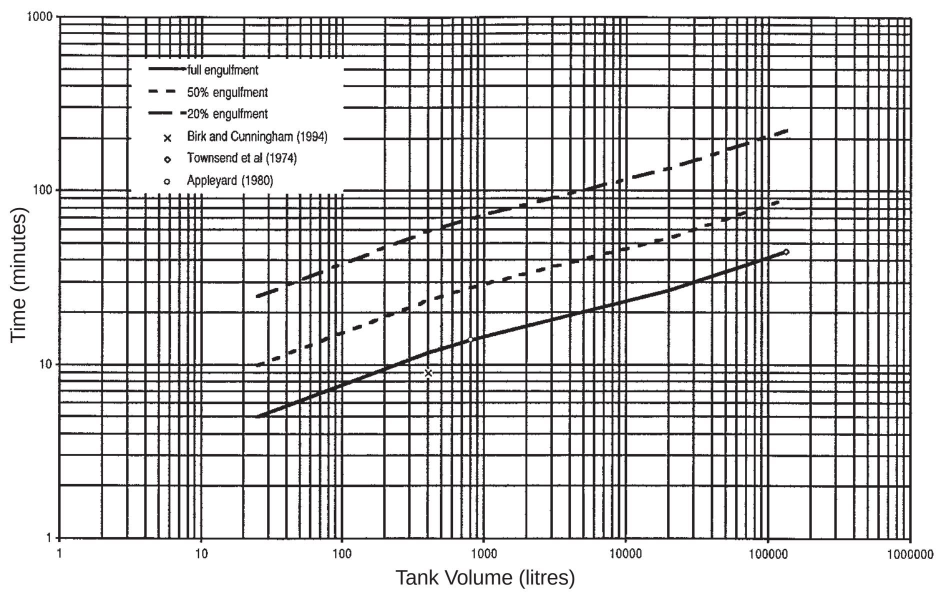
How long should it take for a tank to empty through the pressure relief valve?

This depends on the size and fill of the tank, and the heat input rate. The worse the fire exposure the faster the tank will empty. If the PRV is cycling then the time will be longer (i.e. if the PRV is open 1/10th of the time then the time to empty increases by a factor of 10).

Remember as the tank empties more of the tank wall is exposed to vapour contact and if fire is present, tank weakening can be taking place. In some cases it has taken hours of fire contact before a BLEVE — these may be examples where PRV action or leaks have lowered the liquid level to the point where fire began to contact the vapour space wall.

Figure 7 shows some estimates of times to empty tanks. As can be seen the larger tanks need more time to empty. Also, if the tank is only partially exposed to fire it will empty more slowly.

Figure 7: **Approximate Empty Time Through PRV vs Tank Capacity**



Can a thermally protected tank BLEVE?

YES — if the fire is severe enough or if the thermal protection is damaged and fire is heating the exposed unprotected wall.

In most cases a thermally protected tank is much less likely to fail due to fire exposure. However, thermal insulation can be degraded by mechanical vibration, impact, and by fire exposure. If there is a local loss of thermal protection (for example some insulation is torn off during an impact) and the wall is weakened by fire exposure then a BLEVE can occur. Thermally protected tanks can also be weakened by impact, corrosion, etc.

In general, thermal protection slows the rate of heat addition and this may give responders more time to act. Also note that thermal protection slows the rate at which the tank contents will empty through the PRV. Thermal protection is designed to give responders more time to act but it also means the tank remains partially full of liquid for a longer period of time — more liquid means stronger BLEVE if one happens.

Hazards from BLEVEs

What are the main hazards from a BLEVE?

The main hazards from a propane or LPG BLEVE are:

- fire
- thermal radiation from the fire
- blast
- projectiles

The danger from these decrease as you move away from the BLEVE centre. The furthest reaching hazard is projectiles.

How big is the fireball from a Propane or LPG BLEVE, and how long does it last?

If the propane or LPG release is ignited immediately then a fireball will result. The size of the fireball depends on the mass of the tank contents at the time the tank fails. The shape of the fireball depends on how the tank fails and on the lading temperature.

If we consider a spherical fireball, then an approximate equation for the fireball maximum radius is:

$$R_{fireball} = 3m^{1/3}$$

where,

R_{fireball} = radius of fireball in metres

m = mass of propane in kg

However, keep in mind that fireballs are not always spherical. In some cases, when the tank fails a large ground fire can result that has a radius larger than that predicted above. So don't assume if you are just beyond the predicted fireball radius, that you will be outside of the fire envelope.

If you don't know how full a tank is, then assume the tank is 80% full with liquid when you calculate the fireball size for a given tank size. Also remember that liquid propane at 25 degrees C is about 50% as dense as water — i.e. 1 litre propane = 0.5 kg. This means then that the lading mass in kg is 0.4 x tank capacity in litres.

