Lessons Learned Bulletin No. 14

Chemical Accident Prevention & Preparedness

Learning from incidents involving liquefied petroleum gas (LPG)

The aim of the bulletin is to provide insights on lessons learned from accident reported in the European Major Accident Reporting System (eMARS) and other accident sources for both industry operators and government regulators. JRC produces at least one CAPP Lessons Learned Bulletin each year. Each issue of the Bulletin focuses on a particular theme.

This 14th issue of the Lessons Learned Bulletin (LLB) accompanies the publication of the JRC's Good Practice Report on Risk Management and Enforcement on Liquefied Petroleum Gas (LPG) and Liquefied Natural Gas (LNG) Sites. The Good Practice Report provides an extensive description of the properties of LPG and typical risks associated with LPG production, storage and handling. This issue of LLB focuses on incidents involving LPG mostly on fixed sites however many incidents with LPG on transport have been considered as well. In total 88 incidents have been studied for the purpose of this LLB.

Please note:

The accident descriptions and lessons learned are reconstructed from accident reports submitted to the EU's Major Accident Reporting System

https://emars.jrc.ec.europa.eu

as well as other open sources. EMARS consists of over 1100 reports of chemical accidents contributed by EU Member States and OECD Countries.

The cases selected for this bulletin also generated a number of lessons learned, not all of which are detailed in this bulletin. The bulletin highlights those lessons learned that the authors consider of most interest for this topic, with the limitation that full details of the accident are often not available and the lessons learned are based on what can be deduced from the description provided. The authors thank the experts who provided advice to improve the descriptions of the cases selected.

Case 1 – Fire and explosion of a propane truck at a foundry

Sequence of events

A driver was in the process of transferring 11,000 gallons (41.6 m³) of liquid propane to two 30,000 gallon stationary bulk storage tanks at a metal foundry. Both stationary tanks were connected together by liquid and vapor transfer lines designed to allow transfer between tanks and/or simultaneous filling. As per regulations, each storage tank had pressure relief devices located on the top of each tank. Upon the tanker truck's arrival at the facility, it was discovered that fittings on the liquid delivery line had separated from the hose and would

Fig. 1 Butane tank cylinder and sphere
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require repair prior to offloading of product. These repairs were attempted by the driver and three foundry workers, none of whom had specific training for repairs of high pressure lines. Repairs were made using items found on site including several hose clamps and pins not rated for use on high pressure equipment. These repairs failed following activation of the Power Take Off (PTO) unit used to pressurize the transfer from the truck to the tank assembly. The security camera video clearly showed the driver hooking up this repaired hose to the truck, activating the PTO and walking towards the stationary tanks to open the globe valves on the tank intake manifold. The truck was soon rapidly surrounded with a cloud of highly volatile propane vapors. These vapors found their way into the foundry and 34 seconds later were ignited by an electric arc furnace inside the foundry causing the initial fire and flash type explosion.

Important findings

In transferring liquid propane from a tanker truck to a fixed or stationary storage tank the transfer is accomplished with the use of two separate pressure-rated hoses, the first for delivery of the liquid propane and the second to allow vapors to return to the truck. Each hose should be be rated at a minimum of 1700 PSI with fittings designed for both the pressure and to resist any corrosive or erosive impacts of movement of pressurized material. Unfortunately, in this event, the hasty repair job replaced the original connections with hose connections that were not rated for LP-gas service and would not withstand the pressure. Furthermore, the repaired hose was not tested after assembly to ensure it was free from leaks under normal use.

The transportation and handling of all hazardous material, including propane was regulated by regulations for transportation

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MAHBulletin
TECHNOLOGY INNOVATION IN SECURITY UNIT
Directorate E - Space, Security and Migration
European Commission Joint Research Centre
21027 Ispra (VA) Italy *https://ec.europa.eu/jrc/*

European Commission

Number 14
December 2019
JRC 119239

(Continuation from Case 1)

of dangerous goods that requires all drivers to undertake rigorous training and certification every 3 years. All evidence points to the certifications for the driver being current and valid at the time of the event. Additionally, there were no reports of recent citations of the driver or the vehicle involved.

Adding to the series of events that led to this event was the failure of an internal liquid shutoff valve on the tanker truck. This valve located inside the transportation cargo tank was designed to monitor actual flow rate against a preset safe flow rate. As designed in the event of a rupture or pipe break, the valve should have closed without human interaction within 20 seconds. An additional safety device, a thermally activated valve rated at 250 F also should have closed, shutting off the fuel supply from the fire. These failures allowed fuel to feed the fire resulting in a BLEVE approximately seven minutes later.

An investigation report noted that the valve's nylon plunger lacked sufficient force to push the release lever while under pressure. It also concluded that an appropriate safety factor was not incorporated in the selection of an emergency safety device on an internal valve.

The investigation report does not indicate who was legally responsible for the repair of the hose, the site or the operator.

Lessons learned A number of procedures were violated leading to this accident, including:

- Using hose connections that were not rated for LP-gas service and would not withstand the pressure
- Not testing the repaired hose after assembly to ensure it was free from leaks under normal use.
- Failure of the site operator to train personnel sufficiently on actions to take when the loading operation breaks down
- The engagement of personnel in the repair of the propane system who did not have the requisite competence
- Not having a shutoff valve with means of remote control to protect against uncontrolled discharge of LP gas from piping close to the point where the piping and hose connected.

