Safety History
of
International LNG Operations

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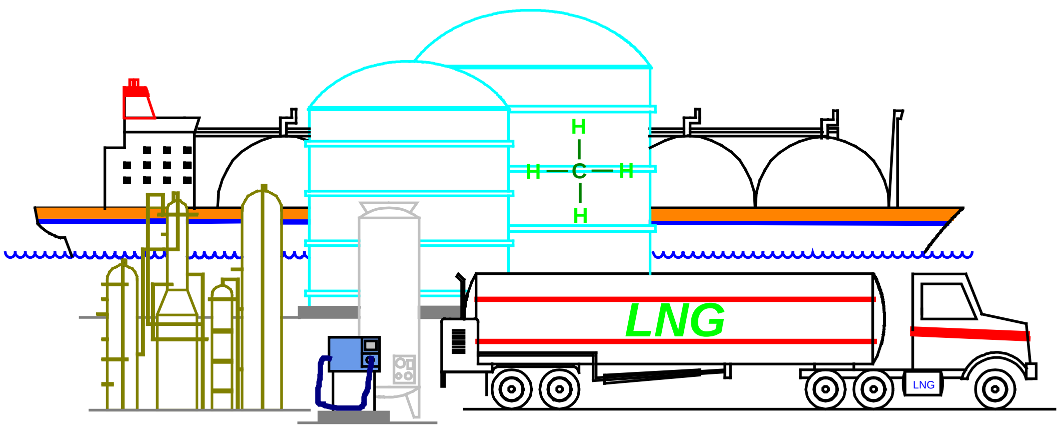

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Safety History of International LNG Operations

INTRODUCTION:

LNG has been safely handled for many years. The industry is not without its incidents and accidents, but it maintains an enviable "modern-day"[1] safety record. The process of natural gas liquefaction, storage and vaporization is not a new technology. Earliest patents involving cryogenic liquids date back into the mid-1800s. The first patent directly for LNG was awarded in 1914. In 1939, the first commercial LNG peak-shaving plant was built in West Virginia. There are over 120 peakshaving and LNG storage facilities[2] worldwide, some operating since the mid-1960s. In addition, there are 18 base-load liquefaction (LNG export) facilities in various countries including Abu Dhabi, Algeria, Australia, Brunei, Egypt, Indonesia, Libya, Malaysia, Oman, Nigeria, Qatar, Trinidad and U.S. (Alaska) currently in operation. LNG is transported by a fleet of about 219[3] LNG tankers of varying sizes from 18,500 M^3 (cubic meter) to 149,000 M^3. This fleet of LNG ships delivers to receiving terminals in the Belgium, Dominican Republic, France, Greece, Italy, Japan, Korea, Spain, Taiwan, Turkey, the U.K. and, of course, the U.S., including Puerto Rico.

The LNG storage tanks at these facilities are constructed of an interior cryogenic wall, usually made of 9% nickel steel, aluminum or other cryogenic alloy. The outside wall is usually made of carbon steel or reinforced concrete. A thick layer of an insulating material such as Perlite separates the two walls.

For land-based facilities, a secondary earthen or concrete containment having a minimum capacity exceeding the capacity of the LNG tank(s) surrounds the LNG tank(s). In some applications a tall concrete wall having an internal diameter slightly greater than the outside wall of the LNG tank, is used to double the integrity of the LNG tank. In others, the tanks are buried below ground level. In both cases, the objective is to minimize the exposed area between the LNG and the secondary containment based on a *catastrophic tank failure*[4] scenario. Many tanks are equipped with top tank penetrations only, i.e., no bottom or side wall penetrations, thus, even in the unlikely event of a piping failure, tank contents remain in place.

With a few exceptions, LNG handling facilities have revealed an exceptionally superior safety record when compared to refineries and other petrochemical plants. With the exception of the 1944 "Cleveland Disaster," all LNG-related injuries and/or fatalities, however devastating, have been limited to plant or contractor personnel. There have been no LNG shipboard deaths. There has not been a member of the public injured by an incident involving LNG since the failure of the improperly

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1 *Modern Day* – Post mid-1950s - Cryogenic technologies came of age during the late 1950s and early 1960s with the development of the U.S. space program where cryogenic fuels such as liquid hydrogen and liquid oxygen had to be routinely and safely handled.

2 This does not include dozens of small LNG vehicle fueling stations and industrial LNG fuel facilities.

3 According to www.coltoncompany.com, November 2006

4 There has never been a *catastrophic tank failure* with any LNG, or similarly designed, storage tank fabricated of the proper cryogenic alloys.

constructed Cleveland facility. Small LNG vapor releases and minor fires have also been reported, but impact was limited to the plant and the hazard was promptly handled by plant personnel. Other accidents have occurred during the construction and repair of LNG facilities. Some of these accidents have been used to tarnish the exceptional safety record of LNG, but as no LNG was directly involved in the incident these accidents can only truly be called "construction" accidents. Damage has always been limited to the plant proper.

The following three sections discuss land-based, LNG ship and over-the-road LNG transport incidents respectively. Each section references an appendix listing the various incidents.

SAFETY RECORD OF LAND-BASED LNG FACILITIES

The first commercial facility for producing or utilizing LNG was a peakshaving plant[5] that began operations in 1941 in Cleveland, Ohio. Since then, more than 150 other peakshaving plants have been constructed worldwide (approximately one-half of these are satellite facilities that have no liquefaction capability). In addition, large natural gas liquefaction plants (export facilities) and about 30 large LNG import terminals have been constructed.

There have been five incidents in operating LNG facilities directly attributable to the LNG process that resulted in one or more fatalities – Skikda, Algeria – 2004; P. T. Badak (Bontang, Indonesia), 1983; Cove Point Maryland, 1979; Arzew, Algeria, 1977; and Cleveland, Ohio, 1944. There were two other "LNG" incidents (Portland 1968 and Staten Island 1973) involving death, but these correctly should be classified as "construction accidents" as no LNG was present. See Appendix A for more details on these incidents and a complete listing of land-based LNG facility incidents.