The duration of the fireball can be estimated from its size by the following equation:

$$t_{fireball} = 0.15 R_{fireball}$$

where,

t_{fireball} = fireball duration in seconds

Table 2: **Shows some fireball sizes and durations for a range of tank sizes**

Tank Capacity (tank 80% full)	**Propane Mass**	**Fireball Radius**	**Fireball Duration**
400 l	160 kg	16 m	2.4 seconds
4000 l	1600	35	5.3
40000 l	16000	75	11.3

How strong is the thermal radiation?

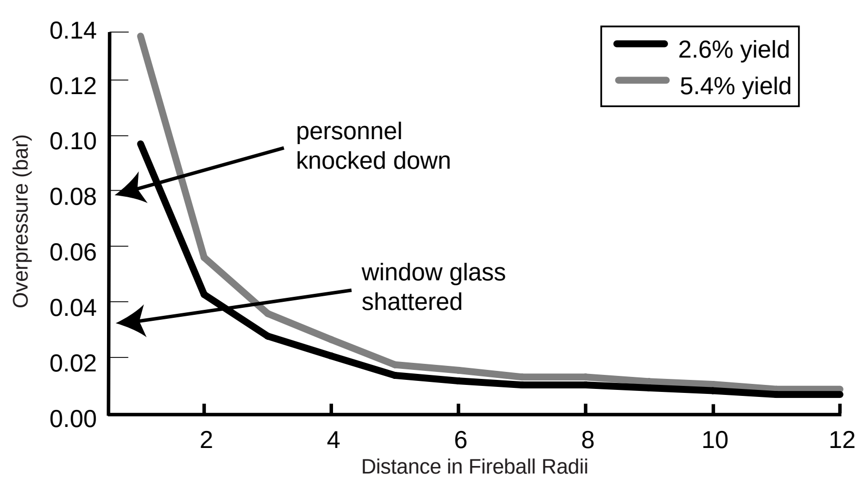
At a distance of about 4 fireball radii the heat radiated from the fireball could be as strong as 21 kW/m^2. At this level, exposed skin would burn in 2 seconds. For emergency responders wearing protective clothing this is enough time for the responder to turn their face away from the fireball to limit the thermal radiation dose.

How strong is the blast from a Propane BLEVE?

A BLEVE is a physical explosion due to the sudden release of a pressurized substance. If the BLEVE happens out in the open then the blast strength at a distance of 4 fireball radii is about 20-30 mbar pressure. This is enough pressure to break window glass and may cause minor damage to buildings. It takes 70-100 mbar pressure to knock personnel down (less if on ladders, etc.).

However if the BLEVE takes place near other objects or structures then the blast wave could cause buildings to collapse, or it could propel objects over considerable distances. This will be discussed further when we consider projectiles.

Figure 8: **Blast Overpressure vs Distance for Propane BLEVE**



You can also have a blast wave from the combustion of a flammable cloud. This could happen if a release of a flammable material is allowed to mix with air and become confined in a structure or sewer. If this is ignited it could result in a powerful explosion with severe blast. This is a very difficult threat to quantify and it can be far reaching. If a flammable liquefied gas is released and it does not ignite to form a fireball then get back — late ignition could cause severe explosions.

What are projectiles?

When the tank fails parts of it or nearby objects can be thrown large distances. These fragments may be small fittings or a major portion of the tank. In any case, these fragments can and have been deadly.

How far can the projectiles go?

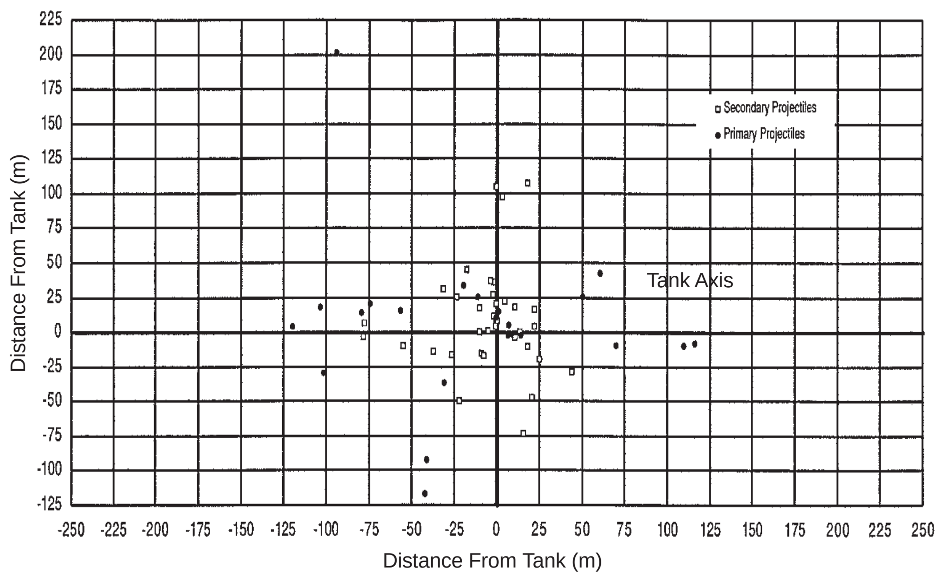
They can go very far. Projectiles are the furthest reaching immediate threat from a BLEVE. Most projectiles fall short of 4 - 6 fireball radii depending on tank size, fill level, liquid temperature and position relative to the tank main axis. Severe rocket type projectiles go as far as 15 fireball radii. In one test of a 460 l propane tank, the tank rocketed to 22 fireball radii.

