GROUPE INTERNATIONAL DES IMPORTATEURS DE GAZ NATUREL LIQUÉFIÉ

THE INTERNATIONAL GROUP OF LIQUEFIED NATURAL GAS IMPORTERS

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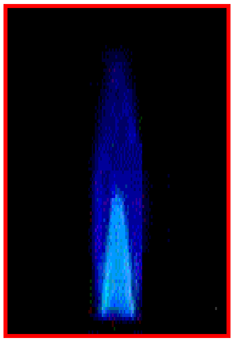

Questions and Answers (Q&A's)

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GIIGNL's Technical Study Group has overseen the development of this Information Series of 7 papers to provide factual information about Liquefied Natural Gas (LNG). This paper attempts to capture and answer frequently-asked questions about LNG. These Questions and Answers (Q&A's) were developed through a collective effort of LNG importers and import-terminal owners. For more information on these topics, references and weblinks are provided at the end of this paper.

Introduction

These Q&A's are organised around general topics related to LNG import terminals and the transportation modes which interface with them. An LNG import terminal consists of the berth or jetty(s) for the ship dockage and unloading (discharge), the LNG itself, the onshore LNG storage tank(s), pumps, vaporisers and other equipment to convert the LNG from a cold liquid back into natural gas. Distribution of the natural gas to consumers via pipeline is the norm; alternatively, LNG can be transported to customers in specially-designed road tank trucks and rail tank cars.

Another type of facility which may receive LNG by ship is known as a peak-shaving facility. These terminals, which may be operated by utilities, store LNG in bulk storage tanks until it is needed at times of peak demand. An LNG peak-shaving facility is normally connected to the gas supply system and the facility; these facilities can take gas from the network as feed for liquefaction and/or receive LNG by ship or road tank trucks. Peak-shaving facilities may include LNG liquefaction equipment to convert natural gas into LNG, LNG storage tank(s), pumps, vaporisers and other equipment to convert the LNG back from a cold liquid into natural gas before sending it back out through the pipeline distribution network to consumers.

The owners of LNG import and storage facilities consider the impact of their operations on the environment and wherever possible, minimise their burden on the environment.

In every part of the world, high environmental standards are demanded by local, national and supranational authorities who require extensive environmental assessments of design and operation before granting their approval to construct and operate.

Answers to the questions have been developed from a number of technical specialists and other sources; they are believed to be accurate based on industry and consultant review.

LNG Basics

What is LNG?

LNG stands for Liquefied Natural Gas. In French, Spanish, Portuguese, or Italian-speaking countries, the abbreviation GNL is used in place of LNG. Natural gas comes from deep in the earth and is extracted through specially-drilled wells. It comes to the surface either as gas or in association with oil. Natural gas at the well head is made up of many constituents including methane, propane, ethane, butane, pentanes, nitrogen, water, and other impurities. The gas is processed at a gas processing plant where most of the impurities and water are removed. Then the natural gas is sent to a liquefaction plant, where additional gas processing removes the rest of the water vapour, other impurities such as mercury, sulphur compounds, and carbon dioxide from the gas. A refrigeration process turns the gas into a liquid. LNG is predominantly methane, with small amounts of ethane, propane and perhaps some butane. LNG appears as a colourless, odourless clear fluid, with about half the density of water. It is generally handled at slightly above atmospheric pressure in large bulk storage tanks and at around 4.5 bar when carried by truck. The temperature of LNG is typically -162°C (-259°F), which is a very low or cryogenic temperature. **Information Paper No. 1** provides additional information on LNG properties.

Why liquefy natural gas?

The conversion to a liquid reduces the volume of natural gas by about 600 to 1, which means one LNG ship can transport enough LNG to equal 600 ships carrying natural gas at atmospheric pressure. Liquefying natural gas makes it feasible to transport natural gas in bulk and to store it in preparation for vaporisation and supply into pipelines. **Information Paper No. 2** describes the liquefaction process in greater detail.

How do you liquefy natural gas?

Natural gas is cooled by a large refrigeration system. First, produced natural gas is processed to condition it for liquefaction by removing components which would freeze such as water vapour and carbon dioxide. In this processing step, other contaminants such as hydrogen sulphide and heavy metals are also removed. If commercially desired, heavier hydrocarbon liquids such as propane and butane are sometimes removed. The remaining natural gas, predominately methane with small amounts of ethane, propane and perhaps some butane, is then cooled by a refrigeration system working on the same basic principles as a refrigerator or an air conditioner. The main difference is the sheer scale of the plant used to produce LNG.

Where does the LNG come from?

The LNG primarily comes from areas where large gas discoveries have been made, such as Algeria, Australia, Brunei, Egypt, Equatorial Guinea, Indonesia, Libya, Malaysia, Nigeria, Norway, Oman, Qatar, Trinidad, and the United Arab Emirates. Some LNG is produced in the US (Alaska) and Europe. For existing and potential import terminals, there is now an increasingly diverse choice of LNG supply sources.

In theory, LNG can be produced wherever natural gas is available. Domestically, pipeline natural gas is also liquefied and stored in peak-shaving facilities around the world (including the US, Europe, and Japan) as an alternative means of storing gas for future use, typically during periods of high, or peak, demand.

LNG import/export projects are based on the economics of surplus gas supplies at a low price at the source, reasonable transport distances at moderate costs, and demand at attractive prices at the destination. The resultant "gross margin" generated by this formula must be sufficient to provide a reasonable rate of return on the required capital investment. The gas surplus may be the result of a natural gas produced in conjunction with oil production (associated gas) or large "dry gas" discoveries (unassociated gas). In either case, the local market usually is too small to consume the production, and pipelines are uneconomical for delivering the gas to consuming regions. Thus the economic value is low or non-existent. For European countries and the US Atlantic Region, Algeria and Nigeria meet these criteria as major suppliers, as well as Trinidad for the US Gulf Coast Region. In the future, Angola, Peru, and other Middle East countries appear positioned to become potential suppliers. Depending on market prices, several existing exporters are available including Australia, Brunei, Indonesia, Malaysia, Oman, Qatar, Trinidad and the US, most of which supply LNG to Japan, Korea and Taiwan. New export projects are planned for Angola, Australia, Indonesia, Iran, Peru, Siberia, the US and Venezuela.

LNG Transportation

How is LNG transported by sea?

LNG is transported in large, specially-designed ships, known as LNG carriers. There are about 300 ships in the worldwide LNG fleet and about 100 more are on order. The cost of LNG ships today is between US$ 225-250 million for a 135,000 cubic metres (m^3) carrier up to about US$ 300 million for the larger ships. LNG Ships are discussed in **Information Paper No. 3**.

LNG ships have design features aimed at a high degree of safety. They are double-hulled and have ballast tanks separate from the cargo tanks. As the cargo is very cold, the cargo tanks are separated from the hull structure by thick insulation. There are from four to six separate cargo tanks. The two cargo tank designs commonly used are membrane tanks and spherical tanks.

The cross section of membrane tanks is essentially the same shape as the ship hull. The metal membrane inside the insulation provides the liquid containment, as does a redundant secondary barrier, should a failure occur to the primary barrier. The cargo hydrostatic and dynamic loads are carried by the insulation through to the hull structure external to the tank.

The spherical tank design incorporates freestanding insulated cargo tanks which are designed for liquid, vapour pressure (1.2 atmosphere absolute pressure or less), and dynamic loads. Spherical tanks are supported at the equator by cylindrical skirts to the hull. All LNG ships carry their cargo at very low-pressure, usually less than 150 kPa (mbar) above atmosphere pressure.

As both designs have proved safe and reliable in service, the choice of cargo tank design is primarily based on economics, i.e., price, delivery schedule and shipyard idle capacity, rather than technical or performance criteria. Both major designs have evolved into a "standard" design with a capacity of 125,000 m^3 to 175,000 m^3 and a service speed of 18 to 20 knots. Typical dimensions are 270 to 290 metres (m) long and 40 to 49 m in width with a draft of about 11.5 m. Some new ships exceed 300 m in length and have a cargo capacity of up to about 267,000 m^3.