The accident at East Ohio Gas Company's peakshaving plant in Cleveland, Ohio, is the only incident that involved injuries or fatalities to persons not employed by the LNG facility or by one of its contractors. This accident is often used as an example of the danger or risk involved in the LNG industry. However, the LNG industry has changed dramatically since 1944, as has virtually every other technology. Modern LNG plants are designed and constructed in accordance with strict codes and standards that would not have been met by the Cleveland plant. For example, the alloy used in Cleveland for the inner vessel of the LNG storage tank is now forbidden and each LNG tank must now be located within a dike capable of containing at least 110% of the tank's capacity. Further, the National Association of State Fire Marshals concluded in their May 2005 report,[6] "*Had the Cleveland tank been built to current codes, this accident would not have happened*."

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5 A peakshaving plant liquefies natural gas when customer demand for gas is low and then vaporizes the LNG when demand is high, thus handling periods of peak demand that cannot be met by existing gas pipelines.

6 "Liquefied Natural Gas: An Overview of the LNG Industry for Fire Marshals and Emergency Responders"

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Although Appendix A is intended to be a comprehensive listing of incidents that have occurred in land-based LNG facilities; it does not include all of the minor, but reportable incidents. For example, the outer roofs or domes of a few conventional double-wall LNG tanks have suffered small cracks as a result of low temperature embrittlement initiated by leaks of LNG from over-the-top piping. These cracks allowed LNG vapor (i.e., natural gas) to escape from the tanks. In each case, the tanks were safely repaired without being taken out of service. Similarly, the inner tanks of several conventional LNG storage tanks (i.e., cryogenic metal inner tank and carbon steel outer tank) have been cracked as a result of frost heave brought on by inadequate or inoperative below-tank heaters. These tanks have been safely entered, repaired, and put back into service.

SAFETY RECORD OF LNG SHIPS

The first transportation of LNG by ship took place early in 1959 when the *Methane Pioneer* (an ex-Liberty ship that had been extensively modified) carried 5,000 M^3 (cubic meters) of LNG from Lake Charles, Louisiana, to Canvey Island, near London, England. Commercial transportation of LNG by ship began in 1964 when LNG was transported from Arzew, Algeria to Canvey Island in two purpose-built ships—the *Methane Princess* and the *Methane Progress*.

The overall safety record compiled by LNG ships during the thirty-nine year period 1964 - 2002 has been remarkably good. During this period, the LNG tank ship fleet has delivered more than 30,000 shiploads of LNG, and traveled more than 100 million kilometers while loaded (and a similar distance on ballast voyages).

In all of these voyages and associated cargo transfer operations (loading/unloading), no fatality has ever been recorded for a member of any LNG ship's crew or member of the general public as a result of hazardous incidents in which the LNG was involved. In fact, there is no record of any fire occurring on the deck or in the cargo hold or cargo tanks of any operating LNG ship.

Among LNG import and export terminal personnel, only one death can be even remotely linked to the loading or unloading of LNG ships. (In 1977, a worker in the LNG Export Facility at Arzew was killed during a ship-loading operation when a large-diameter valve ruptured and the worker was sprayed with LNG. His death was the result of contact with the very cold LNG liquid; the spilled LNG did not ignite. See Item 6 in Appendix A.)

Appendix B summarizes the historical record of LNG ship incidents. Although a major effort was made to ensure the record presented is complete, it is possible that some incidents have been missed. However, it is very unlikely that a major incident has been omitted. Firstly, nearly every shipping incident that results in an insurance claim will be published in "Lloyd's List." Secondly, even if the ship owners are self-insured, news of major incidents travels quickly through the LNG industry because it is composed of a relatively small number of ship and terminal operators that often share experiences through industry associations such as SIGTTO (the Society of

International Gas Tanker and Terminal Operators).

Also included at the end of Appendix B is a description of two separate marine incidents involving liquid petroleum gas (LPG) tankers which are of similar design to many LNG ships. The incidents provide some insight into the integrity of the product storage systems on these ships.

OVER-THE ROAD LNG TRANSPORT ACCIDENTS

Appendix C provides a partial compilation of over-the-road incidents. It is not intended to be comprehensive as reports of these incidents are maintained in different ways from state to state. However, much as with LNG ships, it is very unlikely that a major incident has been omitted. The lists do provide examples of the wide range of potential vehicle accidents that can occur. Most notable, not a single person outside the driver of the transport was injured and rarely did product spill and far more rarely did it ignite.

SUMMARY

The various incidents discussed, when taken on a case-by-case basis, attests to LNG's safety record. The fact that most LNG opponents cite Cleveland and Staten Island as examples of the dangers of LNG, clearly indicate that there is little else to make their point. As devastating as both Cleveland and Staten Island were, they have no relevance when discussing the design and operation of today's LNG facilities.

LNG is cryogenic; it is a liquid; and its vapors are flammable. It is not without its safety concerns – it, however, can be produced, transported and revaporized as safely, and in most cases, more safely, than other liquid energies.

For more information on LNG safety, please see CH·IV's website, particularly:

http://www.CH-IV.com/lng/lngsafty.htm

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APPENDIX A

Chronological Summary of Incidents Involving Land-Based LNG Facilities

1. October, 1944 Cleveland, Ohio, USA ~ *"The Cleveland Disaster"*

LNG Peakshaving Facility

Any time the topic of LNG is introduced to a new audience the *"Cleveland Disaster"* is bound to surface. It was indeed tragic, but an unbiased review will show just how far the industry has come from that horrific incident. The East Ohio Gas Company built the first "commercial" LNG peakshaving facility in Cleveland in 1941. The facility was run without incident until 1944, when a larger new tank was added. As stainless steel alloys were scarce because of World War II, the new tank was built with a low-nickel content (3.5%) alloy steel. Shortly after going into service, the tank failed. LNG spilled into the street and storm sewer system. The resultant fire killed 128 people, setting back the embryonic LNG industry substantially. The following information is extracted from the U.S. Bureau of Mines report[7] on the incident:

On October 20, 1944, the tanks had been filled to capacity in readiness for the coming winter months. About 2:15 PM, the cylindrical tank suddenly failed releasing all of its contents into the nearby streets and sewers of Cleveland. The cloud promptly ignited and a fire ensued which engulfed the nearby tanks, residences and commercial establishments. After about 20 minutes, when the initial fire had nearly died down, the sphere nearest to the cylindrical tank toppled over and released its contents. 9,400 gallons of LNG immediately evaporated and ignited. In all, 128 people were killed and 225 injured. The area directly involved was about three-quarters of a square mile (475 acres) of which an area of about 30 acres was completely devastated.

