Liquefied Natural Gas: Description, Risks, Hazards, Safeguards

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Executive Summary

Liquefied Natural Gas (LNG) continues to be the economic and environmental fuel used all over the world and it is considered as the lifeblood of Qatar's economic success. It can be defined as light hydrocarbon fraction of the natural gas, mainly methane, which is cooled and converted to liquid form storing or transporting. LNG has unique characteristics comparing to other energy sources and the main reasons behind the production of LNG will be discussed. Similarly, the overall process description of LNG will be viewed. LNG process consists of main parts that are discussed in this paper, namely locating, designing, operating, storing, shipping and LNG import terminals in the countries to which Qatar exports its LNG. The risk assessments associated within each part of LNG process will be talked about. LNG process is a very critical aspect in today's technology. It is highly demanded in the energy market; thus for a safe and convenient supplying general safety guidelines are provided within this paper.

Introduction

In the past forty years, oil and gas have been introducing an amazingly innovative product that enhances today's world. As the gas and oil industry grows, the demand for better products increases. Therefore, the emerging of the liquefied natural gas was widely acceptable under the term of production enhancement.

Liquefied Natural Gas (LNG) is the light hydrocarbon fraction of the natural gas, mainly methane, that is cooled and processed for the sake of transferring it into a liquid form.[1] Natural gas contains different fractions of hydrocarbons. It is composed of cross-linked chains that might contain two carbon hydrate and reach up to thirty (CH) component. The Liquefied Natural Gas mainly contains propane (3 carbons) and methane (2 carbons). The Liquefied Natural Gas is a demandable product for many convenience reasons. First, LNG is a source of gas which is known to be the most critical energy supplier today. Second, LNG provides the convenience and efficiency that any client would require in its product. One of the advantages of LNG is its capability to store and transfer large amounts of gas in relatively small spaces.

Liquefied Natural Gas (LNG) plays a significant role in Qatar's oil industry. Qatar is considered one of the major countries that leads in such production. Famous dominating companies in this industry are Shell, ExxonMobil, Qatar Gas and Ras Gas. All these companies divide the major industry into several processes. Although all these corporations agree on the final product, they differ in the path used to reach it. One of the reasons that LNG is demandable in the market is its capability to be transported within large distances. Many significant safety aspects must be associated with such processes to ensure the safety and welfare of both workers and people surrounding the plant. Such precautions must cover every area of the overall process. For example, the safety regulations needed for operating the process itself, storing the product and shipping it.

In this report, a discussion regarding the production of LNG is carried out by specifying how it is done and the risks associated with such product and the safety regulations considered when designing and locating the plant, operating the process, storing the product and finally shipping it. The data gathered to compose this report are collected from two of the most significant LNG producers, QatarGas, ExxonMobil and Total companies. In addition, the information gained for this report was from researching sources such as websites and journals. LNG is very important as it saves up space by covering about one six hundredth of the volume covered by same amount of gaseous natural gas. To have such advantage, the natural gas should be processed to give liquefied product.

Value chain

The LNG value chain elaborates the major components in LNG production and can be seen in Figure 1.

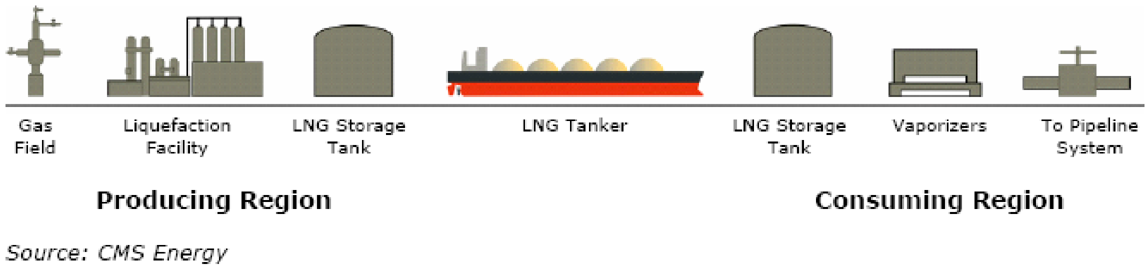


Figure1. LNG Value Chain[22]