What are the flags of registry for LNG ships?

Countries with more than one LNG ship in their registry include Algeria, Australia, The Bahamas, Bermuda, Brunei, France, Isle of Man, Italy, Japan, Korea, Liberia, Malaysia, Malta, the Marshall Islands, Norway, and the United Kingdom. No inference about safety or reliability can be drawn from a ship's flag of registry, the supplier of the cargo, or the nationality of the ship's crew to a particular characterisation of the importers.

The flag of registry is not particularly relevant in terms of rules and regulations and safety level available on LNG carriers since all flag states implement International Maritime Organisation (IMO) Conventions including, for instance, the International Gas Carrier Code (IGC Code), the International Safety Management (ISM) Code, and the International Convention on Standards of Training, Certification and Watching (STCW) Convention. The safety level is directly managed by the ship operator and ship manager. Safety policies for ships are also framed to consider the potential impacts of incidents which could involve the whole LNG chain, not only the tanker.

LNG ships must also be certified by marine Classification Societies during design and construction to ensure that standards are met. Classification inspections or "surveys" continue at regular intervals throughout the ship's working life. The main Class Societies operating internationally for LNG are Lloyd's Register (LR-UK), Bureau Veritas (BV-France), Det Norske Veritas (DNV-Norway), the American Bureau of Shipping (ABS-US) and Nippon Kaiji Kentai Kyokai (NKKK-Japan).

How do those who employ LNG ships know that they are in good repair and working properly?

LNG ships must be designed to meet the requirements of the IGC Code, Classification Society Rules and flag state requirements, and be constructed under Class supervision. Throughout their service life, LNG ships are subjected to regular inspection and survey. The results of this process are recorded in the ship's certificates, which are available for inspection. Without valid certification, an LNG ship will not be accepted for work.

The terminal operators have a vested interest in making sure the LNG carriers unloading at their facility are in good repair and working properly. An accident on the ship while it is docked could significantly impact the operations of the import terminal. In Europe and Japan, the import terminal and/or the charterers carry out ship inspections to check the tanker's suitability to be chartered or to enter port. There occasionally have been incidents in which LNG ships have been turned away until rectification of deficiencies on the ship (which had resulted in its failure to meet the standard).

In the US, the US Coast Guard (USCG) also inspects the ships regularly and issues a new Letter of Compliance certificate every two years. The owners of the terminals may also have a financial interest in the ships. All parties in the LNG process chain are keenly aware of the potential impact to the Industry's safety reputation of even a minor incident or "near miss".

Several means are available to assess the ship conditions. The "Port State Controls" established by the Memorandum of Paris (1981) are recorded in the "Equasis" database available for worldwide access. Generally, operators perform ship inspections according to the Oil Companies International Marine Forum (OCIMF) standards or to their own standards to assess the ship conditions. Reports on the ship's technical and survey status are available through the OCIMF Ship Inspection and Report (SIRE) programme, via the ship's classification society, and through the ship owner. For additional information on the regulations, codes and standards which apply to LNG ships, please refer to Information Paper No. 3.

For a new LNG Carrier arriving in an LNG terminal, how is the ability and training of the crew for performing manoeuvres checked?

The training of the crew must be in accordance with Standards of Training, Certification and Watchkeeping (STCW) Convention from the International Maritime Organisation (IMO). The training level required for the crew is given in the STCW IMO Convention, which requires a "dangerous cargo endorsement" and navigational experience. Certificates are checked by Port State Controls and deficiencies are recorded in the "Equasis" database.

The Society of International Tanker and Terminal Operators (SIGTTO) provides guidance to the industry on good practices and minimum competency standards. Training to meet the particular conditions of an import terminal is managed by the terminal and organised around pre-transfer meetings and ship-to-shore procedures.

Is LNG transported by road?

LNG is transported by road to consumers from import terminals and liquefaction facilities, including peak-shaving facilities, in specially designed LNG road tankers in some countries, including Australia, Belgium, China, Germany, Japan, Korea, Portugal, Spain, Turkey, the UK and the US. These LNG road tankers are double-skinned with insulation in between and contain up to 20 tonnes of LNG.

Transportation via trucks allows the distribution of energy to areas which are far from established gas distribution networks, e.g., areas which do not have pipeline access because of poor economics or difficult terrain. For example, parts of Scotland are supplied by LNG road tankers because the mountains prevent the cost effective laying of pipelines. A growing market is based on the use of LNG as fuel for trucks and large commercial vehicles. A fuel station infrastructure for these vehicles is growing rapidly and is supplied by LNG road tankers.

Economies of scale exist in the liquefaction process. In some areas it is economical to use LNG import facilities as a central "hub". Supplying multiple end-users via trucks has proven beneficial to all members of the energy supply chain.

How many LNG tank trucks are in operation worldwide?

About 700 LNG tank trucks are in service worldwide. A recent industry report estimated to cover more than 70% of the overland transportation for LNG worldwide concluded the following:

- At least 284 LNG tank trucks transport approximately 1,900,000 tonnes of LNG annually;
- **In Europe**: 65,000 individual truck loads travelling more than 18,000,000 km delivering close to 1,200,000 tonnes of LNG;
- **In the Americas**: Just over 21,000 individual truck loads, travelling more than 3,000,000 km with almost 370,000 tonnes of LNG; and
- **In the Far East**: 56,000 truck loads, over 8,000,000 km carrying more than 350,000 tonnes of LNG.

Is an LNG road tank truck like a petrol (gasoline) tank truck? Is it more explosive? Is it more harmful to the environment if it has a spill?

The main similarity between a petrol (gasoline) tank truck and an LNG tank truck is their comparable size. LNG tank trucks are double-skinned with insulation in between, and contain up to 20 tonnes of LNG. LNG if spilled will vaporise and the natural gas will dissipate. Both gasoline and LNG vapours are flammable.

LNG Characteristics

What are the hazards of LNG?

LNG is stored and transported at cryogenic or extremely low temperatures (-162°C; -259°F) which can cause cold injuries upon contact with live tissue. The cryogenic temperatures also can cause brittle fracture when in contact with many materials, e.g., rubber or steel. In a confined space, displacement of air by natural gas (vaporised LNG) can result in there being insufficient oxygen to support life.

LNG (natural gas in liquid form) is primarily used as a fuel; therefore the vapours are flammable and will burn once mixed with the proper amount of air to support combustion. LNG in its liquid state will not burn. Vapours form when LNG goes from a liquid to a gas. In all normal circumstances, LNG warms and begins to boil (and evaporate) as soon as it is released outside its storage container. Therefore, LNG facilities and equipment are designed with special features to assure containment of the LNG and its vapours. When natural gas vapours burn, the fires are very hot; the radiant heat of LNG fires is considered the primary hazard.

Fires

The fire hazards from LNG are broadly similar to other hydrocarbons such as LNG or gasoline. The main differences stem from its vaporisation and dispersion behaviour. If there is a release of LNG, a flammable mixture can develop as the vapours mix with the oxygen in air. Low temperature LNG vapours cause the air to be cooled so that any moisture in the air condenses to form a white cloud or fog. Thus the vapour/air mixture from an LNG release is usually visible. Specifically, it is the atmospheric moisture "fog" which is easily seen rather than the natural gas vapour. Under most conditions, the visible fog is a reasonable indication of the physical boundaries of the flammable mixture. The shape of the cloud is a good indication of the direction of the vapour dispersion.

Initially, the cold LNG vapours are heavier than air and will tend to stay close to the ground, but as the LNG-air vapour cloud warms, it will approach the density of the ambient air. This will limit the amount of sideways spreading of the cloud. When the cloud temperature warms to about -110°C/-166°F, it becomes positively buoyant. In such cases it can rise away from ignition sources at ground level, depending on the surrounding wind and atmospheric conditions.

Three elements must be present in the correct proportions for a fire to occur:

- Fuel (LNG vapour)
- Oxygen (Air)
- Ignition Source (Hot surface or spark)

A flammable mixture of fuel in air exists only between the upper flammable limit (UFL), where there is not enough oxygen, and the lower flammable limit (LFL), where there is not enough fuel. For LNG vapour/natural gas, the lower flammable limit is approximately 5% and the upper flammable limit is approximately 15%.