The Bureau of Mines investigation showed that the accident was due to the low temperature embrittlement of the inner shell of the cylindrical tank. The inner tank was made of 3.5% nickel steel, a material now known to be susceptible to brittle fracture at LNG storage temperature (minus 260°F). In addition, the tanks were located close to a heavily traveled railroad station and a bombshell stamping plant. Excessive vibration from the railroad engines and stamping presses probably accelerated crack propagation in the inner shell. Once the inner shell ruptured, the outer carbon steel wall would have easily fractured upon contact with LNG. The accident was aggravated by the absence of adequate diking around the tanks, and the proximity of the facility to the residential area. The cause of the second release from the spherical tank was the fact that the legs of the sphere were not insulated against fire so that they eventually buckled after being exposed to direct flame contact.

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[7] *"Report on the Investigation of the Fire at the Liquefaction, Storage, and Regasification Plant of the East Ohio Gas Co., Cleveland, Ohio, October 20, 1944,"* U.S. Bureau of Mines, February, 1946.

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Further, it should be noted that the ignition of the two unconfined vapor clouds of LNG in Cleveland did not result in explosions. There was no evidence of any explosion overpressures after the ignition of the spill from either the cylindrical tank or the sphere. The only explosions that took place in Cleveland were limited to the sewers where LNG ran and vaporized before the vapor-air mixture ignited in a relatively confined volume. The U.S. Bureau of Mines, concluded that the concept of liquefying and storing LNG was valid if "proper precautions are observed."

The Cleveland Disaster put an end to any further LNG development in the United States for many years. It was not until the early sixties that LNG began to be taken seriously through construction of LNG peakshaving facilities. A number of elements came together to bring LNG back; these included:

- The advent of the space program and its associated cryogenic technologies
- Successful large-scale fire and vapor cloud dispersion demonstrations
- Extensive cryogenic material compatibility studies
- Construction and operation of liquefaction plants in Algeria and receiving terminals in France and England.

2. May, 1965 Canvey Island, Essex, United Kingdom

LNG Import Terminal

A small amount of LNG spilled from a tank during maintenance. The spill ignited and one worker was seriously burned. No other details have been made available.

3. March, 1968 Portland, Oregon, USA

LNG Peakshaving Facility - *Construction Accident, no LNG present*

Four workers inside an unfinished LNG storage tank were killed when natural gas from a pipeline being pressure tested inadvertently entered the tank as a result of improper isolation, and then ignited causing an explosion. The LNG tank was 120 feet in diameter with a 100-foot shell height and a capacity of 176,000 barrels and damaged beyond repair. Neither the tank nor the process facility had been commissioned at the time the accident occurred. The LNG tank involved in this accident had never been commissioned; thus, it had never contained any LNG.

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4. 1971 La Spezia, Italy

LNG Import Terminal - *First documented LNG Rollover incident*

The LNG carrier *Esso Brega* had been in the harbor for about a month before unloading its cargo of "heavy" LNG into the storage tank. Eighteen hours after the tank was filled, the tank developed a sudden increase in pressure causing LNG vapor to discharge from the tank safety valves and vents over a period of a few hours. The roof of the tank was also slightly damaged. It is estimated that about 100 mmscf of LNG vapor (natural gas) flowed out of the tank. No ignition took place. This accident was caused by a phenomenon called "rollover,"[8] where two layers of LNG having different densities and heat content are allowed to form. The sudden mixing of these two layers results in the release of large volumes of vapor.

5. January, 1972 Montreal, Canada

LNG Peakshaving Facility - *Although an LNG facility, LNG was not involved*

On January 27, 1972 an explosion occurred in the LNG liquefaction and peak shaving plant of Gaz Métropolitain in Montreal East, Quebec. The accident occurred in the control room due to a back flow of natural gas from the compressor to the nitrogen line. Nitrogen was supplied to the recycle compressor as a seal gas during defrosting operations. The valves on the nitrogen line that were kept open during defrosting operation were not closed after completing the operation. This resulted in the over-pressurization of the compressor with up to 250 - 350 psig of natural gas. Natural gas entered the nitrogen header, which was at 75 psig. The pneumatically controlled instruments were being operated with nitrogen due to the failure of the instrument-air compressor. The instruments vented their contents into the atmosphere at the control panel. Natural gas entered the control room through the nitrogen header and accumulated in the control room, where operators were allowed to smoke. The explosion occurred while an operator was trying to light a cigarette.

6. February, 1973 Staten Island, New York, USA

LNG Peakshaving Facility - *Construction Accident, no LNG present*

Proper precautions have been common place in all of the LNG facilities built and placed in service ever since Cleveland. Between the mid-1960s and mid-1970s more than 60 LNG facilities were built in the United States. These peak-shaving plants have had an excellent safety record. This construction accident has consistently been used by opponents of LNG as a case-in-point to depict the danger of LNG, after all, "40 persons lost their lives at an LNG facility."