The natural gas production is the process required in exploring and producing natural gas from the gas field to the processing center called the liquefaction facility. This facility converts natural gas into its liquid state for temporary storage. LNG ships are used to transport LNG to consumers. Re-gasification is the process that converts the natural gas back to its gaseous state using vaporizers. End users would normally get their natural gas through portable gas tank or through the pipelines into their homes.[22]

Liquefied Natural Gas Process Description and Risks Associated

The process described for the production of LNG is covered from Qatar Gas Company. The most significant step along the LNG process mainly stands on the cooling of the extracted gas to a low temperature of -260 ˚F (-162.2 ˚C).

The LNG process mainly consists of ten units within each train. There are number of trains carried out by different companies, they carry out almost similar stages, these difference lies in small specifications. Table 1 shows a brief description of what each unit does.

Table1. QatarGas Typical Train Units.

Unit Number	**Brief Description**
One	Inlet Receiving and Condensate Stabilization
Two	Acid Gas Removal
Three	Dehydration & Mercaptan Removal
Four	Mercury Removal
Five	Gas Chilling and liquefaction (Main Heat Exchanger)
Six	Refrigeration
Seven	Fractionation
Eight	Nitrogen Rejection
Nine	A. Sulphur Recovery B. Acid Gas Enrichment
Ten	Helium Extraction

The numbering of the units does not means that the gas passes the units in that order and within the same arrangement. For example unit four, Mercury Removal, is placed right after unit one because the sooner the mercury is removed the better. This is because the existence of mercury is harmful for the cryogenic equipment and pipe lines. It causes corrosion, and it is dangerous to be dealt with for a long period of time, since it is toxic.

1.1: *Inlet Receiving and Condensate Stabilization*

The raw gas is received from onshore using a pipe. The pipe enters the first unit of the train. The first unit takes up the gas which is composed of different hydrocarbon fractions and condensate it. Condensate stabilization occurs at unit one which mainly focuses on stripping the light ends content (methane and ethane).[2]

1.2: *Acid Gas Removal and Sulfur Recovery*

Acid gas is referred to the hydrogen sulfide and carbon dioxide contained in the gas. In the gas acid removal unit, these contents are to be removed. The process mainly uses aqueous amine solution in order to absorb the acid gas. The withdrawal of this process is the methane that the gas loses along with the emission of the H_2S and CO_2. Carbon dioxide along with the methane are released to the atmosphere and some of it is recovered for the enhancement of the oil product. As for the hydrogen sulfide, because of its danger and toxicity, it is either diluted or sent to the sulfur recovery unit. Recently, new technologies are used to reduce the emission of methane and enhance the product. When the gas acid and sulphur are sent to the ninth unit, they are recovered in order to be recycled and thus enrich the product stream. In the sulfur recovery unit, the hydrogen sulfide is reacted with oxygen at the presence of a catalyst.[3] The equation below represents the reaction carried to recover sulfur from natural gas.

$$H_2S + \frac{1}{2} O_2 \rightarrow S + H_2S$$

1.3: *Dehydration and Mercaptan Removal*

Unit three is where the dehydration and the Mercaptan removal take place. The gas coming from unit two is mainly turned to sweet gas, where both H_2S and CO_2 are removed within a counter current including solfinol. Afterward, the gas is washed with water to remove any excess of Sulfur. Therefore, in unit three the gas must go under dehydration to prevent any ice blockage in the cryogenic equipment when cooling the gas down. The feedstock to unit three is wet natural gas coming from acid gas removal unit. The removal of water out of the saturated gas is very critical. This is because if the product reached the refrigeration state while it is humidified, the water would form ice which might block the pipes causing major problems.