Many of these decisions were taken or encouraged by the driver, who was supposedly highly trained in the operation of propane systems and loading and unloading functions. The site employees did not challenge these decisions and were willfully engaged in the repair and subsequent restart of the loading process. These actions suggest a failure in the safety culture, and particular in communication, on both the part of the LPG supplier and the site operator. The training of LPG truck drivers should result in a clear understanding of the safety consequences of not adhering to proper procedure for repairing equipment and replacing parts. The driver should be motivated to not violate the rules even if it undermines delivery targets.

The site also has a responsibility to inform personnel that interface with propane systems of what to do in abnormal situations and events, such as failure of the LPG equipment, that should trigger management involvement. It may be appropriate for the basic rules of LPG safety to be posted in the vicinity of the tank to avoid serious mistakes that can lead to accidents.

In addition, in this case, the liquid shut off valve and the thermally activated valve did not function on demand. The site, as owner of the equipment, is responsible for the integrity of LPG equipment safety controls, that they are the proper design and are tested and maintained as required.

As shown also in Case 5, maintaining awareness of the safety risks of LPG can be a higher challenge for sites that use and handle LPG only as a fuel to run their business. Nonetheless, the site must adhere to established standards, norms, and procedures in maintaining, repairing, testing and replacing equipment and equipment controls associated with the LPG system. They should also ensure that the rules are communicated to employees and subcontractors with appropriate signage and job aids (e.g., checklists), as well as through routine training for all relevant personnel who have a role in maintaining LPG safety, including staff and management associated with operations, maintenance, infrastructure, purchasing, buildings, utilities, equipment inventory, etc.

The accident information is adapted from: *Hildreth, R. 2013. Executive briefing on fire and explosion at Atlas Castings and Technology.*
http://richhildrethmep.blogspot.com/2014/01/executive-briefing-on-fire-and.html

Case 2 – Flaming propane leak in an LPG tank

Sequence of events In a 1,250 m³ LPG storage installation , a propane leak occurred around 14:45 on a purge valve of one of the pumps of the 3 mounded tanks (2 x 500 m³ + 1 x 250 m³) which were put into service replacing 3 above ground spheres. The vertical jet of gas (7 bar), 6 to 8 m, ignited in less than 5 seconds. The head of the centre saw the fire from his office and activated an external emergency stop which closed the bottom valve of the tanks and the isolation valves. The internal emergency plan was triggered and off-site emergency responders were alerted at 14:50; the mutual assistance protocol was activated with neighboring oil companies which provide fire equipment. The depot personnel, then the firefighters arrived 10 minutes after the alert, cool the neighboring facilities (sheet of piping and pumping) with water cannons and lances. The ignited release lasted for 35 minutes, which was the time taken for the contents of the 20m long and 250 mm diameter line, as far as the shout-off valve. After extinction, the purge valve was closed manually. The internal emergency plan was lifted at 3:40 pm. No injuries resulted. The cooling water was confined to the site. The gas leak was estimated at 350 kg.

Important findings Shortly before the accident, the pump had been used for about 10 minutes to load a small bulk truck. In the same area, 3 employees of a subcontractor were preparing to paint the pipes of the pump involved. This preparation had 2 phases: mounting of a plastic cover to protect the elements not to be painted (e.g., pump, flame detector located above the pump, emergency stop button, etc.) and cleaning of the surfaces to be painted by blowing with a hose connected to an air compressor. A subcontractor, without observing the work instructions, climbed onto the piping supplying the pump to "blow" the dust at height. With his foot, he accidentally hits the ¼ turn purge valve causing a release which ignited. Electrostatic discharge was the likely ignition source. The protective plastic was not compatible for use in an ATEX zone.

Lessons learned The following safety issues are highlighted by this event:

- While the pumps are being prepared for painting, another team is using the pumps in a loading operation. It is not clear that the two teams (the loading team and the painting team) were aware of each other's presence and if their actions had been coordinated and supervised by a manager. All the same, it is not good practice to conduct a maintenance while LPG equipment is still in operation. Although the maintenance work is superficial, the interaction creates an abnormal situation that could lead to unpredictable outcomes. Maintenance work on LPG systems is normally performed in isolation to minimise interference from other nearby or connected operations.

In spite of many years of experience, accidents within the LPG industry continues to occur

Liquefied petroleum gas (LPG) is a long established and substantial part of the oil and gas industry, involving a wide range of actors across the globe. While production has been flat in recent years Consumption of LPG in the European Union has more than doubled since 2007.[1] Moreover, it is believed by many experts that EU demand for LPG will continue to grow firmly throughout the next decade.

In present day, there are at least 700 sites covered by the Seveso Directive associated exclusively with LPG production, storage or distribution, as well as a variety of other sites that produce LPG (mainly petroleum refineries) or use it as feedstock for their operations. In addition, according to a survey of EU Member States, there are at least 11 000 LPG facilities that do not fall under the Seveso criteria in EU and EEA countries.[2] However, accident history gives evidence that serious incidents can also occur on these sites, often with the potential for cascading effects on nearby businesses and residences.