The risks from a LNG fire can be subdivided into two categories:

- *Fires where ignition does occur but is delayed.* When ignition is delayed, a vapour cloud will form and begin to spread. Computer calculations based on experimental data are used to estimate the size and flammability of the LNG vapour cloud and how it will disperse over time in a variety of weather conditions and terrain types. LNG facility designers and operators must demonstrate to regulators that these potential vapour releases and fires pose no hazard to the general public. In some countries, a thermal radiation exclusion zone, based on modelling, is required for sustained fire scenarios. Once ignited, the LNG vapour cloud may, in low wind conditions, burn back to the source of LNG/gas leak and will continue as the second type of fire.
- *Fires with immediate ignition in which a fire persists in burning for extended periods of time*. These fires occur at the point of the gas leak and burn only in the immediate vicinity. Thermal radiation calculations are performed to predict the impact of these fires on other equipment, plant personnel and the general public. LNG facility designers and operators must demonstrate to regulators that these fires pose no hazard to the general public.

Other Hazards

Exposure to LNG liquid can cause freezing of the skin and is destructive to tissue, somewhat like a burn. Hence the expression "cryogenic burn". Exposure to low temperature LNG vapour is less likely to cause tissue damage because the low density and low heat transfer from the vapour means that an extended exposure time is required before damage occurs. Unless a person is incapacitated, exposure to cold LNG vapour should not be life- threatening.

Where LNG vapours have displaced oxygen, as in a confined space, decreased oxygen availability impairs human physical and mental functionality. At low oxygen concentrations (below 10%) unconsciousness and asphyxiation will occur. The hazard from a high concentration of LNG vapour (50% or greater) is the displacement of the oxygen in air rather than any toxic or chemical property of the LNG vapour. Methane is not toxic and is chemically inert.

How does LNG compare in terms of safety hazards to other substances handled in ports, land-based facilities, on roadways and on railways?

LNG is not explosive in open air, toxic, carcinogenic or chemically reactive. It is flammable and will burn – which is its value as an energy source. If a leak or spill occurs, LNG vapours immediately begin absorbing heat from ambient air and soil, become lighter than air, rise and dissipate. If the vapours ignite, the flame speed of flammable vapours burning a cloud in the open air is relatively slow (about 4 metres per second).

Gasoline and fuel oil are more flammable and, in their liquid state and contain toxic components. If these hydrocarbons are spilled, unlike LNG, there will be an environmental impact. The extent and duration depend upon incident-specific conditions. LNG has comparatively fewer hazardous characteristics than some other common fuels, as shown in **Table 1**.

What is that unpleasant odour in natural gas?

Odorants are deliberately added to natural gas used for industrial and residential purposes to provide an early warning sign of escape or leakage. LNG (the liquid) has no odour and the liquid is not normally odorised. Conventional odorants freeze at LNG temperatures and are not sufficiently volatile at low temperatures to create an odour in vapours from an LNG spill. Therefore, the gaseous form of LNG is odorised as required by state regulations after it has been regasified but before entering the pipelines for distribution.

Table 1. Characteristics of commonly used fuels (see notes on table)

HAZARD	LNG	LPG	GASOLINE	FUEL OIL
Toxic	NO	NO	YES	YES
Carcinogenic	NO	NO	YES	YES
Flammable	YES	YES	YES	YES
Asphyxiant	YES, in confined spaces	YES, same as LNG, but higher density encourages accumulation	NO (unless in confined space)	NO (unless in confined space)
Other Human Health Hazards	Low temperature	NO	Eye Irritant, Narcosis, Nausea, others	Similar to Gasoline
Flammable Limits in Air (%)	5 –15	2.1 – 9.5	1.3 - 6	N/A
Stored Pressure	Ambient, except in some small containers	Pressurized	Ambient	Ambient
Behaviour if Spilled	Evaporates forming flammable visible cloud that disperses readily; keep away from ignition sources	Evaporates forming explosive vapour cloud that will hug the ground	Forms a flammable pool, environmental cleanup required	Environmental cleanup required; potentially long term depending upon specific oil type

Will LNG burn?

As noted above, LNG, which is a liquid, does not burn, because liquids do not contain enough oxygen to support combustion. However, LNG vapours are flammable in air, but only when they comprise between 5-15% of the air. If the fuel concentration is lower than 5% it cannot burn because of insufficient fuel. If the fuel concentration is higher than 15% it cannot burn because there is too much fuel relative to the oxygen. Therefore, the fire hazard of LNG is preconditioned on a combination of variables: the LNG being released, vaporising, then mixing with air in a very narrow gas to air ratio of 5-15%, and ultimately finding an ignition source.

Is a BLEVE possible with an LNG road tanker?

The acronym BLEVE means Boiling Liquid Expanding Vapour Explosion, which is the sudden release of a large mass of pressurised flammable liquid to the atmosphere. A primary cause is if an external flame impinges on the shell of a pressurised tank above the liquid level, weakening the shell and resulting in sudden rupture. A BLEVE can only occur in a road tanker under specific circumstances:

- A fire is ignited beneath or impinging on the road tanker;
- The insulation around the vessel fails to prevent heat reaching the LNG;
- The fire burns sufficiently long that the LNG begins to boil;
- The LNG boils so vigorously that valves installed to relieve the increasing pressure are unable to cope, and pressure within the tank rapidly rises;
- The upper part of the shell not in contact with LNG becomes weakened by overheating
- The tanker may then rupture with an intense, localized overpressure and fire.

There are two types of LNG road tankers operating worldwide:

- Double-skinned tankers with insulation between the two metal layers. These tankers are mandatory in the US, and are also common in Europe and Asia. In the double-skinned road tankers the fire can not directly impinge on the inner tank which contains the LNG. Any failure of the inner tank therefore occurs at a pressure too low to cause a BLEVE.
- Single-skinned LNG tankers with external insulation are occasionally used in some European and Asian countries. In single-skinned tankers, the fire has the potential to directly impinge on a tank containing LNG and a BLEVE is possible.

An LNG road tanker left the road and crashed into a gorge at Catalunya in Spain in 2002. A fire began immediately (it remains unclear whether this was a diesel or LNG fire) and 20 minutes later a BLEVE occurred. The driver was killed in this accident.

LNG Safety

What safety codes and regulations govern the transport and handling of LNG?

Specific standards for terminals and ships have been developed and adopted in different parts of the world. For additional information on the regulations, codes and standards which apply to LNG ships, please refer to **Information Paper No. 3**. For additional information on the regulations, codes and industry standards which apply to LNG import terminals please refer to **Information Paper No. 4**.

In the US, the codes and regulations specific to LNG import facilities include:

- 49 CFR Part 193 - *Liquefied Natural Gas Facilities: Federal Safety Standards;*
- NFPA 59A - *Standard for the Production, Storage, and Handling of Liquefied Natural Gas (LNG);*
- 33 CFR Part 127 - *Waterfront Facilities Handling Liquefied Natural Gas and Liquefied Hazardous Gas.*

In Europe, the codes and regulations specific to LNG import facilities include:

- European Union (EU) Seveso II Council Directive 96/82/EC of 9 December 1996 - *Control of Major-Accident Hazards involving Dangerous Substances*;
- European Standard EN 1473 - *Installation and Equipment for Liquefied Natural Gas – Design of Onshore Installations;*
- EN 1532 Installation and Equipment for Liquefied natural gas – Ship to Shore Interface.

The following US standards may also be applied:

- NFPA 59A - *Standard for the Production, Storage, and Handling of Liquefied Natural Gas (LNG);*
- 33 CFR Part 127 - *Waterfront Facilities Handling Liquefied Natural Gas and Liquefied Hazardous Gas.*

The codes and regulations which apply internationally to LNG ships include:

- *International Code for the Construction and Equipment of Ships Carrying Liquefied Gases in Bulk* (the "IGC Code");
- 46 CFR Parts 153, 154 and 157.