Unit three also removes small amounts of mercaptans and other sulfur compounds within the gas to meet the total sulfur specification in the LNG product. In unit three, the dehydration is carried in co-sequence steps, each device works alone followed directly by the other one. The unit consists of three devices, two dehydrators, which consist of bed driers, and one regenerator. The period each dehydrator takes in working is eight hours per dehydrator which makes a total of sixteen hours of dehydrating. This co-sequence cycle increased the needed working hours to their maximum, 16 hours adsorption period. Since such division work, it will enable larger amount of dehydrated gas to be produced and avoid any malfunctioning or poor dehydration. The dehydration specification is to obtain a dry gas with moisture content of only 0.1 ppm (by volume). Fuel coming from both feeds gas and drum is used for both heating and cooling the molecular sieve beds. Each molecular sieve beds contains a catalytic adsorbent media used to remove the water and sulfur compounds. The sulfur compounds are adsorbed in the lower part of the bed, while the water is collected in the upper part.

After that the gas is sent to a pre-cooler. Within the pre-cooler, the treated gas comes out with an outlet temperature of 25 ˚C in order to maximize the amount of water condensate. The water and any hydrocarbons condensate are separated from the natural gas in the drier pre-cooler separator. The water is then sent to the LP, low pressure, sour gas flare and the liquid hydrocarbons are sent to the wet liquid disposal system. Next, come the regenerator, with period of eight hours, in which each dehydrator provides some amount of gas to.[4]

1.4: *Mercury Removal*

The Mercury removal unit is added early in the process. The Mercury is removed for two reasons, to enhance the product and to protect the equipments used such as heat exchangers that come later in the process. Mercury in natural gas is present as an element attached to the hydrocarbon chains.[5] The Mercury is removed using an analyzer with a gold surface trap in order to increase the of Mercury in the stream by absorbing it from the gas stream. Mercury removal is very essential in the LNG process, because it provides convenience and enhancement to the production process.

1.5: *Gas Chilling and Liquefaction*

The regenerator carries down several processes; it contains a heater, cooler and knockout drum. Due to breakthrough, off specification product, each molecular sieve bed is shifted automatically out of the adsorption mode and regenerated through a pass of hot gas stream. This regeneration will help in removing the water and other adsorbed compounds. The regenerator processes are carried as follows: depressurization for 0.5 hour, heating for 3.5 hours, cooling 2.5 hours, repressurization for 0.5 hour, and finally all three beds in the parallel adsorption mode for 1 hour. As for the knockout drum, a separation of the condensate from the gas takes place within it. Afterward, the sweet dried gas is sent to the Mercury removal unit, unit four, at which Mercury is removed from the feedstock gas. Then the gas is sent to the liquefaction unit and so forth (refer to Table 1).

In the Liquefaction unit, clean natural gas (mainly methane) is cooled within a heat exchanger. Then, the gas is introduced into a valve, Joule Thomson Valve, which reduces the gas pressure. After the pressure decreases, the temperature is brought below condensation temperature.[4] Then, the product is headed toward a low-pressure column at which the stream containing methane (LNG) is taken from the bottom; while the other streams are sent to three other heat exchangers to be extensively cooled. Afterward, the nitrogen removal comes across within the following unit.[4]

1.6: *Refrigeration*

After cooling the gas by using the heat exchanger, further cooling is needed. Thus, refrigerator is provided to cool down the gas stream up to -162 ˚C. Basically, the refrigeration cycle is achieved through four steps: expansion, evaporation, compression and condensation. In the expansion step it is required to reduce both the pressure and temperature by flashing the liquid with certain pressure. The pressure is defined in relation to the desired refrigerating temperature. The pressure is controlled using a valve. In expansion, two phases occur, liquid and vapor; therefore the vapor fraction is defined by the use of material balance. Since the vapor formed does not provide any refrigeration, heat is absorbed from the evaporation of the liquid. This occurs under constant temperature and pressure and monitored enthalpy change. The compression step comes after that. In this step the vapor released from the previous two steps would be saturated. Thus, the vapor is compressed isentropically to a certain pressure. The compressing would not be done ideally because of its efficiency. Finally, in the condensation step, the superheated stream leaving the compressor is treated. During condensation, all heat and work gained from the three previous steps must be removed. The condensing pressure will depend on the cooling medium available either by using water, air or another refrigerant. Compression is the most critical stage along refrigeration, because it is the step where most of the liquefied natural gas is produced.[6]