Is it true BLEVE projectiles only go off from the tank ends?

No! Generally speaking the furthest reaching projectiles tend to go off from the tank ends — but this is not always true. Projectiles are also launched from the sides. Also, if there are objects near the tank such as equipment, pipes, structures, etc. these too can be launched by the BLEVE and they can go in any direction.

Figure 9 shows projectile data from 13 BLEVEs of 400 l tanks. As can be seen projectiles were thrown in all directions. Primary projectiles are actual pieces of the tank whereas secondary projectiles are nearby objects that were thrown by the energy of the BLEVE.

Figure 9: **Projectile Ranges (Medium Scale Tests)**



Projectile effects are very unpredictable. There is only one thing for sure that can be said about projectiles — the further away you are from the BLEVE the safer you are.

Response Tactics

Should we go in immediately to put out the fire?

NO - time is very important, but accurate size-up is critical before personnel go in.

When first responders arrive they should stay well back — use binoculars or viewing scopes to view the tank. If there is, or has been severe fire impingement on the tank then the tank should not be approached.

Important questions are:

- how long did it take to get to the site ?
- how long was the fire going before responders arrived ?
- how severe is/was the fire contact?
- are there high risk exposures?
- can other facilities become involved to escalate the situation?
- do you have enough water flow capacity?
- can you apply water for the necessary time?

Remember it takes 5, 10 ... 15 minutes for a severe fire to cause a thermal rupture — are you arriving just in time to witness (or be part of) a BLEVE?

If there has been no fire impingement of the tank — and you are absolutely sure of this then you should make sure the tank does not get impinged by fire — keep it cool with water, get the fire out by shutting the fuel off at the source.

How do we assess the severity of the fire contact?

The severity of the fire contact can vary significantly and it may be very difficult to assess this accurately. We should always try to err on the safe side. Do not assume that you have 10-15 minutes to act.

Assess the fire severity from a safe distance, using aids such as binoculars. The questions to answer are:

i) how long has the fire been burning?
   - it only takes 5, 10, 15 minutes of direct fire contact to severely weaken a tank depending on its size, fill level, and the fire contact severity
   - if you don't know how long the fire has been burning stay back

ii) how large is the fire?
   - large fires may engulf the tank and cause early failure
   - small fires that you can see through generally heat the tank more slowly
   - if you can't see much of the tank because it is engulfed in the fire, then stay away

iii) is the fire contacting the tank shell directly?
   - normally, direct flame impingement is needed for early failure
   - if there is no direct flame contact then protect the tank with water

iv) is the flame torching?
   - torch flames can cause a tank to fail in just a few minutes depending on its size, the torch jet velocity and point of impingement

v) is the fire contact high or low on the tank?
   - high contact is worse than low due to cooling effect of the liquid in the tank
   - remember that you don't know how full the tank is
   - remember that PRV action lowers the liquid level in the tank

vi) is the fire contact only at one end of the tank?
- end contact could promote a tub rocket type failure

vii) what is the source of the fire fuel?
- will it burn itself out in a few minutes?
- can the fuel be shut off safely?
- if the fire can be eliminated then let the tank cool down — don't approach the tank — call in the experts and let them assess the tank condition.

When assessing the fire exposure always look around to see what other facilities could become involved. Are other tanks at danger? How many, what kind ? Can these be protected by water spray? If the other tanks become involved how does this change the size of the danger zone?

What is the safest direction to approach a burning tank?

There is no absolutely safe way to approach a tank exposed to severe fire impingement.

It is probably safer to approach with the wind at your back to stay out of any released clouds that drift down wind. It is also generally safer to approach from the tank side rather than from the tank ends — but note — this is not a sure thing. Tanks can and do pivot or spin before they take off. This means they can be launched in any direction. Also, the trajectory of the tanks can be changed by the tank bouncing off of local structures.