Various LNG operations are governed by different regulatory jurisdictions but all are covered by both regulations and codes. For example, in the US, a prime regulation governing the marine portion of an LNG import terminal is 33 CFR Part 127, *Waterfront Facilities Handling Liquefied Natural Gas and Liquefied Hazardous Gas*.

For marine operations, port authorities also have jurisdiction.

In the EU, the onshore terminals are under the jurisdiction of European Council. The main European regulation applicable to LNG import terminals and storage facilities is European Union Seveso II Council Directive 96/82/EC of 9 December 1996 on the *Control of Major-accident Hazards involving Dangerous Substances*.

Applying their own regulations derived from this Directive, national authorities of each European country have responsibility to issue a certificate to the facility and are the lead agency for review of environmental and safety concerns including public comment meetings and review procedures.

In Asia, specific standards have been developed for each area. The codes and regulations specific to LNG import facilities include:

- Gas Industry law, and
- Electricity Power Industry law.

What is done to assure that LNG ships and land-based facilities are designed and built for safety of operation and to protect the public?

The public safety assurance is accomplished by:

- Safe siting, design and construction of the import terminal per codes;
- Safety studies complying with European Directive Seveso II 96/82/EC for European countries;
- Ship design and construction approval by a "classification society" such as Bureau Veritas, DNV, Lloyd's Register of Shipping, NKKK, RINA and the American Bureau of Shipping;
- Pre-arrival inspections of facilities and ships;
- Third-party safety and code compliance audits;
- Initial and ongoing training programs for all personnel;
- Integrated emergency response programs, including all resources.

What ensures those dealing with LNG are capable of adequately performing their duties so as to protect the public?

LNG facilities are required to be designed and constructed by professionals who have demonstrated competence. This is assured, for example, by government regulations and oversight agencies which license engineers for the practice of engineering. Trained inspectors verify that the facilities are constructed correctly. Safeguard systems for LNG facilities are discussed in Information Paper No. 6.

Operations and maintenance personnel in LNG facilities are required to be trained, both initially and periodically thereafter, in:

- The hazards of LNG;
- The hazards of operation and maintenance activities;
- How to recognize breaches of security and execute security procedures;
- Understanding the potential causes, types, sizes and predictable consequences of fires and knowing and following fire prevention procedures;
- How to perform their assigned functions during both normal operations and emergencies;
- How to provide first aid; and
- Verification of compliance with these requirements is performed by each national dedicated Authority.

A key component of emergency planning is the training of all emergency responders, which incorporates coordination, communication, drills and exercises. Hazards and mitigation scenarios are identified and used to develop responses and role assignments. Simulated emergencies, both table-top and full-scale, are used to validate and improve the effective application of knowledge, skills, and team interactions. Field exercises are used to assure hands-on expertise.

For the European Union all these operation and maintenance activities fall under the control of a Safety Management System required by Directive Seveso II 96/82/EC.

In the US, exercises are required under a variety of authorities, including the US Coast Guard and the Department of Transportation, among others.

What standards and/or regulations define the required systems/methods to detect and notify the operator of a release of LNG from tankers and terminals?

Standards and codes require that combustible gas detectors and low temperature detectors are located at places where an LNG release might occur and where LNG or low temperature vapour might accumulate.

These detectors are continuously monitored. They also have alarms set just above the detection levels and automatic shutdowns at hazard levels.

For facilities on land, monitoring systems are required by EN 1473 in Europe, and 49 CFR Part 193 and NFPA 59A in the US. Onboard ship, monitoring systems are required by the IGC Code, the classification society's requirements and the USCG requirements of 46 CFR 153-154 and 33 CFR Parts 127, 160-169.

In addition to the code-required instrumentation specifically for leak detection, there is abundant normal process instrumentation that will alert an operator to an abnormal condition that may or may not be caused by leakage. Many areas are either covered by remote TV cameras or are visible to a plant operator or from a ship's control room. An LNG release of any size is easily recognized visually, because of the condensation of water vapour from the atmosphere within any resulting cloud.

What safety features are there at the onshore facilities?

There are two types of safety features in an LNG facility: management systems and technology/ equipment systems. The subject of **Information Paper No. 6** is Industry Safeguard Systems which includes a discussion of safety features.

Management systems include studies during the design process that identify hazards and then review the design to ensure that these hazards can be mitigated or controlled. During the operational phases, procedures are written to ensure that safe working habits and procedures are encouraged, inspections and maintenance are carried out in a timely and appropriate manner and impact on the public and employees of any unexpected circumstance is minimised.

In the US, the regulations generally require that these worst-case spill hazards remain on the owner's property such that risk to the public is approaches zero.

In Europe, the Seveso II Directive requires a complete Safety Management System for the control of major-accident hazards. The System must include a safety study with a risk analysis and relevant measures for mitigation of consequences. The final risk level must be acceptable to the authorities.

Emergency procedures and response plans also must be developed. These plans will be discussed with the local, fire, police and medical services. Most facilities have regular simulations of these plans and exercises with the local authorities.

With regard to safety technology and equipment, LNG facilities have multiple levels of hazard detection, mitigation and intervention systems. There are two types of systems: passive technology systems, which work without interaction, and active systems, in which an operator is prompted to take action or which may be automatically deployed.

Passive systems incorporated during the design phase ensure that the correct materials are employed to handle cryogenic temperatures and process pressures; that equipment is correctly sited to prevent any hazard spreading (escalating); and that access is restricted to certain areas. Passive systems also can safely dispose of any gas/LNG during an accidental release. Concrete coatings and protective reinforcement of control rooms are other examples of passive systems. Restricted zones are established around equipment and vessels containing fuel to strictly control or eliminate possible ignition sources.

Active systems include detection equipment for finding leaks such as methane detectors, emergency shutdown devices (ESDs), emergency venting systems, Ultraviolet or Infrared (UV/IR) fire detectors, closed circuit TV; staff monitoring of the facility by regular inspections; training of personnel; specifically-designed systems to mitigate hazards, for example, earthquake protection of LNG storage tanks; and emergency fire-fighting systems.

For additional information, please see **Information Paper No. 6** on Industry Safeguard Systems.

What safety features are there onboard the ships?

Safety features for ships are broadly divided into two categories: ship navigation and cargo handling.

In the area of ship navigation, IMO has established international "Collision Regulations" which applies to all vessels in coastal and international trade. Ships are now equipped with radar which incorporates ARPA (Automatic Radar Plotting Aid). ARPA not only identifies the presence of another ship or other hazard, but also indicates its relative speed and direction. This feature is especially useful for determining a safe course in high traffic areas. Ships are also equipped with GPS (Global Position System), which can pinpoint the exact location of the ship (within a few metres) anywhere in the world. Many of the world's major ports, including most LNG ports, have VTS (Vessel Traffic Services), which are best described as "air traffic control" for ships.

All ships are equipped with GMDSS (Global Maritime Distress and Safety System). GMDSS has replaced the radio operator and Morse Code. The GMDSS system is located on the bridge and can be easily accessed by the bridge watch-standers. In the event of an emergency, a watch-stander can push a distress button, which will automatically send a signal with the ships name and location. The watch can add additional information to the automatic message, such as the type of emergency (fire, sinking, etc.). This message will be forwarded automatically to all ships in the area, so they can render assistance. Included as part of the GMDSS system is an array of lifesaving signal equipment, such as radio beacons and search and rescue transponders. The law requires a minimum number of officers on each ship to be licensed to operate GMDSS.

The cargo system is designed with many features to maintain operation in a safe manner and, if it deviates outside of predetermined parameters, actions will be taken to assure safety. Pressures, levels, and temperatures are monitored automatically. If a problem is identified by the monitoring system, an alarm will sound and equipment will be secured, as necessary, to return the cargo system to a safe condition. Most of the alarms and trips have some form of redundancy to ensure problems are identified and corrected in a timely manner. For example, under the International Gas Code, all LNG ships must have two means of safely disposing of excess gas, thereby controlling the pressure in the LNG tanks.

All vessels are equipped with a gas detection system that senses the atmosphere in specific locations which are subject to potential gas leaks. Such spaces include the insulation space around the cargo tanks, compressor room, control room, and any other spaces where gas can accumulate. Fire and/or smoke detection systems may be available for spaces that contain flammable materials, such as the paint locker.

