Handling the cryo factor

North West Shelf LNG plant, Western Australia. © BP plc.

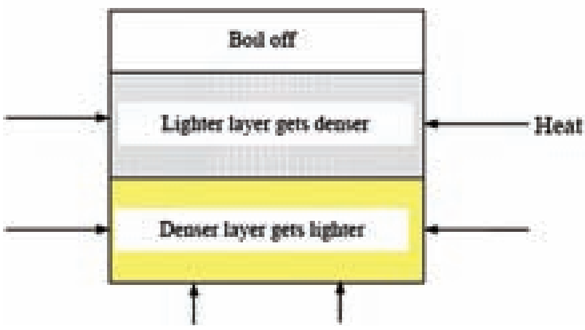
John frame has created and delivered LNG Fire Response training courses and also produced the original book LNG Fire Protection & Emergency Response (IChemE). In this part two of his LNG series he focuses on rollover; international standards; and likely incident scenarios including refrigeration; jetties cargo operations; and tankage/piping.

Rollover

Rollover describes the rapid release of LNG vapours caused by stratification and it occurs when two separate layers of different densities exist in a tank. In the top layer, liquid is warming up due to heat gradually seeping into the tank from air and ground and this liquid rises up to the surface, where it vapourises. The lighter gases in the composition evaporate and the liquid in the upper layer thereby becomes denser.

In the bottom layer, the warmed liquid moves towards the layer interface by free convection but is prevented from evaporating due to the hydrostatic head exerted by the top layer and therefore the lower layer becomes warmer and less dense. As both densities approach each other, the layers mix rapidly and the lower layer which has been heated gives off large amounts of vapour as it rises to the surface of the tank. This LNG vaporisation rate increase can cause tank venting via the LNG storage tank relief valves. Rollovers can occur when a less dense LNG is added to existing LNG from the top or, if a denser LNG is added to the tank from the bottom.

The most notable incident involving rollover was a ship at anchor for about four weeks, during which time the LNG had become heavier due to lighter ends vapourising. When this cargo was introduced to the onshore tank, density difference occurred, leading to rollover.



Rollover is now rare and is avoided by keeping tank contents well mixed using pumps to circulate the liquid from top to bottom.

International standards

Before moving on to the more probable incident scenarios, there are numerous national codes and standards available for LNG, most of which include fire safety and fire protection. Obviously, most countries will either have their own standards, or may utilise some of the following:

European norms:

- EN 1473 Installation and equipment for liquefied natural gas: design of onshore installations.
- EN 1160 Installation and equipment for liquefied natural gas.
- General characteristics of liquefied natural gas.
- EEMUA 14731 Recommendations for the design and construction of refrigerated liquefied gas storage tanks
- EN 13565 EN 13565 Fixed firefighting systems - foam systems
  - Part 1: Requirements and test methods for components
  - Part 2: Design, construction and maintenance

USA codes and standards:

- 49CFR Part 193, Liquefied natural gas facilities: siting requirements, design and construction, equipment operations, maintenance, personnel qualifications and training, fire protection and security.
- 33CFR Part 127 Waterfront facilities handling liquefied natural gas and liquefied hazardous gas.
  - Import and export LNG facilities
- NFPA 59A Standard for production, storage & handling of liquefied natural gas. General plant considerations, process systems, LNG storage containers, vapourisation facilities, piping systems and components, instrumentation and electrical services, transfer of NG and refrigerants, fire Protection, safety and security
- NFPA 11 Standard for low, medium and high expansion foam.
- NFPA 17 Standard for dry chemical extinguishing systems.

Likely incident scenarios

The diagram on the opposite page highlights the LNG process and transport system. LNG import terminals legislation, codes and standards are strict in most countries and regulate the siting, initial and secondary containment, additional site containment, materials use and fire protection requirements. In most cases where LNG is used, either in liquefaction or import terminals, liquid spills may be caused by either human or mechanical error – jetty loading/unloading etc. These are the foreseen scenarios and this leads to the provision of liquid diversion channels to containment pits. These may, or may not be, at safe (radiant heat) distances from other LNG facilities, although on jetties it is often very difficult or almost impossible to do this.

Storage and cargo operations and storage for distribution require containment pits for serious liquid release events.

– part two

Liquefaction operations

The processing of LNG is part of a relatively simple fractionation operation which will be familiar to most readers with refinery or gas plant fire and emergency response roles. Once the natural gas is produced, by separating water, NG's, CO2 and other impurities from the original gas stream, the gas can be converted to liquid state.

The liquefaction operation involves cooling the natural gas via a refrigeration system. This cooling is done in one or more heat exchangers. The natural gas is cooled to near the temperature of the lowest temperature refrigerant, which will be below the condensing temperature of the high pressure natural gas. This liquid at high pressure is then dropped close to atmospheric pressure, which results in a temperature drop in LNG to approx -162°C. The liquid is then sent to storage tanks for export.