If we approach the tank should we stay low or stand up?

If you stand up you increase your chance of being hit by projectiles. If you stay low you may be in low lying vapours .

What is a safe distance for emergency responders?

This is a critical question and unfortunately there is no simple answer. An absolutely safe distance would be so large that it is impractical to use it. However, closer distances require personnel to expose themselves to some risk.

In most cases, the longest reaching hazard is the projectiles or rockets. Figure 10 shows expected ranges vs tank size. The next longest reaching hazard is the fire and thermal radiation from the fireball if a flammable release is ignited immediately. Blast hazard from the explosive release of the tank contents is usually small compared to the other hazards. However, blast due to vapour cloud explosions can be severe and very unpredictable. Vapour cloud drift downwind can also lead to severe fire hazards or toxic exposure.

For firefighters with protective clothing and breathing equipment a working distance should be just beyond 4 R, but never less than 90 metres, where R is the fireball radius. For propane the fireball radius can be estimated from the following equation , $R = 3m^{1/3}$ where m is the propane mass in kg and R is radius in metres.

At 4 R you will be outside of the fireball itself and the theoretical heat radiation from a spherical fireball is less than 21 kW/m^2 . This heat flux level is still quite high and some injury is still possible.

As a crude approximation, projectile ranges can also be related to the fireball radius. The following is suggested as a guide.

- 80-90 % projectiles fall within 4 R from the tank side
- severe rockets can go 15 R
- in very severe, very rare cases it may be possible to see rockets travel 22-30 R

Based on the above, civilians should be evacuated to beyond 15 R — 30 R if possible. As can be seen firefighters positioned at 4 R are still exposed to significant projectile hazards. It must be stressed that the above are based on limited data and should be considered as approximate.

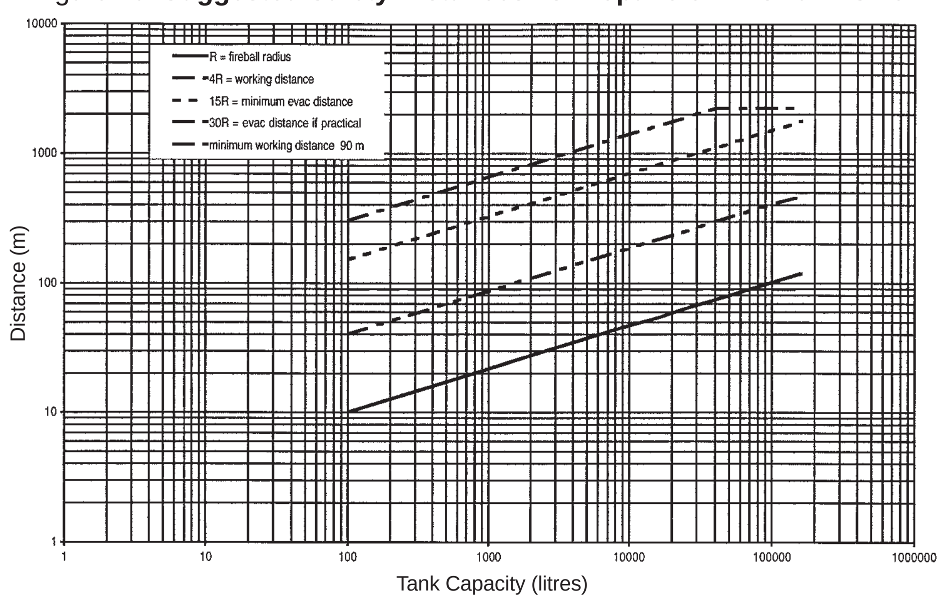
Table 3 shows a summary of this calculation for various tank sizes with Propane as the commodity.

Table 3: **Fireball sizes and durations for a range of tank sizes**

Tank Capacity	Propane Mass	R fireball	Firefighter	Evacuation
400 l (100 US gal)	160 kg	16 m	90 m	245 - 490 m
4000 l (1000 US gal)	1600 kg	35 m	140 m	525 - 1050 m
40000 l (10000 US gal)	16000 kg	75 m	300 m	1125 - 2250 m

Figure 10 shows a summary in graphical form.

Figure 10: **Suggested Safety Distances vs Propane or LPG Tank Size**



The above distances do not consider vapour cloud dispersion, vapour cloud explosions, or related effects. For this reason if the commodity is toxic, or if delayed ignition of a release is a concern then danger distances should be increased, especially downwind if wind is an issue.

When a tank is going to BLEVE — does it give some kind of warning just before it happens?