The navigation bridge is manned twenty-four hours a day at sea and has cargo system monitoring equipment that sounds an alarm whenever a non-standard condition is identified in the cargo system. The cargo control room is manned continuously during periods of cargo transfer to/from the ship.

Smoking is banned except in one or two specific locations within the ship's accommodation area.

Does every body of water have the same rules for LNG carrier safety?

Not every port or import terminal has identical safety rules, but all follow the same guiding principles.

The rules at a specific port for LNG ships are established by the Captain of the Port/Harbour Master. A key reference document for establishing port-specific rules is the International Safety Guide for Oil Tankers and Terminals (ISGOTT). The Terminal Safety Rules are generally gathered in a Terminal Safety and Port Instruction Handbook including a Ship Shore Safety plan with which the vessel shall comply.

The Society of International Tanker and Terminal Operators (SIGTTO) provides guidance to the industry on best practices for ships at sea and at berth. Many port authorities consult widely with their peers prior to determining or changing their operational rules.

Port manoeuvring and departure safety rules vary depending on the port configuration (river, open sea, tide, weather, other traffic). However, many common features exist such as the need for tugs and defined weather limits, tide and visibility restrictions.

What safety features are there on LNG tank trucks?

LNG tank trucks have safety devices to prevent over-filling and over-pressurisation, as well as safety systems to prevent the LNG road tanker from driving away while still connected to the loading facilities. LNG road tankers must comply with country-specific codes for design and operation.

What safety measures are in place at the unloading facilities?

The unloading berth has the same hazards prevention and detection systems as the rest of the import terminal, including closed-circuit TV, emergency shut-down (ESD) systems, fire detection systems and vapour detection. Most also have emergency release couplings on the unloading lines which minimise the spillage of LNG should a ship have to leave the berth unexpectedly, e.g. during extreme wave conditions. The LNG unloading process systems incorporate monitoring and control devices to detect deviation from acceptable parameters, thereby enabling corrective action to prevent unsafe conditions. Closed-circuit TV is used for monitoring the unloading area and as a secondary visual system to the combustible gas detectors and UV/IR fire detectors. There are emergency shut-down buttons at the pier, the control room, and on board the LNG ship which, when activated, will bring the ship and the import terminal to a safe shut-down. This shut-down generally shuts off all pumps and closes off all piping so that the LNG stays either on the ship or in the storage tank.

Who verifies that safety measures are applied and what is the frequency of these inspections?

European area: The Safety Management System, required by the European Directive Seveso II and implemented by the owner, includes internal control loops for every safety activity. In addition, some verifications are made by oversight agencies and inspections are performed by Local Authorities. The frequency of these inspections is variable for each facility. The Seveso II consent must be renewed every 3 years.

US area: Safety activities fall under the jurisdiction of OHSA (Occupational Health and Safety Administration), DOT (Department of Transportation), or Dept. of Homeland Security/US Coast Guard. Each agency will verify the safety activities that fall under its jurisdiction through inspections. The inspection rate is chosen by the responsible agency and will vary by facility. The Federal Energy Regulatory Commission (FERC) requires quarterly reports from the import terminal operators and typically also makes annual inspections.

Other areas: Similar procedures are implemented by government agencies in Asia and wherever a new LNG terminal is constructed.

Security

What measures are in place to assure the security of LNG ships and terminals?

Following the attacks on the US on September 11, 2001, the International Maritime Organisation (IMO) implemented a comprehensive security regime for international shipping which entered into force on July 1, 2004. The mandatory security measures, adopted in December 2002, include a number of amendments to the 1974 Safety of Life at Sea Convention (SOLAS), the most far-reaching of which implements the new International Ship and Port Facility Security Code (ISPS Code), which covers the whole port including any LNG facility therein. The ISPS Code contains detailed security-related requirements for Governments, port authorities and shipping companies in a mandatory section (Part A), together with a series of guidelines about how to meet these requirements in a second, non-mandatory section (Part B).

In addition to addressing security threats from terrorism, IMO is implementing an anti-piracy project, a long-term project which began in 1998. IMO's aim has been to foster the development of regional agreements on the implementation of counter piracy measures. The Regional Cooperation Agreement on Combating Piracy and Armed Robbery against ships in Asia (RECAAP), which was concluded in November, 2004 by 16 countries in Asia, includes the RECAAP Information Sharing Centre (ISC) for facilitating the sharing of piracy-related information. In January, 2009, an important regional agreement was adopted in Djibouti by States in the region, at a high-level meeting convened by IMO. The Code of Conduct concerning the Repression of Piracy and Armed Robbery against Ships in the Western Indian Ocean and the Gulf of Aden recognizes the extent of the problem of piracy and armed robbery against ships in the region and, in it, the signatories declare their intention to co-operate to the fullest possible extent, and in a manner consistent with international law, in the repression of piracy and armed robbery against ships.

Assuring the security of maritime and other critical infrastructure assets has been addressed in country-specific laws and regional agreements. For example, the US passed the Maritime Transportation Security Act (MTSA) in 2002. MTSA applies to vessels operating in U.S. waters (regardless of flag), marine terminals and, in addition to US domestic ports, foreign ports that receive vessels intending to travel to US port facilities. MTSA is similar to the ISPS, except that all parts of MTSA are mandatory. Security vulnerability assessments and security plans are required to be reviewed and approved by the US Coast Guard. The MTSA also introduces the requirement for a USCG-issued Transportation Worker Identification Card (TWIC) for anyone having to enter a secure area of a marine terminal and vessels while in US waters. This includes members of the crew and is required regardless of flag of ship or nationality of the crew.

LNG terminals include a range of layered and multiply-redundant security measures and systems. The specific measures and systems are selected from a wide range of possibilities by risk assessment, usually in conjunction with government security organisations and are deployed according to national alertness criteria.

What would happen if a bomb, missile or plane hit the LNG storage tank at the import terminal?

Security experts do not consider LNG facilities to be a priority terrorist target. Also, if a terminal became a target, the post-9/11/2001 air traffic controls would make it exceedingly difficult to execute the attack. These facilities are indentified as part of a country's critical infrastructure and enhanced security measures have been implemented. Also, research and sophisticated modelling have compared the structural integrity of storage tanks against likely attack parameters. The results show that penetration of the tanks by these modes of attack would be very unlikely. All plant safety and security vulnerability assessments consider this type of scenario as a design case andplant designs provide for spill impoundment for credible accidents. Currently, an evaluation of the consequences has determined some underlying factors which place some boundaries on the risks. These are:

- If an aircraft impact is severe enough to cause a release of LNG, there will be an immediate fire (aircraft fuel and LNG), which precludes the development of a flammable vapour cloud.
- The structure of an aircraft is relatively "soft" except for the engines that are "hard" with considerable mass and penetrating potential.
- The combined structural strength, flexibility and mass of the LNG tank probably preclude a catastrophic failure but may not preclude penetration by the engines.

What would happen if a bomb were attached to an LNG road tanker and then exploded?

The LNG road tanker trailer contains a relatively small amount of LNG. It is double-skinned with insulation between and is therefore highly resistant to damage. If liquid were to be spilled, the result will be a fire and some possibility of LNG entering the road drains.

What would happen if a bomb, missile or plane hit the LNG ship?

This issue has been the concern of government agencies and the LNG industry. The research conducted by the US Dept. of Energy Sandia National Laboratories scientifically addressed the effect of a terrorist attack on LNG carriers, and included the intelligence community in defining scenarios and study parameters. The details of the scenarios are classified information.

Some parallels could be drawn from the experience of the Gaz Fountain, a refrigerated LPG carrier hit by rocket fire in the Persian Gulf in 1984. Three air-to-ground armour-piercing rockets hit the ship. Only one of these caused a rupture of one of the ship's tanks, causing a large fire. Ultimately, the fire was brought under control, a significant portion of the cargo in the other tanks was off-loaded to another vessel and the ship was made safe for removal from the area.

How vulnerable are the ships?