Over the years the LPG industry has implemented improvements to improve safety features and reduce incident risk. There are also numerous standards and codes for ensuring LPG safety, and as well as a number of EU Directives[3] relating to pressure equipment and explosive atmospheres that also may apply to design, installation and operation of LPG tanks. Indeed, the risks surrounding LPG operations are largely well-known and the design of equipment and controls to address these risks is increasingly more sophisticated and effective. Control measures to consider in prevention and mitigation of LPG accidents generally should include:

- Containment, that is ensuring that the containment is designed to the appropriate standard and its integrity is maintained over the course of its operation
- Separation, that is, location and layout of tanks to prevent people and property from harm Ventilation, allowing the rapid dispersion of flammable vapors emitted following a spill, leak or release Control of ignition sources, when there is a risk that a flammable atmosphere could either during normal operation or due to an accidental release
- Pressure relief valve, to relieve pressure if the upper pressure limit is exceeded during operation
- Flow control valves that release or stop flow to various openings in the tank and safety valves that help maintain stable conditions in the tank
- Monitoring equipment, to give readings on pressure, temperature and the volume (level) of the contents
- Detection equipment to detect the presence of flammable vapors, sometimes associated with an alarm or automatic emergency measure (e.g., shutdown of the loading process)
- Procedures surrounding activities associated with storage, distribution and handling of LPG, particularly loading and unloading and maintenance.

JRC analysis of chemical incidents involving liquefied petroleum gas (LPG)

The JRC reviewed 88 reports of chemical incidents involving LPG on commercial and industrial sites from various online open sources, including the EU eMARS database, the French ARIA database, the U.S. Chemical Safety Board, the U.S. National Safety Transportation Board, the German ZEMA database, and the UK Health and Safety Executive.[3] Incidents occurring at consumer vehicle filling stations were excluded from the study as were incidents in which the release of LPG was a secondary impact of an accident not directly associated with LPG operations. The majority of accidents studied occurred in the European Union or North America and all took place between 1966 and 2019. The accident reports varied in length and level of detail about the causality and lessons learned. An accident report was included in the study only if it included some information on the causal conditions.

The purpose of the JRC study was to identify particular patterns in causality that might help sites in reviewing the state of their LPG equipment and practices surrounding their management and operation. In particular, it was expected that the analyses of the reports might give insights on the industry sectors and activities commonly associated with LPG failures, and vulnerabilities associated with operations and control measures typical for LPG management and operation.

Summary of study findings

The study highlighted a number of potential factors that contribute to failure of various control measures. However, the most striking finding was the number of events that seemed to have occurred because of a failure to follow procedures for handling and operating LPG pressurized equipment or a failure to respect maintenance practices or equipment standards essential to minimizing the chance of a catastrophic release. This observation suggests that communicating and training on LPG risks remain particularly important elements of safety control on sites where LPG and LPG tanks and cylinders are produced, handled, or stored, or where LPG is used as feedstock. The safe use of LPG as a fuel is made possible by the presence and synchronization of the design of the tank, safety features in the form of equipment controls, measurement and detection instrumentation, compatible connecting euqipment (e.g., pipes, hoses), and operating procedures that recognise and benefit from the capabilities of all these elements. However, this safety is severely compromised when persons do not understand that their own safety, and the safety of those around them, is dependent on their own decisions being consistent with the built-in protections and integrity of that system.

Other findings from the study are highlighted below:

- A number of events were initiated when a valve was opened for a filling or other liquid withdrawal operation, or when a pressure valve opened in error or failed to close. In many such cases, valves were somehow open at a time when they should have been closed, or precautions were not undertaken that would prevent release of vapors or detect a leaking valve prior to an operation.
- Hose and loading arm ruptures, and even collisions with equipment or another vehicle, also were causal factors in releases during loading and unloading operations.
- Monitoring and automated controls can be critical in the prevention of many serious accidents involving LPG in, especially automated gas detection monitors and shutoff valves. However, it is also essential that these systems are properly calibrated to solicit the correct response in time, also taking into consideration the other alarm activity that maybe taking place.

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[1] Eurostat. *https://ec.europa.eu/eurostat/web/energy/data* as updated 30-04-2019.

[2] Nockels, D. 2017. Participant States LNG/LPG Sites. Mutual Joint Visit Workshop for Seveso Inspections on Risk Management and Enforcement on Liquefied Petroleum Gas and Liquefied Natural Gas (LNG) Sites. 26-28 September 2017, Nicosia, Cyprus. *https://minerva.jrc.ec.europa.eu/en/shorturl/technical_working_group_2_seveso_inspections/mjv_lpg_and_lng*

[3] Links to many references and standards can be found on the back page of this document

- Six catastrophic explosions, as wells as a few less disastrous accidents in the study were either partly caused or made worse due to the equipment location. In at least four cases the internal location (e.g., inaccessible for monitoring, inadequate isolation from other structures) was a significant factor. Other cases showed that offsite populations and neighbouring industries in close proximity to the site can suffer devastating consequences from accident scenarios involving large LPG explosions.
- Reports also indicated a number of events that involved the use of wrong (or in one case, obsolete) equipment on the containment itself or in its handling. Notably, two events in gas bottle filling were initiated in part from a spark generated by the process equipment.
- Illegal activity also was suspected or confirmed as the main factor in four events, of which one was definitively, and the other was suspected to have been caused by sabotage (intending to cause an accident), while the other two events were unintended side effects of an unlawful act, i.e., illegal truck-to-truck transfer and an attempt to steal the LPG from the site.