[8] See Section 3.1 of CH·IV's ***"Introduction to LNG Safety,"*** *Short Course on LNG Rollover.*

Here's the story –

One of Texas Eastern Transmission Corporation's (TETCO) LNG storage tanks on Staten Island had been in service for over three years when it was taken out of service for internal repairs. The tank was warmed, purged of the remaining combustible gases with inert nitrogen, and then filled with fresh recirculating air. A construction crew entered the tank to begin repair work in April of 1972. Ten months later, in February of 1973, an unknown cause ignited the Mylar liner and polyurethane foam insulation inside the tank. Initial standard operating procedures called for the use of explosion-proof equipment within the tank, however non-explosion proof irons and vacuum cleaners were being used for sealing the liner and cleaning insulation debris. It is assumed that an electrical spark in one of the irons or vacuum cleaners ignited the Mylar liner. The rapid rise in temperature caused a corresponding rise in pressure inside the tank. The pressure increase lifted the tank's concrete dome. The dome then collapsed killing the 40 construction workers inside.

The subsequent New York City Fire Department investigation[9] concluded that the accident was clearly a construction accident and not an LNG accident. This has not prevented LNG's opponents from claiming that since there may have been latent vapors from the heavy components of the LNG that was stored in the tank, then it was in fact an LNG incident.

7. March, 1977 Algeria

LNG Export Facility

A worker at the Camel plant was frozen to death when he was sprayed with LNG, which was escaping from a ruptured valve body on top of an in-ground storage tank. Approximately 1,500 to 2,000 m^3 of LNG were released, but the resulting vapor cloud did not ignite. The valve body that ruptured was constructed of cast aluminum. The current practice is to provide valves in LNG service that are made with stainless steel.

8. March, 1978 Das Island, United Arab Emirates

LNG Export Facility

A bottom pipe connection of an LNG tank failed resulting in an LNG spill inside the LNG tank containment. The liquid flow was stopped by closing the internal valve designed for just such service. A large vapor cloud resulted and dissipated without ignition. No injuries or fatalities were reported.

[9] ***"Report of Texas Eastern LNG Tank Fatal Fire and Roof Collapse, February 10, 1973,"*** Fire Department of the City of New York, July, 1973

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9. October, 1979 Cove Point, Maryland, USA

LNG Import Terminal

The Cove Point LNG Receiving Terminal in Maryland began operations in the spring of 1978. By the fall of 1979, Cove Point had unloaded over 80 LNG ships. In 1979, a tragic accident occurred at Cove Point that took the life of one operator and seriously burned another.

Around 3:00 AM on October 6, 1979, an explosion occurred within an electrical substation at Cove Point. LNG had leaked through an inadequately tightened LNG pump electrical penetration seal, vaporized, passed through 200 feet of underground electrical conduit, and entered the substation. Since natural gas was never expected in this substation, no gas detectors had been installed in the building. The natural gas-air mixture was ignited by the normal arcing contacts of a circuit breaker, resulting in an explosion. The explosion killed one operator in the building, seriously injured a second and caused about $3 million in damages.

The National Transportation Safety Board (NTSB) found[10] that the Cove Point Terminal was designed and constructed in conformance with all appropriate regulations and codes. It further concluded that this was an isolated incident, not likely to recur elsewhere. The NTSB concluded that it is unlikely that any pump seal, regardless of the liquid being pumped, could be designed, fabricated, or installed to completely preclude the possibility of leakage. With that conclusion in mind, building codes pertaining to the equipment and systems downstream of the pump seal were changed. Before the Cove Point Terminal was restarted, all pump seal systems were modified to meet the new codes and gas detection systems were added to all buildings.

10. April, 1983 Bontang, Indonesia

LNG Export Facility - *Maintenance Accident, no LNG present*

A major incident occurred on April 14, 1983 in Bontang, Indonesia. The main liquefaction column (large vertical, spiral wound, heat exchanger) in Train B ruptured due to overpressurization caused by a blind flange left in a flare line during start-up. All the pressure protection systems were connected to this line. The exchanger experienced pressures three times its design pressure before rupturing. Debris and coil sections were projected some 50 meters away. Shrapnel from the column killed three workers. The ensuing fire was extinguished in about 30 minutes. This incident occurred during dry-out and purging of the exchanger with warm natural gas prior to introducing any LNG into the system, so <u>no LNG was actually involved or released</u>.

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[10] "Columbia LNG Corporation Explosion and Fire; Cove Point, MD; October 6, 1979" National Transportation Safety Board Report NTSB-PAR-80-2, April 16, 1980

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11. 1987 Mercury, Nevada, USA

Department of Energy Test Facility

An accidental ignition of an LNG vapor cloud occurred at the DOE, Nevada Test Site on August 29, 1987. The large-scale tests involving spills of LNG on water were sponsored by the Department of Energy and Gas Research Institute to study the effectiveness of vapor fences in reducing the extent of downwind dispersion of LNG vapor clouds. The cloud accidentally ignited during Test #5 just after a sequence of relatively strong rapid phase transitions (RPTs) which damaged and propelled polyurethane pipe insulation outside the fence.

The official explanation was that a spark generated by static electricity approximately 76 seconds after the spill was the most likely source of ignition. An independent investigation on behalf of Gas Research Institute showed that a more likely source of ignition was oxygen enrichment between the surface of the LNG pipe and the combustible polyurethane foam insulation. Oxygen enrichment occurred during the long cool-down period with liquid nitrogen that preceded the LNG test. Such enrichment had been previously observed during tests carried out by an LNG tank design and manufacturing company. Impacts during the RPTs may have ignited the insulation but not the nearby fuel-rich vapor cloud. However, when a smoldering insulation fragment was propelled outside the fence by an RPT, it ignited the portion of the cloud that was within the flammable limits. The duration of the fire was 30 seconds. The flame length was about 20 feet above the ground.

There have been other accidental ignitions involving LNG during large-scale tests.

- One occurred in England during large-scale fire tests being carried out by British Gas Corporation. Stray currents from a nearby radar station were blamed for prematurely igniting the primer that was eventually to be used to ignite the LNG cloud.
- Another occurred in Japan during similar large-scale tests carried out by Japan Gas Association. The ignition mechanism was not explained.
- During a test at a research facility near San Clemente, California, a sudden change in wind direction caused the vapor cloud to encounter a tractor that was moving some of the test equipment. The tractor ignited the vapor cloud, badly burning the driver. A researcher was also in the vapor cloud at the time of ignition. He was able to get out of the vapor cloud before the flame front reached him by running crosswind and was not injured.