With their double-hull construction, robust cargo tanks with multiple layers of insulation, implementation of maritime security measures following 9/11/2001, scrutiny from regulators, transit risk mitigation measures, and the training required for the crew, LNG ships are inherently less desirable than all other possible terrorism targets.

Is it fair to characterise an LNG tanker as a floating bomb?

No. An explosive delivers a large amount of energy over a very short time period. Explosives have the reactants inherently contained in the explosive material. The energy release is concentrated and nearly instantaneous. The gases created expand at very high speed, far greater than the speed of sound, thereby causing a "bang".

Although the tankers carry a large amount of LNG, equal to a large amount of stored energy, the physical characteristics of the cryogenic liquid mean that it takes a considerable time to convert this energy into a flammable or explosive state.

A similar comparison would be a warehouse full of wood. This has the stored energy of a bomb but would not be considered dangerous as the related energy would be released only slowly in the event of a fire.

For LNG, the liquid first needs to vaporise and be mixed in the correct proportions with air to become flammable. The flame speed for methane is relatively low (approximately 4 m/s). Unless confined within a building or industrial space, it does not explode. If the cargo tanks were breached by an intentional attack, flammable vapours would form and a fire would likely occur. The aforementioned Sandia research modelled and predicted the radiant heat from the fire from a cargo tank at various distances from the ship.

Have there ever been any attacks or verified terrorist threats against an LNG facility?

None known.

LNG Spills

Is an LNG spill detectable?

LNG's low temperature will typically cause condensation of water vapour in the air and form a visible white cloud which would be readily apparent and small amounts of white (hydrate) material would accumulate on surfaces, much like ice or snow. The air around the release would feel quite cold. LNG vapours have no odour or colour, as many other substances do, to indicate a release.

Flammable vapours are detectable with specialized equipment. Within an LNG facility or onboard a ship, various types of hazard detectors are used to alert personnel to a leak or spill. These could include detection for the presence of gas, flame, smoke, high temperatures or low temperatures. These detection systems are discussed in greater detail in **Information Paper No. 6**.

What is the environmental impact of LNG spills?

If spilled on land or water, LNG will vaporise and the natural gas will dissipate. The environmental impact of LNG spills is minimal because the components of LNG are non-toxic and insoluble in water. Therefore, if there is an LNG release on water or on land, the LNG will completely evaporate with no residue. However, freezing of the ground and organic tissue will occur upon contact with the cryogenic liquid.

What happens when LNG is spilled on land?

Most simply, an LNG spill on land will result in vaporisation of the liquid to form a vapour cloud, predominantly of methane vapours. The vapour cloud will become buoyant when its temperature reaches approximately -110°C/-166°F, depending on the actual LNG composition and ambient weather conditions. If ignition sources are not present when the cloud is within flammable limits (5-15% natural gas in air), no fire will occur.

Initially, there is a large temperature difference between the spilled LNG and ambient, warmer surfaces. The initial evaporation rate of LNG is quite rapid but will decrease if a pool of spilled LNG accumulates. As time progresses and a pool accumulates, and/or the leak continues, the ground temperature drops which results in a slower evaporation rate. The pool of LNG would continue to evaporate until it completely vaporises.

The evaporation rate can be controlled by restricting the land surface area available for evaporation through dikes or walls to create spill basins or sumps. Insulation of the ground surface using special concrete also helps reduce the initial vaporisation rate. The vapour evaporation rate eventually depends on the size of the pool surface in contact with the air and the strength of the wind, rather than the contact with the ground. Managing the evaporation rate from this point depends on the response objective – whether it's better to slow down or speed up vapour cloud formation. Terminal personnel are knowledgeable about how to implement strategies to achieve response objectives. For example, high-expansion foam can blanket the surface of contained spills to reduce vaporisation rate and therefore control the rate at which the vapour cloud can form.

What happens when LNG is spilled on water?

A spill of LNG on water evaporates about five times faster than on land because of the higher heat transfer rates associated with the water and a tendency for the water not to completely freeze. The high heat capacity and the circulation of the water at the surface usually inhibits significant ice formation. Depending upon the quantity spilled and the conditions, LNG has a tendency to spread and form a pool on the water surface because it is insoluble. This pool of LNG will evaporate and create a vapour cloud which expands, begins to dilute, and moves with the ambient wind conditions. The actual size, rate of expansion, movement of a vapour cloud depends upon incident-specific conditions. A first approximation is that the size of the LNG pool will increase until the vapour generation rate equals the LNG release rate. If ignition sources are not present when the part of the vapour cloud that is within flammable limits (5-15% natural gas in air), then no fire will occur.

Some LNG spills on water may have a Rapid Phase Transition (RPT). This is essentially a flameless overpressure caused by the very high transient rates of heat transfer from the water to the LNG. This causes the LNG to change from the liquid to the gas phase so quickly that a rapidly expanding vapour cloud is generated. The cloud can expand so quickly that a sonic boom and localized overpressure is created.

The RPT "explosion" phenomenon for LNG on water has been observed in a number of situations and has been studied extensively in both laboratory and large-scale tests. While this phenomenon is spectacular to observe at large-scales tests, the actual energy release is modest. An RPT is a very unpredictable phenomenon and the exact circumstances of its formation remain unclear. The temperature of the water and the actual composition of the LNG are important factors in predicting whether or not an RPT will take place. Work has also been performed to examine the impact of an RPT on the LNG ship and pier structure. Measured overpressures are insufficient to cause more than minor damage either to the ship or pier.

What happens when LNG is spilled on a ship?

Small spills of LNG have occurred onto the decks of LNG carriers during the loading and unloading process. The cold of the LNG has caused the carbon steel deck plates to crack in some cases. Fire hoses and deck water sprays are used to warm the spill area and increase the evaporation rate of the LNG.

Unlike deck plates, LNG tanks within a ship are made of metals which do not crack or become brittle in the presence of cryogenic temperatures. All LNG ships have two systems to prevent leakage from the LNG tanks. If one tank fails for whatever reason, the LNG is held safely by the secondary protection system. LNG tank types are designed to leak before failure, thereby allowing the crew to empty the affected tanks before significant damage can take place.

The LNG tanks and insulation spaces are kept free of air to prevent any leak from creating a flammable mixture. The tanks themselves always contain liquid LNG and some LNG vapour above the liquid.

The insulation spaces on membrane ships are filled with nitrogen (an inert gas) and monitored continuously for the presence of methane (flammable vapour).

What is the risk from an LNG vapour cloud?

The main risk from a natural gas vapour cloud (mostly methane) is the potential for a fire. Risk analyses require all credible and possible release scenarios to be determined and evaluated. For the identified scenarios, codes and mathematical models are used to calculate the maximum excursion of the flammable mixture under adverse conditions.

If ignition of a vapour cloud does occur, the flame will burn slowly (3-4 m/s) back through the vapours to the point of release. If, at the time of the spill, the wind speed is more than a few metres per second, the flame will not propagate back to the source; it will burn out down wind from the ignition point. It will continue to burn until extinguished or until all the leaking LNG/fuel is consumed. Thus, the hazard area is limited to the path between the point of ignition and the point of release.

Unconfined methane vapour clouds cannot explode. If ignited, the cloud will deflagrate: the flame front will progress through the flammable portion of the cloud at the rate of a few metres per second. Once the vapour cloud is diluted below the lower flammable limit, it can no longer be ignited, nor will it burn.

A **confined** methane vapour cloud can explode and a cloud that enters a congested region can produce an explosion, if the amount of congestion is sufficient to accelerate the flame sufficiently. There is no evidence from any of the experimental programs or incident history that an LNG vapour cloud is capable of undergoing a transition to a sustained detonation, as has been observed with other more reactive hydrocarbon gases. (It should be noted that detonation occurs when the blast front progresses through the flammable cloud at sonic velocity, i.e., some 300 m/s. Normally, in an unconfined LNG vapour cloud, the flame front velocity is about 3-4 m/s, and shows no tendency to accelerate).

LNG Incidents

Have there ever been any major LNG accidents at import terminals worldwide?