Industry sectors where the incidents occurred

Only reports of incidents associated with fixed installations were included in the study. More than half of the incidents studied (45) occurred in LPG distribution and storage sites and 20% occurred at LPG production facilities, including 15 petroleum refineries and 3 LPG production sites. Since LPG is a feedstock for many other types of industries, it is not surprising that a number of downstream users (including cosmetics production, recreation facilities, and paper manufacturing) also experienced LPG accidents. Chemical manufacturing, metal processing and farming are also known to use LPG as a primary source of fuel in their operations.

Impacts of the incidents in the analysis

If it finds an ignition source, accidental release of LPG can cause a major disaster. Among the incidents studied, 39% (34) caused harm to human health, including over 600 deaths and 7000 injuries reported for one incident alone, an LPG explosion in Mexico City occurring in 1984. Fortunately, LPG accidents over the last few decades have had less impact on human health in the EU and North America. (This is not necessarily the case in other parts of the world.) The study indicated only 21 deaths and 62 injuries resulting from LPG accidents that occurred after the year 2000, including 45 injured from one incident alone, the LPG explosion in Glasgow, United Kingdom in 2004. However, the significant economic impacts in more recent cases is evidence that LPG accidents remain a high risk, including damage to nearly 6,000 homes from a propane explosion in Toronto, Canada in 2008, and 14 million in property damage from an explosion in Tacoma (WA), USA in 2007.

Type of activity underway when the incident occurred

The reports give evidence that releases occur more often during activities that involve opening or handling the LPG containment as opposed to when a tank or cylinder is operating in steady state, e.g., fueling a system or when no intervention takes place in storage. A release event occurred during a loading/unloading in 41%, or 36, of the 88 events studied) (see Figure 1). There was also a notable number of events (29% or 26) associated with other types of interventions requiring opening the container, or refilling or unloading, including maintenance and startup operations, sampling and interventions such as draining, during storage. Although 11 events (13%) occurred in storage, four of these events were during some type of intervention on the tank during storage. A little over 22% of events (19) occurred during normal operations, meaning that the report did not implicate any direct activity on the LPG tank as a trigger for the sequence of events.

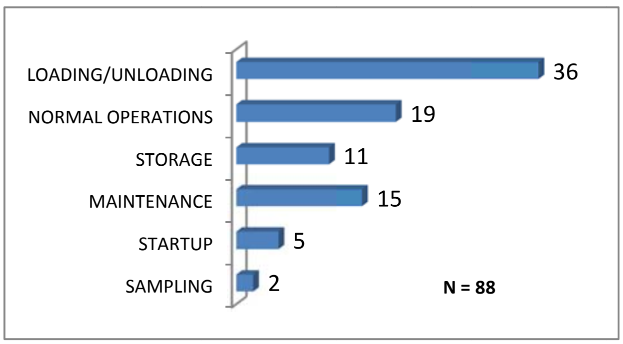

Figure 1 Type of activity underway when the incident occurred

According to the study, 56% (49) of the incidents began with a failure associated with a fixed storage tank. All but 8 of these tanks were above ground. Another 14% (12) of the incidents initiated with a problem associated with a road or rail tanker on the site for the purpose of loading or unloading an LPG product. Eleven incidents (13%) started in pipework connected to LPG storage tanks. Six incidents (7%) resulted from a failure in the connecting equipment of the transfer process (either a failure of the hose or loading arm or a leak at the connection to the tank).

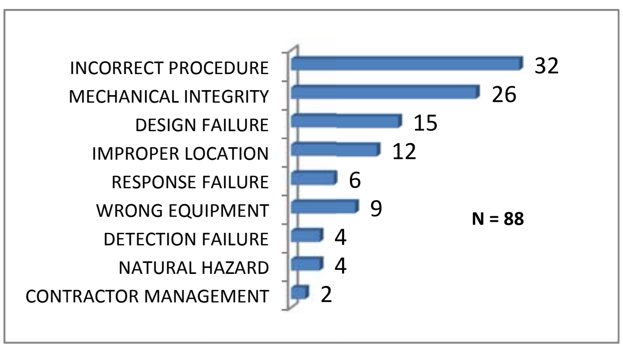

Figure 2 Underlying causes associated with the LPG release events analysed. An event can be associated with more than one failure.

Types of failures triggering the sequence of events

As shown in Figure 2, the triggering event for several incidents was linked most commonly to an equipment failure, but sometimes also to human action (incorrect procedure, illegal action). The most common type of failure involved a valve operation, a situation that occurred in a little over a third of the incidents (32). An additional 34% of the events (30) could be attributed to either a pipe or hose failure, usually due to a mechanical integrity failure or a failure at the joint. Some events were initiated by a combination of failures, for example, a failure to check for the presence of gas vapors before performing maintenance or failing to close a valve after loading. At least four events were caused by an illegal activity or other type of security breach, and three events were cited as preventable if a detection or monitoring system had performed as intended.