Don't expect to hear or see a warning that gives you time to get out. Common practice tells you to look for bulging, or discoloration, or deep gouges, or listen for pinging noises — but these signs may not always be visible or audible. In some cases the tank splits and hesitates before the BLEVE but this hesitation may only last a few seconds, sometimes only 1/10 th of a second. In most cases the tank is intact one instant and the next moment the tank is flat on the ground, engulfed in a rising fireball.

What effect does wind have on these kinds of cases?

You should approach the tank with the wind at your back to stay out of any escaped vapours. If there is a fire on a tank the wind will tend to blow the fire to the leeward side of the tank. This means the fire will probably be hottest on the side of the tank facing away from the approaching responders. This may make it hard for the responders to see the full effects of the fire.

If the tank fails, it will probably fail on the hottest side, and if this is the leeward side the contents may be directed up and away from the approaching responders. However, the resulting thrust may propel the tank towards the responders.

This is an example of how a procedure may be safer in one respect, but less safe in another respect — keep this in mind.

What is the most effective way for firefighters to protect a tank from fire impingement?

Water spray has been shown to be effective at cooling fire exposed surfaces — ***if water is applied immediately.*** Remember — it only takes minutes of severe fire contact to weaken a tank and cause a BLEVE.

Experiments have shown that to cool metal heated by fire contact it takes approximately 14 litres/min per square metre of exposed surface (0.35 gal/min per square foot of exposed surface) — ***this is not true for severe torch impingement.*** This flow rate applies if the water is turned on immediately when the fire starts.

You may be arriving 5, 10, 15 or more minutes after the fire has started and by this time the tank may be severely weakened. If you arrive after the fire has already caused damage to the tank, then you are taking a big risk if you go close enough to setup monitors for water cooling.

If the tank is not impinged by fire, but is being heated by radiation from a nearby fire then water application is very important to protect the tank from possible damage. A rule of thumb suggested by some is 5 x square root of the tank capacity (gal) for the required gal/min. Table 4 shows how this flow increases with tank size.

Table 4: **Summary of Water Flow Needed for Tank Cooling**

Tank Capacity	Approx. Tank Dimensions	Water flow (5 x square root of capacity (gal))
400 l (100 gal)	0.61 m diameter 1.5 m long	50 gpm
4000 l (1000 gal)	1.1 m diameter 5 m long	160 gpm
40000 l (10000 gal)	2.1 m diameter 12 m long	500 gpm

NFPA states that 250 -500 gal/min streams are needed to carry an effective cooling stream 50 -100 ft — ***personnel should never be located this close if a BLEVE is a possibility!***

A metal surface at high temperature will cause violent flashing (steam) of the cooling water when it contacts the wall — take this as a sign that the tank has been severely heated. The instant the water hits the hot metal may be the most dangerous. So make sure you are out of danger before the water is turned on. Make sure you have enough water to keep the water flow going for the necessary time.

When is it NOT a good idea to apply water for cooling?

When there is no fire, and there is a damaged tank, and the tank temperature is below the cooling water temperature (i.e. winter time, etc.) — applying water may actually heat the tank and slowly increase the pressure and thereby increase the stresses in the tank wall. If a tank has already been severely weakened by fire or impact, then the increased stresses could initiate a failure and BLEVE.

What should we do if we don't have enough water?

If you don't have enough water then there is very little you can do. If the tank is exposed to fire and the fire cannot be eliminated then stay back out of range of projectiles and fire.

Should we cool a damaged tank if it is being heated by the sun?

If a tank has been damaged by fire or impact it may be undesirable to have the pressure increase in the tank. If the tank is being heated by the sun the pressure is probably rising in the tank. To control this it is normally a good idea to cool the tank with water. For sun heating it is only necessary to have enough water flow to keep the tank surface wet.

If the fire is put out, how long should we wait before we approach the tank?

This depends on the size of the tank and its fill level. If cooling water has been applied, continue with water cooling of the tank. However, in severe cases personnel should stay back and let the tank and remaining lading cool naturally until the pressure in the tank has dropped back down to normal values — this could take several hours for a large tank!

Time will also result in the tank recovering some of its strength as the wall temperature drops back down to normal values. But remember, the tank may have been severely weakened by the fire and it may have suffered permanent deformation and thinning.

In any case, keep away from the tank. Call in experts from industry who have the equipment to evaluate the tank condition. You don't have the tools necessary to make a proper evaluation of the tank structural integrity.

Under what circumstances is it appropriate to send personnel deep into the danger zone?

There is no simple answer to this question. This document has made some suggestions about working distances. Some will find these distances very large and may choose to ignore them. However, it should be made very clear — if you go closer, and if the tank BLEVEs, your chances of injury or death increase rapidly.

Don't go closer.

How can we prepare for such an event?