Liquefaction upstream scenarios

The upstream liquefaction incident scenarios are similar to any gas processing or refinery processing operations and will involve pressurised gas releases or jet fire events. The unignited gas release may be mitigated by use of water sprays. The jet fire obviously requires cooling of heat affected exposures and plant involved, while reducing and then isolating the gas feed pressure.

Dry chemical may be used for extinguishment, if safe to do so – if the release is of a manageable size for responders – but this needs to consider residual gas developing into a flammable gas cloud, thereby creating a larger and potentially more dangerous incident.

For an unignited gas release, tactics should consider:

- Water curtains can dilute and divert gas but avoid water in the liquid pool;
- Portable detection for gas drift to ignition source or semi or fully-confined areas where an explosion is possible;
- Water monitors may offer limited dilution.

For jet fires, tactics should consider:

- Isolate pressure source (pumps/operations);
- Prioritise cooling;
- Cool any flame affected steelwork or plant;
- Cool radiant heat affected steelwork/plant;
- Foam cannot extinguish a pressure fire (if C5 or C6 liquids are involved);
- Dry chemical may extinguish jet fire – but – pressure gas cloud will remain.

LNG carrier British Innovator. © BP plc.

Refrigeration incident scenarios

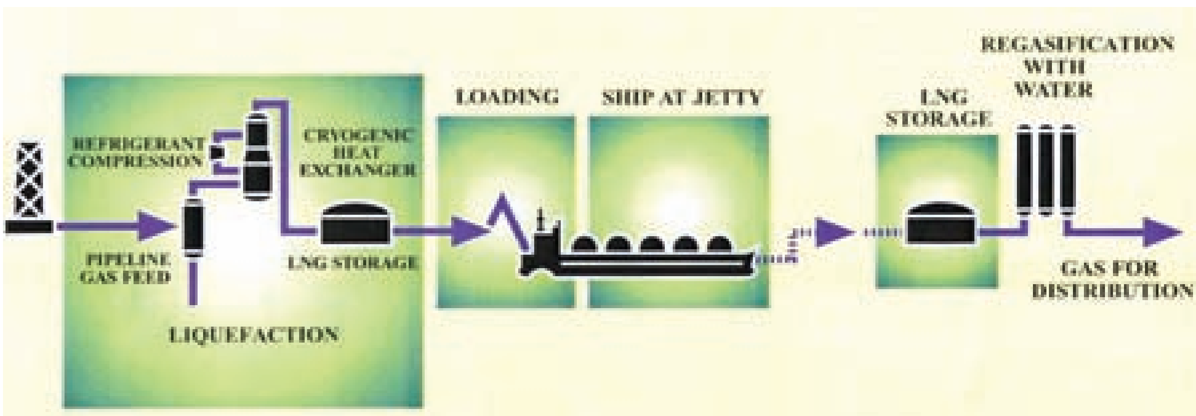
The refrigeration and LNG transfer to storage have the additional hazards of cryogenic liquid contact and liquid pool formations on release. LNG under pressure from transfer pumps has the potential to create large vapour clouds, two phase jet fires or limited size spill fires (due to high vapourisation rate preventing liquid build up on the ground). For the large vapour cloud scenario, the same gas release tactics listed for Upstream (above) should be considered, and for jet fires the same tactics for Upstream above should be considered.

Most LNG liquefaction areas will have channels and containment pits for accidental releases from piping and tank fittings. Thus, for contained LNG fires, water spray may be used for heat affected exposures, or high expansion foam may be used to reduce radiant heat impact on exposures.

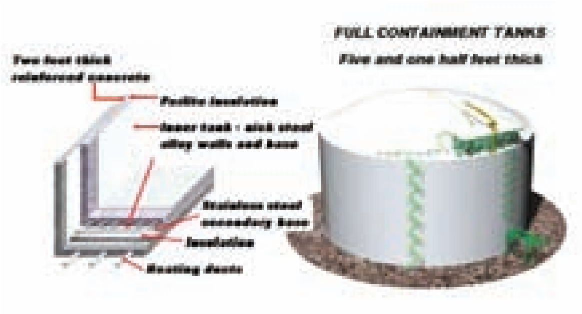
For Containment Pit LNG fires, tactics should consider:

- Cool any heat or flame affected steelwork or plant;
- Avoid water in the burning pool;
- Use of high expansion foam to reduce fire size (radiant heat reduction);
- Dry chemical can be used - but gas cloud will remain;
- A combination of fixed foaming to reduce for approach and dry chemical for extinguishment, or, dry chemical fire knock down and foaming thereafter to reduce vapourisation, once all resources are in place to do so.