The detail on accident causality varied considerably in the reports, but more than 90% (68) of the reports included some information on factors that may have contributed to the failure. As indicated in Figure 5, analysis of this element highlights the importance of having clear and safe procedures for any intervention (32 or 36% of cases) that require opening the tank, filling or emptying a tank, and sufficient training on these procedures. A number of cases (26, or 30%) also indicated the presence of corrosion, fatigue, cracks or joint leakage, pointing to a failure in mechanical integrity and possibly also the inspection and/or equipment replacement regimes. The configuration of the equipment itself (design or wrong equipment) was cited as a problem in 24 cases (27%) and a failure in detection or response was noted in 10 cases. In contrast, automated detections helped to mitigate the magnitude of the release in at least 10 other cases (11%), but most releases in the study that were stopped before they became a major event were detected via human observation (sight or smell).

- The subcontractor climbed onto a safety tank is clearly in violation of work procedure. Climbing on the tank creates an elevated safety risk because of damaging, dislodging, or loosening equipment controls or otherwise provoking a malfunction that could eventually lead to an unplanned release. The contractor is responsible for hiring competent workers who know the safety rules of performing work on LPG systems. The site manager should require verification of competence through certification or equivalent, duly updated. In addition to prior verification, there should be protocols established for on-the job monitoring to check that job instructions and safety procedures are properly followed.
- The subcontractors appeared to protective plastic that was not antistatic and therefore not suited for explosive atmosphere (ATEX) zones. The contracting company is responsible for ensuring that equipment, clothing and footwear its subcontractors are using during LPG maintenance are appropriate for ATEX zones. The site operator should verify that the contractor has documentation that confirms that everything used or worn by its subcontractors is ATEX-safe.

As with Case 1, this case highlights again the importance of the operator implementing protocols that ensure that third parties involved with LPG systems on the site can and do work safely.

Source: *As translated from the ARIA database, No. 36310 https://www.aria.developpement-durable.gouv.fr/*

Case 3: Collapse and explosion of an LPG tank from earthquake impacts

Sequence of events On 11th March, 2011 at 14:46 hrs. (Japan Standard Time) the eastern part of Japanese archipelago was hit by a magnitude 9.0 (Mw) undersea megathrust earthquake with an epicenter approximately 70 kilometers east of the Oshika Peninsula of Tohoku region and at a depth of around 30 km from the surface of the ocean. The powerful tsunami that was triggered by the earthquake reached up to heights of 40.5 meters in Iwate Prefecture and travelled up to 10 km inland.

During the main-shock at 14:46, the peak ground acceleration at an oil refinery was recorded at 114 gal (cm/sec^2). One of the LPG tanks in the storage tank area of this industrial complex, filled with water for maintenance reasons, had its braces damaged by the strong ground motion. At 15:15 an aftershock measuring 99 gal was recorded. This time the legs of the tank could not survive the blow and the entire tank collapsed at around 15:20. The collapse took the neighbouring pipes with it and led to the release of LPG. At around 15:47 the LPG caught fire which triggered a series of explosions which were completely extinguished at 10:10, March 21st, 2011.

The vapor cloud from the LPG storage tank farm flew over to a neighbouring petrochemical company (around 100-150 m from the LPG tank area) and triggered a fire there. A second fire was ignited and the operating room burned down. The radiant heat from the refinery fire also sparked a fire at another chemical company nearby and a warehouse burned down.
The explosion of the LPG tanks led to the projection of a lot of debris. Some of the debris was discovered at distances as far as 6.2 km. The area within a radius of 700m around the burning LPG tanks, including over 1,100 residents of the surrounding community, was evacuated for 8 hours. Damage of asphalt tanks in the neighbouring chemical company led to release of asphalt into the ocean (later reported to have been completely recovered). Three fire fighters and three employees at the petrochemical company suffered injuries.

Important findings There were 17 tanks in the LPG storage farm area of the industrial complex. During maintenance the tanks are filled with water to check that the equipment still performs to design pressure (hydrostatic testing), a practice that normally takes place over the course of 2-3 days. On March 11, Tank no. 364 was holding water for 12 days. Also, before the earthquake, there was a confirmed leakage of air from the hose to which air was supplied to activate the emergency shut-off valve. As a temporary measure this valve was switched to open until the hose could be repaired. This meant that the emergency shut-off function had been disabled. In manually switching of the emergency valve to the "open" position, the operator was in violation of existing law. Not only could the valve not be closed through activating the pneumatic system, it could not close through the melting of the pneumatic hose in the event of a fire which is a safety function of pneumatically operated valves. Unfortunately, this emergency shut-off valve stayed open at the time of the earthquake too. After the first earthquake, the bracing of the LPG tank no. 364 suffered some damage since the tanks were designed for holding LPG and not for the temporary confinement of water, whose weight is 1.8 times heavier than LPG.

The damage was not identified during the visual inspection after the main shock at 14:46 hrs. It is difficult to visually inspect a tank of 20 m diameter and 2000 kl capacity in a short period of time. At 15:15 the aftershock occurred. The emergency valve was still not closed as it was wrongly assumed that the integrity of the tank was not compromised. At 15:20 the legs failed and the entire tank collapsed. The collapse damaged the neighboring pipelines and triggered a release of LPG.

Figure 3 *Cosmo oil refinery explosion 11 March 2011 (Wikipedia) (This file is licensed under the Creative Commons Attribution-Share Alike 3.0 Unported license.)*

Lessons Learned Working with pressurized equipment is a dangerous activity and companies that handle LPG have to reinforce this message from the top down. Maintaining mechanical integrity of LPG equipment takes precedence over any other business objectives, since the failure of any part of the LPG operation can lead to a serious accident, even loss of life. The failure to repair the leaking emergency valve had the disastrous effect of prolonging the fire until all the tanks were empty. In this case, the decision to violate the law and postpone a critical repair created enormous risk for workers and residents in the area and caused millions in property damage.