The only incident at an import terminal which can be considered major was in 1979 at Cove Point, Maryland, US. An explosion occurred in an electrical switch room. LNG leaked through the electrical gland of an LNG pump, and travelled through 60 m of electrical duct and entered an electric substation. Since natural gas was not supposed to be in this part of the facility, there were no gas detectors. An electrical arc ignited the mixture of natural gas and air, causing a confined explosion of natural gas. One operator was killed and another one seriously injured.

Incidents involving other kinds of LNG facilities have happened, and they must neither be forgotten nor ignored. (NOTE: A Chronological Summary of Incidents Involving Land-Based LNG Facilities is presented in the CH-IV report, 2006). For instance, at the peak-shaving plant in Cleveland, Ohio, US, in 1944, many people died, as the result of LNG's worst accident. However, it occurred more than 60 years ago, at the beginning of the industrial application of LNG and long before the introduction of the stringent LNG safety standards which exist today. Moreover, it is the only incident involving public safety issues (meaning either public injuries or damage to businesses external to the LNG site). Indeed, since then, there have been no fatalities or injuries to the public due to incidents in LNG terminals.

Additionally, there have been few incidents involving LNG, as the industry has been making huge efforts in this regard and has developed a very conservative approach to the safe design, construction, and operation of LNG facilities. The industry continues to improve its record of reliability and safety. Like many industries involving complex infrastructures and intricate industrial processes, the LNG industry (LNG export and import terminals, LNG peak-shaving plants and transportation systems) has the potential for hazards to occur. The LNG industry has learned from past incidents, and it continues to improve technology, thanks to the benefits of the experience acquired from the handling of the same product over several decades.

The changes which have been made are the expression of these efforts: the incidents which occurred led to significant changes, not only in codes, standards, and safety rules, but also in staff training, storage tank design and construction, plant and equipment technologies, and many other fields. As a result, the study of safety performance indicators highlights the LNG industry's admirable safety record when compared to that of the overall Oil and Gas industry.

What caused the tragic incident in Cleveland, Ohio in 1944?

Mr. Ted Lemoff of the US NFPA (National Fire Protection Association) recently analysed the Cleveland incident in detail and presented a paper at GASTECH 2008, one of the industry's global conferences. Excerpts from this paper are included in this answer.

Background

In an effort to assess ways in which to commercialise LNG, a pilot plant was constructed in Cornwell, W.V., US in 1940. A primary objective of the pilot plant was to address several technical issues, such as investigating what construction and insulation materials would be suitable for LNG storage. The pilot plant ran for 4 months and the operators learned that steel with less than 3.5% nickel and less than 0.09% carbon is brittle below –45ºC (-50ºF). Papers were presented at natural gas conferences and in technical magazines to make engineers aware of the new technology.

The winter of 1939-40 was an unusually cold winter in the US Northeast, and there were gas shortages. In that era, it was normal for industrial gas customers to stop using natural gas during periods of heavy demand, to assure a sufficient natural gas supply for heating of homes and for cooking. The East Ohio Gas Company (EOGC), a natural gas utility company serving Cleveland and surrounding areas, constructed the first commercial LNG storage tanks designed to have additional supplies of natural gas for cold winters. The "Number 2 Works" in East Cleveland was selected because it was the central point of the city gas distribution network and natural gas could easily be introduced into the system. The site had been in use for 50 years and it contained shops and buildings in the natural gas business. Recognizing the importance of the Charpy Impact Test (a procedure used to evaluate the brittleness of metals), three spherical tanks were constructed using 3.5% nickel steel in 1941. The need for additional storage capacity resulted in the new construction of a fourth tank, a semi-toroidal design. This design, although smaller and more expensive than spherical tanks, was selected because the design made for a stronger vessel. When the centre dish of the semi-toroidal tank was filled, the liquid overflowed and a crack developed; it was repaired. Extensive testing occurred on all the tanks when they were constructed. Dams were constructed around the 4 tanks to contain small spills, and an overflow tank was constructed. A tank designer objected to the dams because they would confine the air in the space beneath the tanks, interfering with air circulation. The tanks were designed assuming the outside of the insulating jacket would be at room temperature.

The Incident

According to operating records, on October 20, 1944, the 4 LNG tanks had been filled and Sphere #1 was being topped off. At 2:40PM tank #4 failed (the toroidal tank). Plant employees testified that they heard a low rumbling. The 3,800 m^3 stored in tank #4 flowed over a large area and began vaporising immediately, forming a white cloud. A fire started shortly thereafter. About 20 minutes after #4 tank failed, the #3 tank failed (1,900 m^3), probably as a result of its support columns failing either from fire damage or from damage suffered from fragments of tank #4. Some of the liquid entered the sewers, which later ignited and exploded. The fires were brought under control early the following day. Tanks #1 and #2 survived the fire without leakage. The radiant heat from the LNG fires was intense. The fire resulted in 128 fatalities (the largest number were plant employees), over 200 injuries, and significant damage to the plant and wood buildings within 400 m.

Investigation and Conclusion

Investigations were conducted by the Bureau of Mines, Case Western Reserve University, the coroner, and the National Board of Fire Underwriters. Metal fragments collected within 91 m of tank #4 indicated a pressure explosion from ammonia cylinders which were used in the liquefaction process. Fragments of tank #4 showed fractures consistent with low-temperature embrittlement. Investigators analyzed at least 7 possible causes for the tank failure but in the end were unable to reach a definitive conclusion. Their report listed possible contributing factors to the incident, including improper design (wood support of the inner tank), and the use of steel subject to brittle fracture.

Recommendations

The Bureau of Mines report made the following recommendations (among others):

- LNG Plants should be isolated from other activities. They recommended a separation distance of at least 800m.
- Dikes to contain any LNG spill must be provided.
- Low temperature properties of metals should be investigated and published.
- Cryogenic liquids storage should not be made of 3.5% nickel steel unless brittle failure is determined not to be the cause of #4 tank failure.

- All cryogenic pipe joints should be bolted.
- Extreme caution should be taken to prevent spilled LNG from entering sewers.
- The appearance of frost spots on the outer shell of storage tanks should be investigated by emptying the tank.
- Efforts should be made to prevent wide variation in temperature in LNG storage tanks when they are first filled.
- Remote closing valves should be provided.
- All nearby sources of electrical ignition should be eliminated.
- Means for rapid egress should be provided for plant employees.

Where appropriate these recommendations have subsequently been incorporated into the various standards, codes, regulations and best practices discussed in **Information Paper No. 4**.

Have there ever been any incidents involving LNG ships at import terminals?

There have been five incidents reportedat import terminals where small amounts of LNG have been spilled during unloading, which caused minor cracks on the ships' deck plate. (NOTE: A Chronological Summary of Incidents Involving LNG Ships is presented in the CH-IV report, 2006). Also, LNG ships are reported to have bumped a jetty, or berth, while docking on two occasions.

SPILLS DURING UNLOADING

DATE	VESSEL	DESCRIPTION
May 1965	***Methane Princess*** 27,400 m^3 Conch tanks	LNG leaked during disconnection of the loading arms. Small crack on ship deck.
April 1966	***Methane Princess*** 27,400 m^3 Conch tanks	Cargo leakage; no details
April 1979	***Mostefa Ben Boulaid*** 125,000 m^3 Membrane tanks	Equipment failed while unloading at Cove Point, US, spilling small amount of LNG on deck plate which cracked
April 1979	***Pollenger*** 87,600 m^3 Spherical tanks	Equipment failed while unloading at Boston, US, spilling small amount of LNG on tank weather cover plate, which cracked
1985	***Isabella*** 35,500 m^3	LNG tank overflowed while vessel was being unloaded, causing a crack to the deck plate.

COLLISIONS WITH JETTIES

DATE	VESSEL	DESCRIPTION
October 1997	***LNG Capricorn*** 125,000 m^3 Spherical tanks	Collided with a dolphin while docking near Osaka, Japan. Ship was pushed into the dock by high winds and sustained minor damage on the aft quarter. No cargo was released.
September 1999	***Methane Polar*** 71,500 m^3 Membrane tanks	Engine failure while docking at Trinidad and Tobago. Vessel struck and damaged an adjacent pier. No cargo was released.