If ignition does not occur, control of LNG vapour clouds from containment pits is limited to either high expansion foam or water spray but great care is needed in using water spray for vapour



The processing, transport, storage and distribution route of LNG.



Example of a full containment tank, where only spills from pipe attachments are likely. No tank bund/dyke is required.

cloud control – see "Water spray" further on.

For unignited LNG spills into pits, tactics should consider:

- Water curtains can dilute and divert gas but avoid water in the liquid pool;
- Portable detection for gas drift to ignition source or semi or fully-confined areas where an explosion is possible;
- Portable detection for gas drift to semi or fully-confined areas where an explosion is possible;
- Use high expansion foam for vapour reduction;
- Water monitors may offer limited dilution.

Jetties cargo operation incident scenarios

The export and import of LNG is recognized as having more frequent and probable instances of releases of LNG. However, most of these will be minor leaks from valve stems and flanges, rather than serious spills – given the cycling from ambient to cryogenic temperatures and ambient again, some very minor leaks are to be expected. Leaks are also possible from loading arms and valves. Leaks from ship manifold valves, flanges and gaskets could occur.

Short duration, rapid LNG flow leaks from failures on or of loading arms (where rapid ESD and disconnect fails also), will normally be collected in channels and run to containment pits. These pits may be at the jetty ends or on a mooring dolphin, depending on layout. Responding to jetties needs to be a carefully pre-planned operation. There will usually be limited vehicle access and width for turning. It must always be remembered that any response is moving toward a potential flammable gas cloud or radiant heat area.

For jetties, tactics should consider:

* Similar to the liquefaction LNG strategies, for contained LNG pit vapour clouds, water spray and or high expansion foam may be used with caution regarding water spray.

* For LNG fires, water spray may be used for heat affected exposures or high expansion foam may be used to reduce radiant heat impact on exposures, with the same caveat on water spray. Note that the ship's crew will be managing their own response.

Example of LNG containment pit with channel run from potential spill areas. High expansion foam system supplies two pourers. Pourers must be capable of withstanding the very high burn temperatures that will result from an LNG fire. Use of light alloy for such pourers is not recommended.

Tankage incident scenarios

Most tanks will have two means of containment with a primary inner tank and either an outer tank or outer berm, which would contain LNG if the primary tank failed, something that has not occurred since 1944. Should the primary tank fail, the secondary containment would contain the liquid although there may be then a rise in vapourisation, at least initially. Obviously, much depends on the type of tank in use at facilities. Where an increase in vapourisation occurs and tank safety relief valves open, the site vent or flare, if there is one, may also have to operate for some time until vapour pressure reduces.

The above might mean standing off at a safe distance, but it's recommended that this particular scenario for the tank types in use is discussed in detail as part of the pre-planning at sites.

Some sites have high-expansion foam systems fitted to LNG storage tank bund/dyke walls, where such bunds/dykes are provided, to reduce vapour travel or radiant heat impact on adjacent tanks or plant. This envisages older tank types. For modern tankage where full containment tanks are provided, there is no need for such bund/dyke arrangements.

For most tanks, radiant heat from an external fire will not immediately impact on LNG within a primary tank and if the outer wall is concrete, there will be little heat transfer inward. It is for this reason that double walled storage tanks are less likely to BLEVE as there is no direct heat on the liquid to cause boiling and weakening of the steel shell.

An assessment of cooling requirements should always follow the practical example of playing a water stream over the face of the exposed plant, equipment or tank area and if the water steams, the surface needs cooling. If not, leave it alone and check it later. LNG tanks are highly unlikely to fail under normal circumstances and normal operations. The more probable scenario for tanks will be an increase in vapourisation within and opening of the relief valves with subsequent ignition (rollover). A release from pipe fittings is also possible but the LNG should then be run to a catchment pit if this occurred. Dry chemical may be used if it proves necessary to extinguish the valve vent fires – meaning if the vent fires are likely to affect other steelwork on the tank. Risk assessment must determine if responders should access the tank top and it is safe to do so, but this assessment should be part of the pre-planning.

For tank related unignited LNG releases, tactics should consider:

- If no tank relief valve dry chemical system and no ignition occurs, heavy cold vapours might drift or cascade down tank side;
- Portable detection for gas drift to ignition source or semi or fully-confined areas where an explosion is possible;
- Water curtains can dilute and divert gas;
- Water monitors may offer limited dilution.

For tank related LNG fires, tactics should consider:

- Cool any heat or flame affected tank face, piping or valves etc;
- Avoid water in the burning pool causing any external fire affecting tanks;
- If relief valves involved, check fixed dry chemical system has actuated or if back-up discharge can be remotely actuated.