The tank was not designed to resist a strong earthquake while carrying water, so it failed and triggered a catastrophic sequence of events. LPG tanks can be vulnerable to the impacts of natural hazards, including earthquakes, strong winds, hurricanes and floods. Maintenance functions may increase the vulnerability of LPG systems because they are abnormal operations, and protections can sometimes be disabled temporarily for maintenance purposes. For this reason, it should be routine to include natural hazard impacts in job risk analysis for maintenance tasks to ensure that control measures are in place to minimize the chances that a natural hazard will damage the equipment.

The sequence of events and important findings are adapted from: *Chakraborty, A., Ibrahim, A., Zhao, B., Minamide, K., Han, S., Gao, Y., 2017. Natech Accident Investigation during the 2011 Great East Japan Earthquake and Recommendations for Disaster Preparedness Based on a Resident Survey. Capstone project report. Kyoto University.*

With reference also to:

Krausmann, E., Cruz, A.M., 2013. Impact of the 11 March 2011, Great East Japan earthquake and tsunami on the chemical industry. Nat. Hazards 67 (2), 811–828. https://doi.org/10.1007/s11069-013-0607-0

Krausmann, E., 2012. Field Visits to Industrial Areas Affected by the Great East Japan Earthquake and Tsunami, Japan, 28/11–02/12 2011 (Summary report).

Case 4 – Release and ignition of LPG following corrosion of underground metallic pipework

Sequence of events On Tuesday 11 May 2004, at about noon, an explosion occurred at a plastics production and distribution facility that caused the substantial collapse of the main building. As a result, 9 people lost their lives and 45 people were seriously injured or exposed to the risk of death or injury. The investigation established that the explosion was caused by the ignition of an explosive atmosphere that had formed in the basement area of the building. The explosion produced high overpressures that caused the building to collapse more or less within its own footprint.

Important findings The immediate cause of the explosion was the escape of LPG from the substantially corroded underground pipework at the cracked right-angled bend close to the southern wall of the building, the tracking of the escaped gas into the basement of the building at the west end, the accumulation of the gas in the basement to a point where it constituted an explosive mixture in air, and the ignition of that mixture. A test using a tracer gas demonstrated that there was a path through the basement wall, which would have allowed LPG leaking from the pipe to enter the basement of the building.

When the pipe was excavated, it was discovered that when the level of the yard had been raised 30 years earlier, the section of the pipe in which the main leak occurred had been packed around with loose fill material. Beneath the surface hard-standing a large concrete slab rested on top of the pipe where it turned and entered the building. The main leak at the final bend had been caused by external corrosion aggravated by the weight of the piece of concrete that rested on it.

Further examination of the pipe showed that the steel pipework associated with the LPG tank had originally been galvanised but otherwise had no other corrosion protection and that the screwed malleable iron fittings, straight couplings, bends and elbows joining lengths of pipework were, with one exception at the tank end, were ungalvanised and had no other corrosion protection. Also, the pipe lengths and fittings were substantially corroded, with a significant reduction in wall thickness in the pipework overall.

In the 1980s, the UK Health and Safety Executive included a recommendation to check the condition of the buried pipework but the recommendation was never implemented. Moreover, over its lifetime until the accident, the LPG tank was serviced at various times by two LPG supply companies. Both companies assumed that the customer had fulfilled all responsibilities in relation to any section of underground service pipework and that it was in safe condition.

Lessons learned The investigation of this incident produced a comprehensive description of lessons learned from this accident. The recommendations largely centred on two main areas:

- design, installation and maintenance practices for ensuring the integrity of LPG pipework over time, and
- the importance of establishing clear rules and accountability for ensuring the integrity of the pipework among all the principal parties engaged in its design, installation, operation and the regular supply of fuel throughout the life of the system.

Recommendations from the investigation were subsequently formalised in LPG guidance published by the UK Health and Safety Executive following the incident. Highlights of these recommendations are provided below, but for more details it is strongly advised to consult the UK guidance on "Safe use of liquefied petroleum gas (LPG) at small commercial and industrial bulk installations" (*http://www.hse.gov.uk/gas/lpg/safeuse.htm*).

- Corrosion of underground metallic pipework is most common near to a building because the soil nearest to the building has greater moisture, usually because of the run-off of rain. LPG pipework should not be installed in a basement or open void, and if such pipework existsit should be subject to a risk assessment. LPG will track the easiest route and accumulate at the lowest point. It can permeate through subterranean structures.
- Fulfillment of LPG safety responsibilites requires full documentation of original equipment configuration, maintenance operations, and testing results. Changes to the equipment over time and the environment in which it is situated should be managed as potential risks and documented. In the accident case discussed here, the main leak was identified as the point at which the riser for the LPG pipework (the pipe that carries the LPG vapour from the bulk storage tank to the building) became buried in the hard core and under the concrete hard standing when the floor was raised 30 years before. The raising of the floor was a significant change that was neither recognised nor managed in terms of its impacts on the condition of the LPG pipework.
- In the normal case ownership, the primary responsibility for LPG safety is on the user. It is the user who brings onto the land a highly volatile and dangerous gas. If other cases are more complicated, for example, where there are multiple parties involved, the responsibilities should not be overly complicated, and all parties should know the extent of their ownership the nature and extent of their legal rights and duties.
- Notwithstanding the primary responsibility of the user, the LPG supplier should have a strategy for the periodic inspection and testing of all pipework. The LPG supplier normally has specialised knowledge and experience in LPG, and retaining a formal role in supporting its customers in ensuring LPG safety provides a necessary redundancy to in the safety and reliability of the LPG system.