This problem is so technical that it is very difficult to account for all the factors at the scene of an accident. This means that planning ahead is very important. Fire Departments should do the following:

- go out and survey facilities
- become aware of the safety devices and how they work
- locate critical valves, etc.
- know the capacity of various tank types, and prepare for an accident by calculating fireball dimensions, safety distances, etc.
- know how much water is available at the site
- know how long it takes to get to the site — how long will it take you to setup at the site
- plan ahead for all possible situations from minor leaks to major fires

  If you don't think your team can handle the situation then let your Fire Marshal know so that something can be done.

Summary

The following table gives a summary of tank properties, critical times, critical distances and cooling water flow rates for various tank sizes. This table is provided to give responders some guidance but it should be used with caution.

The tank dimensions are approximate and can vary depending on the tank design and application.

The minimum time to failure is based on **severe torch fire impingement** on the vapour space of a tank in good condition, and is approximate. Tanks may fail earlier if they are damaged or corroded. Tanks may fail minutes or hours later than these minimum times depending on the conditions. It has been assumed here that the tanks are not equipped with thermal barriers or water spray cooling.

The minimum time to empty is based on an engulfing fire with a properly sized PRV. If the tank is only partially engulfed then time to empty will increase (i.e., if tank is 50% engulfed then the tanks will take twice as long to empty). Once again, it has been assumed that the tank is not equipped with a thermal barrier or water spray.

If tanks are equipped with thermal barriers or water spray cooling then the times to failure and the times to empty both increase significantly. A thermal barrier can reduce the heat input to a tank by a factor of ten or more. This means it could take ten times as long to empty the tank through the PRV.

The fireball radius and emergency response distance are based on the equations given earlier and are approximate. They assume spherical fireballs and this is not always the case.

Two safety distances are given for public evacuation. The minimum distance is based on tanks that are launched with a small elevation angle (i.e., a few degrees above horizontal). This is most common for horizontal cylinders. The preferred evacuation distance has more margin of safety since it assumes the tanks are launched at a 45 degree angle to the horizontal. This might be more appropriate if a vertical cylinder is involved.

It is understood that these distances are very large and may not be practical in a highly populated area. However it should be understood that the risks increase rapidly the closer you are to a BLEVE. Keep in mind that the furthest reaching projectiles tend to come off in the zones 45 degrees on each side of the tank ends.

The water flow is based on the rule of thumb $5\sqrt{capacity(USgal)}$ = usgal/min needed to cool tank metal.

Warning: the data given are approximate and should only be used with extreme caution. For example, where times are given for tank failure or tank emptying through the PRV — these times are typical but they can vary from situation to situation. Therefore, never risk life based on these times.

capacity	diameter	length	propane mass	minimum time to failure for severe torch	approximate time to empty for engulfing fire	fireball radius	emergency response distance	minimum evacuation distance	preferred evacuation distance	cooling water flow rate
litres	m	m	kg	minutes	minutes	m	m	m	m	USgal/min
100	0.3	1.5	40	4	8	10	90	154	307	25
400	0.61	1.5	160	4	12	16	90	244	488	50
2000	0.96	3	800	5	18	28	111	417	834	112
4000	1	4.9	1600	5	20	35	140	525	1050	158
8000	1.25	6.5	3200	6	22	44	176	661	1323	224
22000	2.1	6.7	8800	7	28	62	247	926	1852	371
42000	2.1	11.8	16800	7	32	77	306	1149	2200	512
82000	2.75	13.7	32800	8	40	96	383	1435	2200	716
140000	3.3	17.2	56000	9	45	114	457	1715	2200	935

Who can we call for expert advice?

You can call the Canadian Transport Emergency Centre — C A N U T E C (collect at 1-613-996-6666). CHEMTREC is a service made available by the Chemical Manufacturers Association (CMA) and can be reached at 1-800-424-9300.

Region
Transport Canada Regional Office

ATLANTIC

Transport Dangerous Goods Office
45 Alderney Drive - Suite 1415, Queen Square Building
DARTMOUTH, Nova Scotia B2Y 2N6
Telephone: (902) 426-9351/Fax: (902) 426-6921

QUÉBEC

Bureau du transport des marchandises dangereuses
685, rue Cathcart - Suite 701
MONTRÉAL (Québec) H3B 1M7
Telephone: (514) 283-0303/Fax: (514) 283-8234

ONTARIO

Transport Dangerous Goods Office
20 Toronto Street - Suite 600
TORONTO, Ontario M5C 2B8
Telephone: (416) 973-2989/Fax: (416) 973-5905

CENTRAL

Transport Dangerous Goods Office
101 - 22nd Street East, Federal Building - Room 305
SASKATOON, Saskatchewan S7K 0E1
Telephone: (306) 975-5059/Fax: (306) 975-4555