1.7: *Fractionation and Nitrogen Rejection*

The liquefied gas produced after refrigeration needs further processing in order to meet the product specification. What happens through the fractioning column is as follows: "Heat is introduced to the reboiler to produce stripping vapors. The vapor rises through the column contacting the descending liquid. The vapor leaving the top of the column enters the condenser where heat is removed by some type of cooling medium. Liquid is returned to the column as reflux to limit the loss of heavy components overhead."[7] In the column the entering vapor will be cooled while the entering liquid is heated; therefore, constant formation of both phases is observed along the column. Then, the heavier components that are collected at the bottom of the column are released as the bottom product. As for the light components, they are released from the top being either partially or totally condensed. To make sure that all desired material are collected, the top product is condensed and recycled to the fractioning column.[7] After fractioning, the product stream will undergo further processing at which the liquefied natural gas is purified and treated to meet specification.

For nitrogen removal, the product is installed into a unit called the "Nitrogen Rejection Unit." In the Nitrogen rejection unit, the method used is the low temperature rectification.[4] The method mainly put the vapor and liquid phases in contact at which mass and heat transfer occur. Due to the difference between the boiling points of methane, nitrogen and helium, separation of Nitrogen is possible. The resulted products from such unit would be a stream of gaseous that is rich of helium, liquid nitrogen and finally liquefied natural gas which is the desired stream.[4] The rich liquid is carried out into a low-pressure column where the final extraction of the nitrogen takes place. The rich liquid would contain only about 4% of nitrogen.[4] Leaving the desired stream, all the other streams will be either recycled to enhance the product or dumped safely.

1.8: *Helium Extraction*

After the removal of water, sulfur, nitrogen and other impurities within the liquefied natural gas, helium is finally removed. The removal of helium is classified as a chronological process. Information regarding the Helium extraction is non-descriptive and rare. Thus, it was hard to find a descriptive process of how exactly helium is removed other than using an absorber to do so. The process is considered essential because it provides one of the major helium sources in the world. In general, helium extraction includes expanding the gas, separating the helium-rich fraction, feeding the natural gas stream to a heat exchanger to be heated and extract the final portion of helium within it.[8]

1.9: *Process Risks, Hazards and Safeguard*

LNG hazards are highly dependent on the basic properties of LNG itself. Among the many potential hazards for LNG, six hazards will be elaborated briefly on its affect on the process itself. The six hazards are explosion, vapor clouds, freezing liquid, rollover, rapid phase transition, and terrorism.

Since the LNG process is under constant pressurized conditions, the potential for an explosion due to ignition is possible. Explosions occur when substances expand rapidly while changing their chemical state. Overpressure due to uncontrolled temperature control is highly unlikely due to the automated system for the plant's process. A highly likely scenario is for an external ignition source to come into contact with the process itself due to a massive structural failure for the storage tanks or pipelines. The advantage of LNG is that it is stored at atmospheric temperature where an immediate explosion is also highly unlikely.[22]

If for whatever scenario LNG leaves the temperature-controlled container, a vapor cloud will be formed when it begins to warm up and returning to its gaseous state. This vapor cloud is formed above the liquid and will begin to disperse as it mixes with the surrounding air. The major requirements for this vapor cloud to ignite are the presence of an ignition source and the vapor concentration should be within its flammability range.[22]

Freezing liquid could cause cryogenic burns to human skin upon direct contact. Damage to equipments that could not withstand freezing liquid could also occur. Basic inherent safety measures such as separating the process from other non-essential equipments and designing the tank to hold 110% of the process should prevent such events to occur.[22]