The description of this case is adapted from The ICL Inquiry Report. Explosion at Grovepark Mills, Maryhill, Glasgow. 11 May 2004. Presented to the House of Commons and the Scottish Parliament under S26 Inquiries Act 2005. HC 838. Edinburgh: The Stationery Office. SG/2009/129. ISBN: 9780102952247. Crown Copyright 2009.
https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/229279/0838.pdf

Case 5 – Propane release when unloading a tank truck

Sequence of events At 7.45 am, when unloading a tank truck on an LPG storage site, the pump attendant visually observed a continuous release of gas from the delivery head of the vapour collection arm. They stopped unloading. After a quick check of the installations and seeing no obvious cause, the pump attendant triggered the emergency stop at the transfer stations. All the automatic valves were closed, the compressor stopped and the truck stations were water-treated by sprinklers. He asked drivers to secure their trucks.

Despite this, the leak via the delivery head of the vapour recovery arm persisted. The pump attendant and the depot manager checked the gas concentration. A maximum of 3% of the lower explosive limit (LEL) was measured at the edge of the site via a mobile detector and the threshold of 20% of the LEL was reached at the rear of the truck via an in-situ sensor. The warehouse manager asked the drivers to block the road. After another series of checks, he noted that the manual valve and the bottom valve of the LPG truck are not closed. The leak is stopped at 8:15.

Important findings A failure of the manual self-closing purge valve (automatic return in the closed position by a spring) of the arm was the cause of the incident. Failure of the valve is related to uncoupling of the valve control shaft from the valve body. This failure was related to wear of the axis. It allowed the passage of product through the vapour recovery hose and the delivery head when starting the new unloading.

The duration of the leak (30 minutes) was explained by the non-closure of the emergency shut-off valve on the truck by the driver contrary to the procedure. Although this procedure is explained to the drivers during the annual awareness training, the description of the procedure is given in very general terms such that they can be easily misunderstood.

Source: *As translated from the ARIA database, No. 50686 https://www.aria.developpement-durable.gouv.fr/*

Case 6 - Leak and flash of LPG in a refinery

Sequence of events The driver of an LPG-haulage firm suffered severe burns whilst loading his road-tanker and as a consequence died. The LPG road-tanker was connected to the loading installation via a jointed loading-arm. Loading was carried out under "spray loading", in which the liquid phase is pumped through the foot valve into the vapour phase of the road-tanker's tank. No vapour phase exchange took place. After around 15 tonnes of LPG had been loaded there was a spontaneous separation of the connection between the loading-arm and the vehicle at the threaded coupling. This led to a release of LPG, which ignited and engulfed the driver. The driver died a number of days later as a result of the injuries received. The force of the separation was sufficient to propel the loading-arm backwards until it impacted with the housing of the loading station. This led to the activation of the "pull- away" quick release coupling and the flow of LPG from the refinery was stopped. The fire melted the pneumatic hose for the foot valve of the road-tanker and the pneumatic valve closed, stopping the release of LPG from the tanker. The size of the release was estimated to be about 20 litres (ca. 10 kg).

Important findings The investigation carried out after the accident showed that the cause of the LPG release was the failure of the threaded coupling. A closer inspection showed that the 3¼" ACME threaded coupling was very badly worn. The trapezium cross-section of the thread of the threaded ring was worn so badly, that it was reduced to a triangular form. The fitting (road-tanker) was worn so that it was slightly conical. The connection was therefore extremely instable. This meant that even vibration or a slight movement of the loading-arm could have been sufficient for the connection to fail.

Clearly visible on the threaded ring was the deformation caused by hammering the lugs (ears) with a hammer to tighten the coupling.

Lessons learned Hammering to tightening the coupling was a common place practice. However, hammering has a number of effects including: the thread may be worn by over-tightening or the ring may become deformed (oval). Near to the loading-station a wrench for tightening the coupling was found on the ground, so it can probably be discounted that this driver had tightened the coupling by hammering in this case.

Following this accident, all LPG distributors, LPG storage tanks > 15 tonnes capacity, LPG tanks known and LPG road-tankers in the jurisdiction were inspected in order to identify all couplings and fittings "at risk" of being in a damaged state. In no single case was serious wear on the ACME-threads of the LPG storage tank fittings identified. In a few individual cases minor wear was identified. In these cases the fittings were replaced as a precaution by the operator. However it was also reported that several operators were already informed by their LPG supplier and had already replaced the relevant fittings in their installations as a precaution. It is not possible to say afterwards, whether a fitting that has been replaced had signs of excessive wear or not.

In a few cases signs of hammering could be identified on the threaded ring of the coupling, although the thread itself showed no signs of damage. The operators were required to ensure, that in future the coupling was no longer tightened using a hammer – as was common practice in the past.