Piping scenarios

Minor leaks are possible from defective flanges, gaskets and valves but icing at these locations will indicate such small releases. On a larger scale, any short duration, rapid flow leaks from damaged LNG piping or valve failures etc should be collected in channels and run to containment pits on site.

For containment pit LNG fires, tactics should consider:

* Cool any heat or flame affected steelwork or plant;

* Avoid water in the burning pool;
* Use of high expansion foam to reduce fire size (radiant heat reduction);
* Dry chemical can be used – but gas cloud will remain;
* A combination of fixed foaming to reduce for approach and dry chemical for extinguishment, or, dry chemical fire knock down and foaming thereafter to reduce vapourisation, once all resources are in place to do so.

For unignited LNG spills into pits, tactics should consider:
* Water curtains can dilute and divert gas but avoid water in the liquid pool;
* Portable detection for gas drift to ignition source or semi or fully-confined areas where an explosion is possible;
* Use high expansion foam for vapour reduction;
* Water monitors may offer limited dilution.

LNG road tankers

Until 2002, there were no catastrophic incidents involving LNG road tankers. Databases in Europe and the USA indicated that although there were a number of road accidents and subsequent leaks from road tankers, there were no consequential fires involving LNG. Road transport up to this time had therefore been considered relatively safe.

Although further such incidents may have occurred recently and are therefore not mentioned here, responders need to be aware that since 2002, there have been two incidents involving tankers where fire occurred. One occurred in September 2005, in Lyon County, Nevada, USA when a rear valve leaked and the vapour ignited. This was handled safely by local evacuation, cooling the tanker and allowing to burn out. The other involved a road tanker in June 2002, in the foothills of Catalonia, Spain which resulted in a BLEVE. Hitherto, there were no recorded instances of BLEVE involving any LNG road tanker and it was widely thought that such an event was extremely unlikely, if not impossible (something as responders we always avoid saying!) and was limited to LPG road and rail tankers.

Briefly, this incident occurred due to brake failure on a bend and the tanker overturned causing an LNG spill which ignited quickly. The driver died in the vehicle overturn. After some 15-20 minutes, the tank exploded in a classic BLEVE event with blast wave, fireball and missile debris. Other cars (unoccupied) were destroyed and a nearby house was badly damaged. The fact it was a rural area assisted in the lack of fatalities.

According to the official report, the BLEVE occurred because of the heating of the LNG tank by the fire, which originated because of the vehicle overturn. It's not clear whether the flames were due to the truck diesel fuel burning, or to LNG burning. More probably, the report believes both fuels were involved. The remains of the tank indicated that there was flame impingement on the right side of the tank, which was not in contact with the cryogenic LNG. What is clear is that after about 20 minutes of burning, the tank exploded. The explosion seems to have followed a two-step mode with the formation of an initiating crack in the tank, followed by a two-phase (vapour and cryo liquid) discharge and then the restart of the crack, resulting in catastrophic failure of the tank.

The radius of damage appears to have been in the order of 300m, with the fireball in the order of 150m diameter. Two persons received burns at a distance of 200m from the fire area. Approximate calculations show that they may have received in the order of 16 kW/m2 for a brief spell. Given this information, it is obvious to responders that where such incidents occur, a life safety distance minimum of 1,000m radius may be advisable. It may be argued that countries use different types of road tank construction and insulation from each other, that one country's road tanker construction standards may not be as stringent as another's and so on, but, this does not eliminate the BLEVE incident potential. The obvious lesson should be that regardless of vehicle, road tank construction or country, the possibility of BLEVE should always be a high priority for emergency responders.

The LNG tanker on fire minutes before the BLEVE.

The BLEVE aftermath. The road tanker was located in the lower left of the photograph. Part of the tank smashed into the house in the background.

For any road tanker unignited spill or vapour release, the tactics should be same as for an LPG road tanker:
- Precautionary non-essential personnel evacuation to minimum distance of 1000 metres;
- For vapour cloud, water curtains to dilute/contain/divert;
- Portable detection for gas drift to ignition source or semi or fully-confined areas where an explosion is possible;
- Avoid water on any LNG liquid – this will increase cloud;
- Evacuation of all responders once water curtains in place.

For any road tanker LNG spill fire, the tactics should be same as for an LPG road tanker
- Precautionary non-essential personnel evacuation to minimum distance of 1000 metres;
- Cool tanker if on fire but expect greater fire intensity if liquid LNG involved in fire;
- Cool any nearby tanker loading/unloading plant, equipment or other heat affected exposures;
- Evacuation of all responders once cooling in place.

In the final part of this series John Frame will look at use of water spray for LNG incidents; use of foaming for LNG vapour control; foaming for fire control; foam application duration; extinguishment using dry chemical; and ship cargo operations response.