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12. August, 1985 Pinson, Alabama, USA

LNG Peakshaving Facility

The welds on an 8 - ¼ inch by 12 inch "patch plate" on a small aluminum vessel (3 feet in diameter by 7 feet tall) failed as the vessel was receiving LNG which was being drained from the liquefaction cold box. The plate was propelled into a building that contained the control room, boiler room, and offices. Some of the windows in the control room were blown inward and natural gas escaping from the failed vessel entered the building and ignited. Six employees were injured.

13. 1988 Everett, Massachusetts, USA

LNG Import Terminal

Approximately 30,000 gallons of LNG were spilled through "blown" flange gaskets during an interruption in LNG transfer at Distrigas. The cause was later determined to be "condensation induced water hammer."[11] The spill was contained in a small area, as designed. The still night prevented the movement of the vapor cloud from the immediate area. No one was injured and no damage occurred beyond the blown gasket. Operating procedures, both manual and automatic, were modified as a result.

14. 1989 Thurley, United Kingdom

LNG Peakshaving Facility

While cooling down the vaporizers in preparation for sending out natural gas, low-point drain valves were opened on each vaporizer. One of these drain valves had not been closed when the pumps were started and LNG entered the vaporizers. As a result, LNG was released into the atmosphere as a high-pressure jet. The resulting vapor cloud ignited about thirty seconds after the release began. The flash fire covered an area approximately 40 by 25 m. Two operators received burns to their hands and faces. The source of ignition was believed to be the pilot light on one of the other submerged combustion vaporizers.

15. December 9, 1992 Baltimore, Maryland, USA

LNG Peakshaving Facility

A relief valve on LNG piping near one of the three LNG tanks failed open and released LNG into the LNG tank containment for over 10 hours, resulting in an estimated loss of over 25,000 gallons into the LNG tank containment. The LNG also impinged on the LNG tank causing embrittlement fractures on the outer shell. The LNG tank was taken out of service and repaired. No plant personnel were injured and no vapor traveled outside the plant area.

[11] See description in Section 3.1 of CH·IV's ***"Introduction to LNG Safety"***

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16. 1993 Bontang, Indonesia

LNG Export Facility

An LNG leak occurred in the open run-down line during a pipe modification project. LNG entered an underground concrete oily-water sewer system and underwent a rapid vapor expansion that overpressured and ruptured the sewer pipes. No ignition of the vapor occurred, but the sewer system was substantially damaged.

17. September, 2000 Savannah, Georgia, USA

LNG Import Terminal

In September 2000, a 580-foot ship, the Sun Sapphire, lost control in the Savannah River and crashed into the LNG unloading pier at Elba Island. The Elba Island facility was undergoing reactivation but had no LNG in the plant. The Sun Sapphire, carrying almost 20,000 tons of palm and coconut oil, suffered a 40-foot gash in her hull. The point of impact at the terminal was the LNG unloading platform. Although the LNG facility experienced significant damage, including the need to replace five 16" unloading arms, there was no indication that had LNG been present in the piping that there would have been a release. Given the geometry of the Savannah River at Elba Island, it is doubtful that had an LNG ship been present that a similar ramming could have penetrated the double hull and released any LNG.

18. January 19, 2004 Skikda, Algeria

LNG Export Facility

A leak in the hydrocarbon refrigerant system formed a vapor cloud that was drawn into the inlet of a steam boiler. The increased fuel to the boiler caused rapidly rising pressure within a steam drum. The rapidly rising pressure exceeded the capacity of the boiler's safety valve and the steam drum ruptured. The boiler rupture was close enough to the gas leak area to ignite the vapor cloud and produce an explosion due to the confined nature of the gas leak and an ensuing fireball. The fire took eight hours to extinguish. The explosions and fire destroyed a portion of the LNG plant and caused 27 deaths and injury to 72 more. No one outside the plant was injured nor were the LNG storage tanks damaged by the explosions. A joint report[12] issued by the U.S. Federal Energy Regulatory Commission (FERC) and the U.S. Department of Energy (DOE) was issued in April 2004. The findings in the report indicate that there were local ignition sources, a lack of "typical" automatic equipment shutdown devices and a lack of hazard detection devices.

[12] "Report of the U.S. Government Team Site Inspection of the Sonatrach Skikda LNG Pant in Skikda, Algeria, March 12-16, 2004"

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Chronological Summary of Incidents Involving LNG Ships

1. 1964/1965

25,500 M^3 *Jules Verne*

While loading LNG in Arzew, Algeria, lightning struck the forward vent riser of the ship and ignited vapor, which was being routinely vented through the ship venting system. Loading had been stopped when a thunderstorm broke out near the terminal but the vapor generated by the loading process was being released to the atmosphere. The shore return piping had not yet been in operation. The flame was quickly extinguished by purging with nitrogen through a connection to the riser.

A similar event happened early in 1965 while the vessel was at sea shortly after leaving Arzew. The fire was again extinguished using the nitrogen purge connection. In this case, vapor was being vented into the atmosphere during ship transit, as was the normal practice at that time.

2. May, 1965

27,400 M^3 *Methane Princess*

The LNG loading arms were disconnected before the liquid lines had been completely drained, causing LNG to pass through a leaking closed valve and into a stainless steel drip pan placed underneath the arms. Seawater was applied to the area. Eventually, a star-shaped fracture appeared in the deck plating in spite of the application of the seawater.

3. May, 1965

25,500 M^3 *Jules Verne*

On the fourth loading of Jules Verne at Arzew in May 1965 an LNG spill, caused by overflowing of Cargo Tank No.1, resulted in the fracture of the cover plating of the tank and of the adjacent deck plating. The cause of the overfill has never been adequately explained, but it was associated with the failure of liquid level instrumentation and unfamiliarity with equipment on the part of the cargo handling watch officer.