A rollover is another hazard that could occur within the process of LNG. LNG has multiple densities as throughout the process. Hence, when filled into a storage tank, these multiple densities do not mix initially and will hence form multiple layers. These multiple layers may rearrange themselves inside the tank and this is called a rollover. In other words, the lower layers would change density (due to change in temperature) to become lighter than the upper layer and may vaporize. The hazard behind rollover is that the sudden vaporization could increase the pressure inside the tank considerably higher than what the pressure control valve was designed to do. This excess in pressure could cause internal cracks in temporary storage tanks or pipes. Rollover prevention measures include constant monitoring of the LNG density.[22]

Rapid phase transition (RPT) is more specific to the shipping process and hence elaborated in that section. Other risks and hazards such as Earthquakes and terrorism is also elaborated in the shipping section.

The safeguard for an LNG process involves many layers and is summarized in the Figure 2.

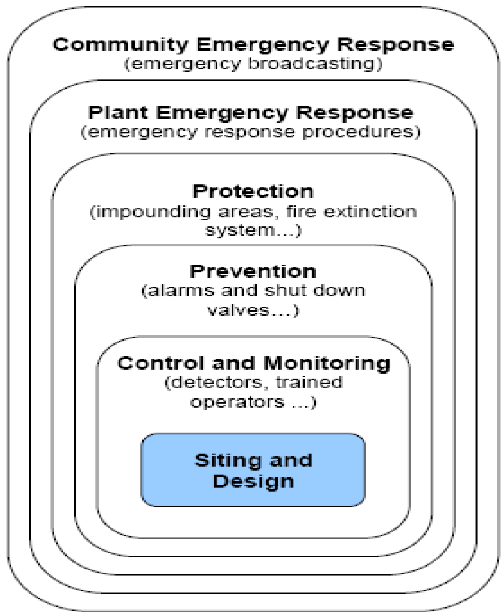


Figure2. Safety Layers for LNG Process.[22]

Standard practices advice by GIIGNL to prevent LNG leaks include compliances with stringent codes, locating facilities at a safe distance, use of specified materials, overpressure protection, leakage detection, ignition source control, fire zoning, emergency depressurizing, passive and active fire protection.[24] The most important point mentioned above is the locating procedure of LNG facilities. It is the interest of inherent safety to locate LNG facilities far away from any other industrial areas or public areas in case of a major incident. LNG facilities not only include on-shore peak-shaving facilities but also shipping berths to be located at a safe distance from the community.[24]

Risk-mitigation measures for LNG processes include spacing and design of LNG equipments such LNG tanks and pipes. Also, detectors should be placed in as many as locations possible and must be maintained properly. In case of any emergency, emergency shut-down (ESD) valves should be able to automatically close all pipelines to prevent LNG losses to the surroundings.[24] Impound areas should also exist at certain parts of the plant to contain pool fires. Fire control systems should also be present everywhere in the LNG plant as well as vapor reduction systems. Finally, on-site personnel must be sufficiently trained to handle any emergencies that might occur. A preparedness cycle provided by US FEMA can be seen in Figure 3.[24]

Figure3. Preparedness Cycle.[24]

Finally, the liquefying of natural gas is a very difficult and time consuming procedure. It mainly depends on the heat exchanger process. The separation of the raw gas to get the desired product makes it harder. Therefore, manipulating some of the inlet conditions and changing utilities might help in providing easier processing of the natural gas. Since most of the separated components have significant risks, a risk management should be carried while handling such process. Precautions are very crucial to ensure the safety of the people; therefore it must be followed and not be taken for granted.

Safety and Risk Assessments in LNG Main Parts

It is critical to encounter the need for safety guidelines in handling LNG. The LNG process begins when the natural gas is received from offshore and ends when it is loaded in the consumer tanks. All steps in between should take into consideration the hazards within them and the safety regulations that should be followed.