LNG Benefits and Economic Considerations

How is LNG ultimately beneficial to citizens around the world?

LNG supplements the natural gas supply, which is a key component of the energy mix. In the **World**, LNG is 5.3 % of consumed gas (in **Europe** LNG is 7.3% of consumed gas; in the **US** LNG is about 2.5% of consumed gas; in **Japan**, **Korea** and **Taiwan** LNG imports comprise more than 90% of their consumption of gas). Natural gas is used in residential homes for cooking, to provide heat and hot water, and in industry. The unique properties of LNG provide compelling reasons for its use in some circumstances. The ability to store LNG (mainly for short term or seasonal use) enables energy companies to meet fluctuations in demand, be it from day to night or from summer to the coldest day in the winter. In the long term, many countries need to diversify their gas supply and LNG imports are part of the answer.

Some countries may have gas reserves or pipeline supplies, but there are several additional factors that result in the need for LNG importation. Some of these factors are economic and some are strategic. Gas reserves are large but not infinite. The portion of the total natural gas supply that can be derived from imported LNG must be evaluated by area, pipeline transportation cost and capacity and load fluctuations. However, the demand for natural gas is increasing primarily because many new power plants are fuelled by natural gas for environmental reasons and the high purity of LNG can be an additional advantage. Worldwide, it is expected that the portion of energy supply from LNG will increase with time.

For example, the European natural gas market is expected to grow from 23% to 28% of total energy consumption in 2020 (i.e., within the next 10 years). In order to meet that growing demand, LNG must play an increasingly larger role in the Europe's energy mix.

In the US, natural gas is used in residential homes for cooking, to provide heat and hot water. In order to meet growing demand, LNG must play an increasingly larger role in the country's energy mix. Currently, only a very small percentage of the overall natural gas supply is served by LNG (about 2.5% in year 2007). New England, in the coldest weather, has derived as much as 40% of their natural gas use from LNG. It is expected that the portion of US energy supply from LNG will also increase in the future.

Although new natural gas reserves will be used in the future, the costs to deliver to market will be greater, as will the costs of deepwater production from the North Sea, the Gulf of Mexico and from other places in the world. In contrast, LNG project costs are stable and the number of sources is increasing. Thus, the portions of supplies from LNG will be primarily dictated by the cost of production and transmission of domestic natural gas, as well as the cost of natural gas from the areas which produce and export LNG.

The natural gas prices are sensitive to imbalances, even small ones, in supply and demand. Along with various natural gas imports by pipeline, diversification of sources through LNG imports will work toward a more stable balance and offset the upward price pressure during periods of tight supply.

What would be the economic impact of losing an LNG import terminal?

The loss of an LNG import terminal would result in an important decline in natural gas supply to the subject country as a whole, as well as having an adverse effect on the local area. The severity of these impacts would depend upon the pipeline capacity in the area, but the loss of an import terminal is the equivalent to two major offshore supply areas being unavailable. There would also be a ripple effect. If natural gas is scarce, in tight supply, there will be more demand for oil resulting in its price increase. This in turn would increase the price of energy in general and electricity, gasoline, and chemicals in particular.

What would be the economic impact of losing an LNG peak-shaving facility?

The loss of an LNG peak-shaving facility would mean an important loss of natural gas supply to the local or regional area, or even the entire supply chain in the country, depending upon the design of the distribution system and relative size of the country. The severity of the economic impact would depend upon the quantity stored in the facility's LNG tank(s), the time of year of the loss, and the relative importance of the facility in the economy of the region or area.

What would be the economic impact of discontinuing LNG imports?

The short-term economic impact would be an increase in domestic natural gas prices, intermittent curtailment during peak demand periods and a reversal of the trend to use natural gas for power plants instead of oil and coal. The long term economic impact would be an increase in natural gas prices due to higher cost of exploration and production, higher transmission costs due to new, longer pipelines, higher prices due to scarcity and a switch to less environmentally friendly fuels.

Key Points and Conclusions

In closing, the reader should remember the following key points of this Information Paper. In addition, most of these points apply to the entire Information Series about the LNG industry.

1. In a world where economic, political and sociological pressures have combined to create far-reaching global strife in the simple search for energy, LNG deserves serious consideration as an attractive source of reliable and secure energy supply for many years to come.
2. Like every other member of the family of energy industries, the LNG industry has some inherent hazards and risks.
3. While the LNG industry has been in world-wide existence for well over sixty years, there have been relatively few accidents, incidents, injuries or deaths in any facet of the entire industry, despite the presence of ships and trucks travelling the oceans, seas and roadways of this diverse and vast planet. No injuries to the public have occurred at a LNG facility since the tragic accident in Cleveland, Ohio, US over 60 years ago, when LNG first became commercially viable.
4. Like other members of this energy family, the safety hazards and risks of LNG can be effectively and efficiently managed through the multiple layers of codes, standards, best practices, measures, and contingency planning applied throughout the industry.
5. Historically, the members of the LNG industry have demonstrated their commitment to manage these risks in a most comprehensive, complete and responsive way. A graphic illustration of this framework and commitment is reflected in the "Multiple Safety Layers" figure on the last page. These layers are firmly based on a foundation of solid Industry Standards, Regulatory Compliance mandates and Codes. These "safety layers" include several key components of this overall Risk Management System. Included among them are Primary and Secondary Containment, Control Systems incorporating Knowledge and Experience (which are reinforced by comprehensive and ongoing training). A protective umbrella of Safeguard Systems, Separation Distances, and Contingency Planning further enhances the safe management of LNG.

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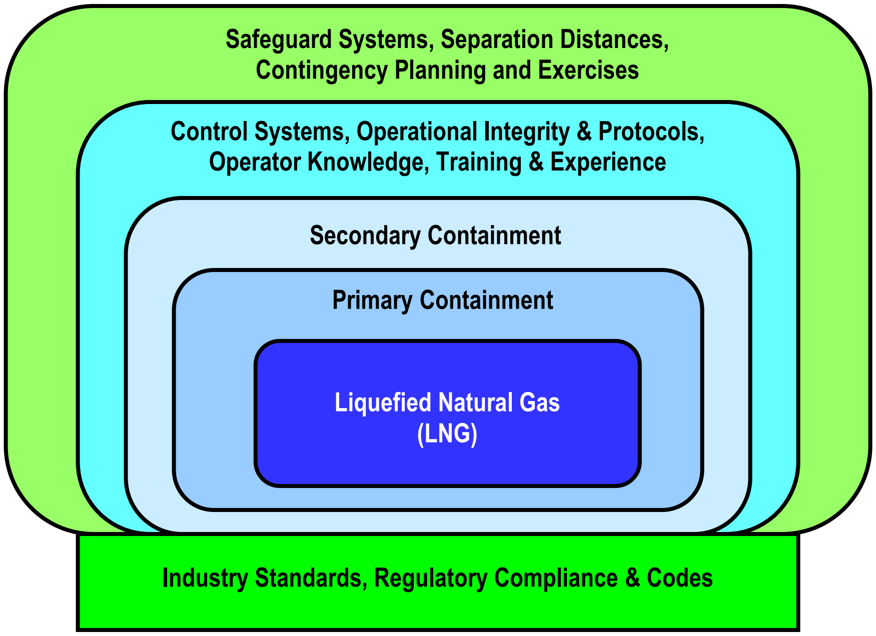
Multiple Safety Layers Manage LNG Risk



The GIIGNL Technical Study Group has developed this 7-paper series to provide public readers with factual information about the LNG industry's multiple layers of safety, as illustrated in the figure to the left.

The GIIGNL Information Papers include:

- No. 1 – Basic Properties of LNG
- No. 2 – The LNG Process Chain
- No. 3 – LNG Ships
- No. 4 – Managing LNG Risks – Operational Integrity, Regulations, Codes, and Industry Organisations
- No. 5 – Managing LNG Risks – Containment
- No. 6 – Managing LNG Risks – Industry Safeguard Systems
- No. 7 – Questions and Answers (Q&A's)

For more information about these and other topics, or to obtain copies of this report series contact:

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