Source: *Hailwood, M. Lessons learnt from industrial accidents. Release then flash of LPG at tank truck loading point in a refinery. IMPEL Seminar on Lessons Learned from Accidents. Caen, France, 15-16 June, 2005. ARIA No. 29590 https://www.aria.developpement-durable.gouv.fr/ (Detailed report)*

Case 7 – An accidental release of LPG occurred during a ship to shore transfer (UK/2008/003)

Sequence of events A bursting disc fitted to a 4 inch spur of the West 14 inch Import pipeline operated, resulting in 163 tonnes of unstenched liquid Propane (LPG) being released into a storage tank bunded area

Important findings At some unknown time prior to the start of the release, the bursting disc on the West import pipe line ruptured during a routine ship to shore discharge. There is no evidence of over pressure within the discharge line as the pumping rates and pressures were within limits.

However, two bursting discs are on site, one on each of the two import pipe lines. The bursting discs had not been included in the sites planned preventative maintenance programme and evidence suggests that they had not been changed in over eleven years. It is believed that the bursting disc probably failed due to fatigue. The manufacturer of the bursting disc confirmed that this type of disc is now obsolete. They also recommend that the bursting disc is changed every year.

Source: *eMARS database – Incident occurrence: 27-10-2008*

Motto of the year

"Every 1$ invested in proactive measures saves 6$ for recovery"

from a study of the National Institute of Building Scientists, USA

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European Commission

(Continuation from Case 7)

Lessons learned for Cases 5, 6 and 7

Equipment failure is a frequent cause of unintended release of LPG. The JRC study indicated that 22% of 74 LPG release incidents were associated with corrosion or wear and tear that impaired the functionality of the LPG tank or connected equipment. In a number of cases, it appeared that the inspections programme had not respected norms regarding frequency of inspections or had never been inspected since entering into service.

LPG equipment is highly standardised and inspection frequency, that is usually well-established by government or industry standards and recommendations. Operators and users of LPG tanks should be knowledgeable about these norms and establish and implement inspection and maintenance plans accordingly.

Likewise, each element of the LPG system has an expected service life that is normally communicated by the manufacturer. Replacement plans should be established and implemented in accordance with these instructions. It is understood that the documentation may not be available, but it is expected in these cases that the operator addresses this issue within a risk-based inspection programme.

Training and awareness needs have already been addressed within prior cases, but Cases 5 and 6 also highlight the need for training that is sufficiently specific and rigorous for personnel to perform their duties safely in any situation.

A selection of European Directives and Standards for LPG storage in tanks and bottles, filling, and testing

EU Directives

The Pressure Equipment Directive (PED) (2014/68/EU) for stationary pressure equipment with a maximum allowable pressure greater than 0,5 bar.

The ATEX Directive 2014/34/EU covers equipment and protective systems intended for use in potentially explosive atmospheres.

The Aerosol Dispensers Directive (ADD) (75/324/EEC) Further guidance materials is available at: *https://ec.europa.eu/growth/sectors/pressure-gas/pressure-equipment/directive_en*

Technical standards

These standards are developed and published by the European Committee for Standardization (CEN) and can be found, together with other standards, under: (https://standards.cen.eu/index.html)

EN 12542:2010	LPG equipment and accessories - Static welded steel cylindrical tanks, serially produced for the storage of Liquefied Petroleum Gas (LPG) having a volume not greater than 13 m³ - Design and manufacture
EN 12817:2019	LPG Equipment and accessories - Inspection and requalification of LPG pressure vessels up to and including 13 m³
EN 12819:2019	LPG equipment and accessories - Inspection and requalification of LPG pressure vessels greater than 13 m³
EN 13110:2012 +A1:2017	LPG equipment and accessories - Transportable refillable welded aluminium cylinders for liquefied petroleum gas (LPG) - Design and construction
EN 13175:2019	LPG Equipment and accessories - Specification and testing for Liquefied Petroleum Gas (LPG) pressure vessel valves and fittings
EN 13776:2013	LPG equipment and accessories - Filling and discharge procedures for LPG road tankers
EN 13799:2012	LPG equipment and accessories - Contents gauges for Liquefied Petroleum Gas (LPG) pressure vessels
EN 13952:2017	LPG equipment and accessories - Filling operations for LPG cylinders
EN 14129:2014	LPG Equipment and accessories - Pressure relief valves for LPG pressure vessels
EN 1439:2017	LPG equipment and accessories - Procedure for checking transportable refillable LPG cylinders before, during and after filling
EN 14422:2013	Clamp type coupling assemblies for liquefied petroleum gas (LPG) transfer hoses
EN 14570:2014	LPG equipment and accessories - Equipping of overground and underground LPG vessels
EN 14841:2013	LPG equipment and accessories - Discharge procedures for LPG rail tankers
EN ISO 14245:2019	Gas cylinders - Specifications and testing of LPG cylinder valves - Self-closing (ISO 14245:2019)
EN ISO 15995:2019	Gas cylinders - Specifications and testing of LPG cylinder valves - Manually operated (ISO 15995:2019)
CEN/TS 16769:2019	LPG equipment and accessories – Terminology

A more detailed description of each standard is available in a table that can be downloaded with this publication at: *www.minerva.jrc.europa.eu* on the "Publications" web page.