4. April 11, 1966

27,400 M^3 *Methane Progress*

Cargo leakage reported. No details.

5. September, 1968

5,000 M^3 *Aristotle*

Ran aground off the coast of Mexico. Bottom damaged. Believed to be in LPG service when this occurred. *No LNG released.*

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6. November 17, 1969

71,500 M^3 *Polar Alaska*

Sloshing of the LNG heel in No. 1 tank caused part of the supports for the cargo pump electric cable tray to break loose, resulting in several perforations of the primary barrier. LNG leaked into the interbarrier space. *No LNG released.*

7. September 2, 1970

71,500 M^3 *Arctic Tokyo*

Sloshing of the LNG heel in No. 1 tank during bad weather caused local deformation of the primary barrier and supporting insulation boxes. LNG leaked into the interbarrier space at one location. *No LNG released.*

8. Late 1971

50,000 M^3 *Descartes*

A minor fault in the connection between the primary barrier and the tank dome allowed gas into the interbarrier space. *No LNG released.*

9. June, 1974

27,400 M^3 *Methane Princess*

On June 12, 1974 the *Methane Princess* was rammed by the freighter *Tower Princess* while moored at Canvey Island LNG Terminal. Created a 3- foot gash in the outer hull. *No LNG released.*

10. July, 1974

5,000 M^3 *Barge Massachusetts*

LNG was being loaded on the barge on July 16, 1974. After a power failure and the automatic closure of the main liquid line valves, a small amount of LNG leaked from a 1-inch nitrogen-purge globe valve on the vessel's liquid header. The subsequent investigation by the US. Coast Guard found that a pressure surge caused by the valve closure induced the leakage of LNG through the bonnet and gland of the 1-inch valve. The valve had not leaked during the previous seven or more hours of loading. Several fractures occurred in the deck plates. They extended over an area that measured about one by two meters. The amount of LNG involved in the leakage was reported to be about 40 gallons. As a result of this incident, The U.S. Coast Guard banned the Barge Massachusetts from LNG service within the U.S. It is believed that the Barge Massachusetts is now working in liquid ethylene service.

11. August, 1974

4,000 M^3 *Euclides*

Minor damage due to contact with another vessel. *No LNG released.*

12. November, 1974
4,000 M^3 *Euclides*
Ran aground at La Havre, France. Damaged bottom and propeller. *No LNG released.*

13. 1974
27,400 M^3 *Methane Progress*
Ran aground at Arzew, Algeria. Damaged rudder. *No LNG released.*

14. September, 1977
125,000 M^3 *LNG Aquarius*
During the filling of Cargo Tank No. 1 at Bontang on September 16, 1977, LNG overflowed through the vent mast serving that tank. The incident may have been caused by difficulties in the liquid level gauge system. The high-level alarm had been placed in the override mode to eliminate nuisance alarms. Surprisingly, the mild steel plate of which the cargo tank cover was made did not fracture as a result of this spill.

15. August 14, 1978
124,890 M^3 *Khannur*
Collision with cargo ship *Hong Hwa* in the Strait of Singapore. Minor damage.
No LNG released.

16. April, 1979
125,000 M^3 *Mostefa Ben Boulaid*
While discharging cargo at Cove Point, Maryland on April 8, 1979, a check valve in the piping system of the vessel failed releasing a small quantity of LNG. This resulted in minor fractures of the deck plating. This spill was caused by the escape of LNG from a swing-check valve in the liquid line. In this valve, the hinge pin is retained by a head bolt, which penetrates the wall of the valve body. In the course of operating the ship and cargo pumping system, it appears that the vibration caused the bolt to back out, releasing a shower of LNG onto the deck. The vessel was taken out of service after the incident and the structural work renewed. All of the check valves in the ship's liquid system were modified to prevent a recurrence of the failure. A light stainless steel keeper was fashioned and installed at each bolt head. Shortly after the ship returned to service, LNG was noticed leaking from around one bolt head, the keeper for which had been stripped, again probably because of vibration. More substantial keepers were installed and the valves have been free from trouble since that time.

Safety History of International LNG Operations

APPENDIX B

Chronological Summary of Incidents Involving LNG Ships

17. April, 1979

87,600 M^3 *Pollenger*

While the Pollenger was discharging LNG at the Distrigas terminal at Everett, Massachusetts on April 25, 1979, LNG leaking from a valve gland apparently fractured the tank cover plating at Cargo Tank No. 1. The quantity of LNG that spilled was probably only a few liters, but the fractures in the cover plating covered an area of about two square meters.

18. June 29, 1979

125,000 M^3 *El Paso Paul Kayser*

Ran aground at 14 knots while maneuvering to avoid another vessel in the Strait of Gibraltar. Bottom damaged extensively. Vessel refloated and cargo transferred to sister ship, the *El Paso Sonatrach*. *No LNG released.*

19. December 12, 1980

125,000 M^3 *LNG Taurus*

Ran aground in heavy weather at Mutsure Anchorage off Tobata, Japan. Bottom damaged extensively. Vessel refloated, proceeded under its own power to the Kita Kyushu LNG Terminal, and cargo discharged. *No LNG released.*

20. Early 1980s

125,000 M^3 *El Paso Consolidated*

Minor release of LNG from a flange. Deck plating fractured due to low temperature embrittlement.

21. Early 1980s

129,500 M^3 *Larbi Ben M'Hidi*

Vapor released during transfer arm disconnection. *No LNG released.*

22. December, 1983

87,600 M^3 *Norman Lady*

During cooldown of the cargo transfer arms, prior to unloading at Sodegaura, Japan, the ship suddenly moved astern under its own power. All cargo transfer arms sheared and LNG spilled. No ignition.

23. 1985

35,500 M^3 *Isabella*

LNG released as a result of overfilling a tank. Deck fractured due to low temperature embrittlement.

APPENDIX B

Chronological Summary of Incidents Involving LNG Ships

24. 1985

35,500 M^3 *Annabella*

Reported as "pressurized cargo tank." Presumably, some LNG released from the tank or piping. No other details are available.