PACIFIC

Transport Dangerous Goods Office
625 Agnes Street - Suite 225
NEW WESTMINISTER, British Columbia V3M 5Y4
Telephone: (604) 666-6740/Fax: (604) 666-7747

Highway Tanks
Jurisdiction Provincial/Territorial Department

ALBERTA

Director, Dangerous Goods Control
Motor Transport Services
Alberta Transportation and Utilities
Twin Atria Building - 1st Floor, 4999 - 98th Street,
Edmonton, ALBERTA T6B 2X3
Telephone: (403) 427-8901 Ext 233/Fax: (403) 427-1044

BRITISH COLUMBIA

Manager, Dangerous Goods Office
Commercial Transport and Inspection Department
Ministry of Transportation and Highways
2631 Douglas Street,
Victoria, BRITISH COLUMBIA V8T 5A3
Telephone: (604) 387-5585/Fax: (604) 356-8986

MANITOBA

Environment Officer
Dangerous Goods/Hazardous Wastes
Department of Environment
139 Tuxedo Avenue, Building 2,
Winnipeg, MANITOBA R3N 0H6
Telephone: (204) 945-7025/Fax: (204) 948-2420

NEW BRUNSWICK

Registrar of Motor Vehicles
Department of Transportation
P.O. Box 6000
Room 570, York Tower - King's Place,
Fredericton, NEW BRUNSWICK E3B 5H1
Telephone: (506) 453-2407/Fax: (506)453-3076

NEWFOUNDLAND

Manager, Transportation Regulation Enforcement
Motor Registration Division
Department of Works, Services and Transportation
Motor Vehicle Registration Building
P.O. Box 8710,
St. John's, NEWFOUNDLAND A1B 4J5
Telephone: (709) 729-3454/Fax: (709) 729-0120

NORTHWEST TERRITORIES

Director, Motor Vehicle Division
Department of Transportation
P.O. Box 1320
4510 - 50th Avenue, Highways Building, 1st Floor,
Yellowknife, NORTHWEST TERRITORIES X1A 2L9
Telephone: (403) 873-7406/Fax: (403) 873-0120

ONTARIO

Compliance Branch
Ministry of Transportation
1201 Wilson Avenue, Room 212, West Building,
Downsview, ONTARIO M3M 1J8
Telephone: (416) 235-3580/Fax: (416) 235-4549

PRINCE EDWARD ISLAND

Highway Safety Co-ordinator
Highway Safety Division
Department of Transportation and Public Works
P.O. Box 2000, W.P.J. MacMillan Building - 17 Havelind Street,
Charlottetown, PRINCE EDWARD ISLAND, C1A 7N8

QUÉBEC

Direction du transport intermodal
Ministère des Transports du Québec
700, boulevard René Lévesque Est, 23e étage
Québec (QUÉBEC) G1R 5H1
Telephone: (418) 643-3242/Fax: (418) 646-6196

SASKATCHEWAN

Manager, Dangerous Goods Transport
Saskatchewan Highways and Transportation
1855 Victoria Avenue, 8th Floor,
Regina, SASKATCHEWAN S4P 3V5
Telephone: (306) 787-5527/Fax: (306) 787-8610

YUKON

Deputy Registrar of Motor Vehicles and DG Co-ordinator
Department of Community and Transportation Services
P.O. BOX 2703, 308 Steele Street - Lynn Building - 1st Floor,
Whitehorse, YUKON Y1A 2C6
Telephone: (403) 667-5313/Fax: (403) 668-7864

Jurisdiction Department Responsable and Contact for Non-Transport Tanks

ALBERTA

Alberta Boilers Safety Association
Administrator (Chief Inspector), Pressure Equipment Safety
Province of Alberta
10808 - 99th Avenue,
Edmonton, Alberta T5K 0G5
Telephone: (403) 427-6855/Fax: (403) 422-3562

BRITISH COLUMBIA

Ministry of Municipal Affairs
Office of the Fire Commissioner
800 Johnson Street,
Victoria, British Columbia V8V 1X4
Telephone: (604) 356-9000/Fax: (604) 356-9019

MANITOBA

Department of Labour, Mechanical Engineering
Boiler and Pressure Vessels,
Room 500, Norquay Building, 401 York Avenue,
Winnipeg, Manitoba R3C 0P8
Telephone: (204)945-3374

Department of Environment
139 Tuxedo Avenue, Building 2,
Winnipeg, Manitoba, R3N 0H6
Telephone: (204) 945-7110

Office of the Fire Commissioner, Department of Labour,
Room 508, Norquay Building,401 York Avenue,
Winnipeg, Manitoba R3C 0P8
Telephone: (204) 945-3374