2.1: *Safety in Locating LNG Plants*

LNG plant is one of the biggest and multistage chemical plants. Due to all the risk associated with working in such plant, the location of it must be chosen carefully. The LNG plant is mainly consisted of one or more trains depending on the plant size. Each train consists of multi-apparatus that are referred to as units. The unit is assigned for a certain process such as cooling, extracting, fractionating or refrigerating; thus, they operate under different conditions with different safety guidelines. Overall, the LNG process encountered number of safety guidelines that emphasize on the idea of proper location. Certain factors are taken in mind when engineers are designing and locating the LNG plant. The factors are gathered based on what is referred to as the worse case design.

Optimizing the maximum security of the people is essential. Therefore, first factor to be considered when locating the LNG plant is to be far from cities and towns where large populations are located. Since LNG is a highly flammable material, it is critical to locate it in a place that does not contain any flammable material which encourages the spread of the fire. For example, LNG plant is preferred to be located in the desert rather than a place filled with trees that would spread the fire easily. Another factor that must be considered when locating the LNG plant is the toxicity of H2S which might cause large number of fatalities. The dispersion of un-expected released clouds must be studied well so that, it enables the proper choice of location to be taken. The factors represent a very essential stage that might affect the LNG production in the future. Safety of the people always comes first; therefore, it is important to cover every hazard and all the risks encountered when locating LNG plant at specific place.

Furthermore, explosions also must be taken into consideration when locating the plant. This is because explosions resulted from high pressures are dangerous and may cause the greatest harm if the LNG process is placed improperly. Offices are usually located near plants for the convenience of transportation; yet, this is not safe. All incidents and accidents resulted from the previously mentioned reasons and many others might occur and eliminating them is hard; thus, the best way to deal with them is by minimizing their harm as much as possible. In order to minimize the risk of locating offices close to the LNG plant, fair distance must be taken in between. Recently several software have been created to encounter the consequences regarding chemical disasters. The software enable the user to input worst case values in terms of leaking or explosions and estimate the damages associated with the conditions. One of these software is Phast. Phast allows the user to input certain conditions and assumptions to estimate the range at which a certain degree of harm would occur. This software is important because it provides an indication of how far the damage might reach clarifying at which degree. For example, for very far distances the explosion effect might get less; thus Phast provides an estimate for the ranges at which the explosion would be most harmful, harmful and least harmful. The Phast works best in estimating consequences of dispersions. After defining where to locate the LNG plant safely, how safe would the operation be must be investigated also.

2.1-1: *Phast Simulation*

Just like Phast, FLACS is a leading CFD tool in modeling three-dimensional dispersion such as gas explosion, gas dispersion, and dust dispersion for different scenarios.[27] FLACS is a very useful validation model especially for the Burro, Coyote and Maplin Sands experiments. An example three-dimensional model from FLACS can be seen in Figure 4. The scenario for Figure 4 is a release of 1000kg/s of LNG from a cylindrical tank unto the ground.[27] The left column shows a sequence of events for the liquid LNG spill while the right column shows a sequence of events showing the dispersion of methane vapor cloud volume above the liquid pool. The sequence of events is within 200 seconds for an interval of 25s, 50s, 100s, 150s and 200s. The distance travelled by the LNG was no more than 400m within this time frame.[27]