25. 1985

126,000 M^3 *Ramdane Abane*

Collision while loaded. Port bow affected. *No LNG released.*

26. February, 1989

40,000 M^3 *Tellier*

Wind blew ship from its berth at Skikda, Algeria. Cargo transfer arms sheared. Piping on ship heavily damaged. Cargo transfer had been stopped. According to some verbal accounts of this incident, LNG was released from the cargo transfer arms.

27. Early 1990

125,000 M^3 *Bachir Chihani*

A fracture occurred at a part of the ship structure, which is prone to the high stresses that may accompany the complex deflections that the hull encounters on the high seas. Fracture of the inner hull plating led to the ingress of seawater into the space behind the cargo hold insulation while the vessel was in ballast. *No LNG released.*

28. May 21, 1997

125,000 M^3 *Northwest Swift*

Collided with a fishing vessel about 400 km from Japan. Some damage to hull, but no ingress of water. *No LNG released.*

29. October 31, 1997

126,300 M^3 *LNG Capricorn*

Struck a mooring dolphin at a pier near the Senboku LNG Terminal in Japan. Some damage to hull, but no ingress of water. *No LNG released.*

30. September 6, 1999

71,500 M^3 *Methane Polar*

Engine failure during approach to Atlantic LNG jetty (Trinidad and Tobago). Struck and damaged Petrotrin pier. No injuries. *No LNG released.*

31. December 2002

87,000 M^3 *Norman Lady*

A U.S. nuclear submarine, the U.S.S. Oklahoma City, raised its periscope into the ship necessitating her withdrawal briefly from service for repairs due to penetration of outer hull allowing leakage of seawater. *No LNG released*

APPENDIX B

Chronological Summary of Incidents Involving LNG Ships

LNG carriers have a very similar construction to LPG tankers. Two examples of the robust nature of the design and construction of an LNG ship are the attack on the LPG tanker *Gaz Fountain* and the collision of the LPG tanker *Yuyo Maru No. 10* and the *Pacific Ares*.

The Gaz Fountain, 1984

Maverick Air-to-Ground Missile
Length: 8'; Diameter: 12";
Wingspan: 2.4'; Weight: 677 lbs;
Warhead: 300 lbs of high explosives

On the morning of October 12, 1984, during the Iran-Iraq War, the double-hulled *Gaz Fountain* was fired upon by an Iranian aircraft using three air-to-ground, armor-piercing Maverick missiles (See box at right). Two of the missiles exploded on or above the ship's deck, causing relatively minor damage. The third missile penetrated the deck and exploded above one of the LPG cargo tanks, opening a 65 square-foot hole in the roof of the tank. The escaping gas ignited, establishing a large fire on deck above the missile entry hole. After being hit, the *Gaz Fountain* crew tripped the cargo emergency shut-down system, stopped its engines and then abandoned ship. The entire 33-person crew escaped without serious injury from the attack or ensuing fire. The fire aboard the *Gaz Fountain* was successfully extinguished by a salvage ship, her gas-tight integrity was restored and her remaining cargo (93%) was successfully unloaded to another LPG tanker. She was successfully salvaged and put back into service.

Yuyo Maru No. 10, October, 1974

The following information pertains to a liquid petroleum gas tanker (LPG) which has a similar construction to an LNG tanker. The information was obtained from a Japanese marine registry record. The annotations [text] were added by the authors for clarity. This incident is included in this document to help illustrate the integrity of LNG tanks onboard LNG ships. There is much discussion today around the impact of a terrorist attack perpetrated on an LNG tanker.

The Motorship "Yuyo Maru No. 10" (gross tonnage of 43,723), laden with 20,831 MT of light naphtha, 20,202 MT of propane and 6,443 MT of butane, left Ras Tanura, in the Kingdom of Saudi Arabia, for Kawasaki, and the port of Keihin on October 22, 1974. While the vessel was sailing northward along the Naka-no Se Traffic Route in Tokyo Bay on November 9, she collided with the Motorship "Pacific Ares" (gross tonnage of 10,874), manned with a Taiwanese Master and 28 crew members, laden with 14,835 MT of steel products, en route from Kisarazu for Los Angeles, USA. The collision occurred about 13:37 hours on the same day slightly northward of the boundary line of the Naka-no Se Traffic Route.

As a result of the collision, the "Yuyo Maru No. 10" suffered a large hole at the point of collision, with her cargo naphtha [The naphtha was carried in its outer ballast tank (between the insulated LPG tanks and the hull of the ship). This is effectively what makes up the "double hull" with LNG ships. The LPG cargo tank was not penetrated. LNG tankers never carry any thing other than air or ballast (water) in these tanks.] instantly igniting into flames. As a result of the outflow of naphtha overboard, the sea surface on her starboard side literally turned into a sea of fire. The "Pacific Ares" showered with fire burst into flames in the forecastle and on the bridge. While explosions occurred one after another [naphtha, not propane], attempts were made to tow the "Yuyo Maru No 10", outside the bay, but she ran aground in the vicinity of Daini Kaiho. She was successfully towed out of Tokyo Bay and sunk south of Nojima Saki on the afternoon of November 27 [Thirty-six days after the original collision.] by cannon, air bomb and torpedo attacks staged by the Maritime Self-Defense Force. [Please note "cannon, air bomb and torpedo attacks" were required to sink the ship. Other reports indicate that these attacks lasted one and a half days. The author has seen a black and white film of these attacks. It appeared that the LPG tanks were for the most part fully in tact prior to the attacks. The ship's LPG vent stacks were melted down to just above the decks and on fire indicating that LPG remained within the storage tanks.]

On board the "Yuyo Maru No. 10", five crew members were killed and seven others injured by this accident. The "Pacific Ares", whose forward section was completely crushed and superstructures burned down, was later repaired. Her crew members were all killed except one person, who was injured but rescued.