NEW BRUNSWICK

Department of Environment
Operations Branch, Industrial Programs Section
P.O. Box 6000,
Fredericton, New Brunswick E3B 5H1
Telephone: (506) 457-4848/Fax: (506) 453-2265

NEWFOUNDLAND

Director of Operations
Government Service Centre
Department of Municipal and Provincial Affairs
5 Mews Place, P.O. Box 8700,
St. John's, Newfoundland A1B 4J6
Telephone: (909) 729-3086 or 3084

NORTHWEST TERRITORIES

General Operations Manager
Products Division
Department of Public Works and Services
Rankin Inlet, Northwest Territories XOC 0G0
Telephone: (819) 645-5172

NOVA SCOTIA

Department of Environment
5151 Terminal Road,
Halifax, Nova Scotia B3J 1A1
Telephone: (902) 424-5300

ONTARIO

Chief Engineering
Engineering and Standards Branch
Fuel Safety and Pressure Vessels Safety Engineering
Ministry of Consumer and Commercial Relations
3300 Bloor Street, West - 3rd Floor West Tower,
Etobicoke (Ontario) M3X 2X4
Telephone : (416) 234-6024

PRINCE EDWARD ISLAND

Department of Environmental Resources
P.O. Box 2000,
Charlottetown, Prince Edward Island C1A 7N8
Telephone: (902) 368-5057

QUÉBEC

Régie du Bâtiment du Québec
145, Crémazie, 7e étage
Montréal (Québec) H2M 2V2
Telephone: (514) 873-6538
Fax: (514) 873-9936

SASKATCHEWAN

Department of Municipal Government
Boiler & Pressure Vessel Branch
1855 Victoria Avenue, 3rd floor,
Regina, Saskatchewan S4P 3V8
Telephone: (306) 787-4509

YUKON

Department of Community and Transportation Services
Public Safety Branch
P.O. Box 2703, 308 Steele Street - Lynn Building,
Whitehorse, Yukon Y1A 2C6
Telephone: (403) 667-5825

Sample Problem

You have arrived at a scene and a tank is severely exposed by fire. You stop at a distance of about 200 m and you look at the tank with binoculars. One end of the tank is completely engulfed in a fire. There is a loud noise coming from the tank and a jet of fire is coming out of the tank top (probably the PRV). It took you 7 minutes to get to the site and therefore this tank may be ready to blow. It is too late to cool the tank with water — the most important thing now is to get any residents out of harms way.

You look at what is near the tank, some lumber, a small shed and you evaluate the potential for fragments being thrown if the tank ruptures. You also note the wind direction and the orientation of the tank.

You start evacuating the immediate area, keeping in mind that downwind residents and residents located off the tank ends may be at more risk. You now need to estimate how large an area needs to be evacuated.

You estimate that the tank diameter is about 1 m (based on a comparison of nearby objects) and the tank is about 6 times as long as its diameter. Now you need to estimate the mass of propane in the tank.

The tank volume is approximated from Figure 4. With D = 1 m and L/D = 6 the volume is approximately 5000 l (1250 USgal).

Propane has a mass about half that of water (1 litre water = 1 kg, or 1 litre propane = 0.5 kg). If we assume the tank is filled to 80% capacity with propane then the propane mass is:

$$m = 5000 \times 0.8 \times 0.5 = 2000 \text{ kg}$$

The fireball radius is:

$$R = 3m^{1/3} = 3\,(2000)^{1/3} = 38 \text{ m}$$

this fireball will last about 0.15 R seconds or in this case about 0.15 x 38 = 5.7 seconds.

A reasonable distance for emergency responders to observe the tank from is 4R or 90m which ever is larger. In this case 4R is 151 m. You move in to about 150 m, with the wind at your back and away from the tank ends.

At this distance you would be safe from the fireball if you are wearing protective clothing. The blast expected at 4R is about 30 mbar (0.44 psi) and could break window glass and it could knock personnel off their feet so be careful. The real danger at this location is tank fragments.

This size of tank can send large pieces of the tank up to 15 R — in this case 567 m. In very rare cases it could send a fragment up to 30 R or 1130 m. Therefore, evacuate the public out to a distance of 15 R or 567 m in this case, and if it is practical evacuate out to 30 R or 1130 m in this case.

The evacuation is in progress and you are evaluating the situation further.

- where is the fire fuel coming from — can it be eliminated safely?
- are there other tanks that could be exposed to fire heating or fragment penetration if the first tank BLEVEs ?

If there is no risk to life let the fire burn until the fire burns itself out, the tank empties through the PRV or it blows up.

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Liquefied Petroleum Gases Handbook, 3rd Edition, T. C. Lemoff Editor, NFPA, 1992, Quincy Mass. USA.