Safety History of International LNG Operations

APPENDIX C

Chronological Summary of LNG Tanker Truck Incidents

	Date	Location	LNG Carrier
1.	June 1971	Waterbury, VT	Capitol

Blowout, hit rocks by road, tore hole in tank, 20% spilled, no fire, remainder dumped. Single wall tanker?

2. August 1971 — Warner, NH — Gas, Inc.
Driver fatigue, drove off road, rollover cracked fittings, small gas leak, no fire.

3. October 1971 — N. Whitehall, WI — Indianhead
Head-on collision with truck. Gasoline and tire fire, no cargo lost.

4. October 1973 — Raynham, MA — Andrews & Pierce
Truck side swiped parked car; brakes locked and trailer overturned. No cargo on-board, no fire

5. 1973 — Rt. 80 & 95 JCT, NJ — Chemical Leaman
Driver couldn't negotiate turn off. Rollover demolished tractor and severe damage to trailer. No fire. $40,000 damage to trailer.

6. February 1974 — New Jersey Turnpike — Gas, Inc.
Faulty brakes caused wheel fire. Check valve cracked 5% leaked out. No fire.

7. February 1974 — McKee City, NJ — Gas, Inc.
Loose valve leaked LNG during transfer operation.

8. January 1976 — Chattanooga, TN — LP Transport
Rollover, no fire, caused by oil spill on exit ramp. Truck righted and continued delivery of cargo.

9. November 1975 — Dalton, GA — LP Transport
Rollover, no fire. Driver swerved to avoid pedestrian, hit guardrail and rolled over and down an 80 foot bank. $18,000 damage to trailer.

10. September 1976 — Pawtucket, RI — Andrews & Pierce
Car hit trailer at landing wheels, rollover, no LNG loss or fire.

11. April 1977 — Connecticut Turnpike — Chemical Leaman
Truck parked (with blowout) hit by a tow truck in rear. No leak or fire.

12. July 1977 — Waterbury, CT — LP Transport
"Single Wall" Lubbock hit in rear by tractor-trailer, axle knocked off. Rollover. No loss of cargo.

13. December 1977 — I5 & I10, Los Angeles — Western Gillet/SDG
Rollover with little product loss, no vacuum loss, no fire. Driver had 3 broken ribs.

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APPENDIX C

Chronological Summary of LNG Tanker Truck Incidents

	Date	Location	LNG Carrier
14.	**February 1981**	**Barnagat, NJ**	**LP Transport**

Driver failed to negotiate turn due to excessive speed on country road. Driver not hurt seriously. Loss of some product through relief valve resulted in serious damage to transport.

15. September 1981 — Lexington, MA — Andrews & Pierce

Rollover, no fire, no product loss (empty), driver not seriously hurt. Extensive damage to transport. Cause: rain and poor road conditions.

16. October, 1993 — Everett, MA — TransGas

Trailer slide off third wheel just before entering highway. No fire, no product loss

17. May 1994 — Revere, MA — TransGas

Trailer over turned when trying to negotiate a traffic circle at too high of speed. No product loss, no fire. Trailer emptied into second trailer without incident.

18. October 1998 — Woburn, Ma — TransGas

Trailer traveling at high speed is sideswiped by car then careens into guardrail ripping open diesel fuel tanks. Ensuing diesel fuel fire traps driver in cab where he perishes. Fire engulfs LNG trailer until extinguished. No loss of product experienced. LNG partially transferred to second trailer. Trailer then uprighted and sent to transport yard to complete the transfer of product.

19. June 22, 2002 — Tivissa, Catalonia, Spain — Not Available

An LNG road tanker overturned and caught fire on the C-44 road and subsequently (about 20 minutes later) suffered a boiling liquid expanding vapor explosion (BLEVE), the first such LNG-related incident reported. However, the design of the trailer involved was very different from that used in the U.S. It was simply a pressure vessel insulated with unprotected polyurethane insulation, whereas cryogenic trainers in the U.S. are double-walled, vacuum-jacketed pressure vessels. When the trailer overturned the insulation was readily scraped off the pressure vessel and directly exposed to the fire, the typical scenario required for a BLEVE. It is unclear what actually caused the leakage of LNG, but U.S trailers in addition to having the outer tank protection also have recessed protected piping further reducing the potential for leakage due to overturning. In spite of the severe nature of the incident there was no report of injury to the driver or a member of the public.

20. September 2003 — Woburn, Ma — TransGas

Trailer traveling too fast on a highway exit ramp overturned. There was no leakage of cargo from the overturned truck. The truck driver was slightly injured and received a speeding citation.

See Note at end of next page.

Safety History of International LNG Operations

APPENDIX C

Chronological Summary of LNG Tanker Truck Incidents

	Date	Location	LNG Carrier
21.	**September 14, 2005**	**Near Reno, NV**	**Logistics Express**

The driver of an LNG tractor trailer stopped at a truck stop on I-80 near Reno and noticed that LNG was leaking from the fireblock valve. He notified the local emergency responders. Shortly after their arrival the LNG vapor ignited. The on-scene emergency responders decided to first close the Interstate and evacuate people from local businesses and residences and then expand the evacuation area for about three hours. When the fire subsided, the evacuation was cancelled. The trailer performed as designed and there was no loss of vacuum on the trailer. The trailer was removed from service for minor damage repair and returned to service within a week. Unfortunately, the emergency responders did not understand LNG or the design of LNG trailers or they would not have executed such a large evacuation.

Note: Incidents 16 through 18 and 20 were reported on television and/or presented in the local Boston print media. In every case the media attempted to create a disaster scenario using meaningless phases such as *"blast zone"* and *"police cruisers turned off lights to prevent explosions."* In one case a totally misinformed fire chief stated that the situation was "*potentially a giant bomb. . . . An explosion would devastate a half-mile in all directions."* One of the worst "facts" reported was that *"water was hosed onto the tanker to keep the LNG cool"*! Unfortunately, the emergency responders near Reno, NV had the same misconceptions about the explosive nature of LNG, read on.