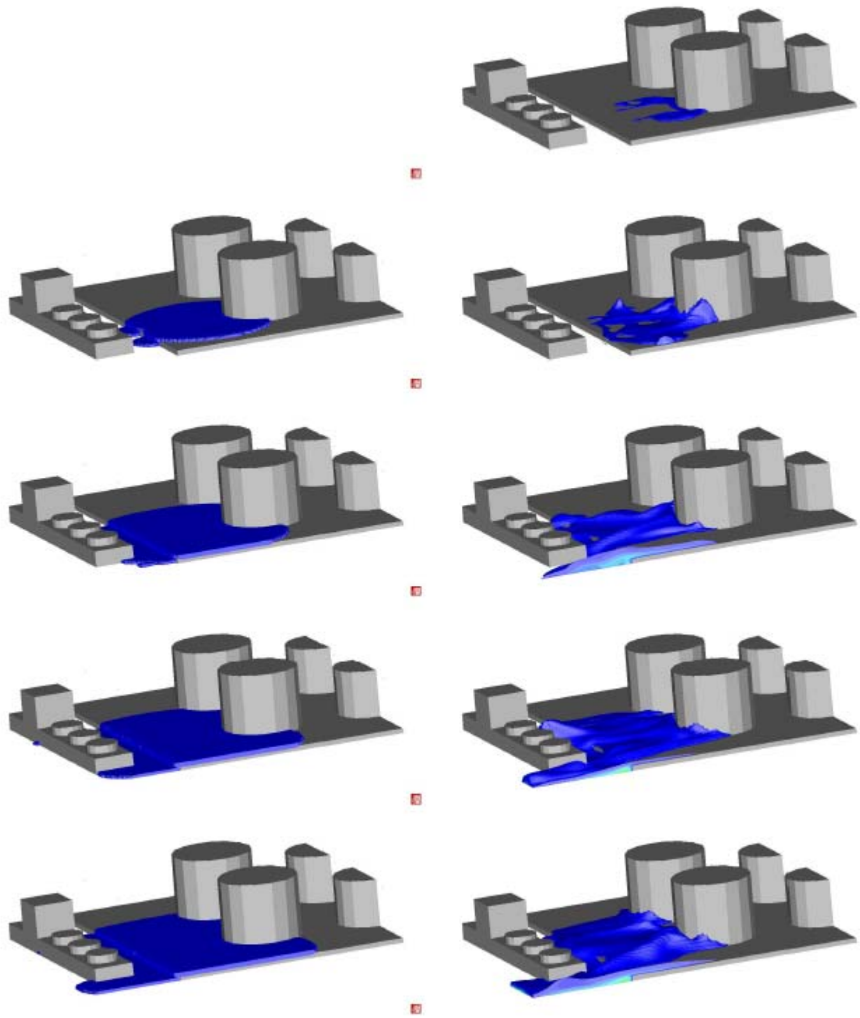


Figure 4: Sequence of Events for a LNG Spill from Cylindrical Tank[27]

2.2: *Safety in Process Operation*

For the operating section of LNG, several operating characteristics will be discussed. The main characteristic is that LNG temperature is kept by good insulation and pressure control. This is because LNG has a heating and cooling device. These two devices are controlled by a temperature control device. The insulation will not keep LNG cold enough by itself, but the heat leakage will warm and vaporize the LNG. Because the insulation is very efficient, only a relatively small amount of boil off is necessary to maintain temperature. The most practical thing to do in industry is to keep storing LNG as a boiling cryogen. Boiling cryogen of a liquid is defined as “liquid with a normal boiling point for the pressure at which it is stored which the atmospheric pressure.”[9] Another characteristic is that LNG should be stopovers of 1 to 2 days for both loading and unloading which correspond to 10,000 to12,000 m^3/h.[10] A specific duration is important for the operation stage where the process should be stored for a current time before operating. In addition, all tanks kept under cold temperature (below -90 °C) at all times except for drydocking which is every 2.5 years as an average or maintenance.[10] Drydocks are usually used for the construction, maintenance, and repair of ships, boats, and other watercraft.

2.2-1: Risk Assessment in LNG Process Operation

LNG is stored as a pressurized liquid at very low temperatures value between the range of -130 to -160°C (-200 to -260°F), so it include the risk of skin and eye burns on contact.[11] Hazards need to be identified and quantified in terms of the impact they will have on different applications and designs. This could be done by collecting from existing resources all of the phenomenological data on LNG into a single report, then identify all of the accident-initiating events using master logic diagrams, failure modes and historical operating experiences. In addition a perfect training, proper Personal Protective Equipment (PPE) should be provided for the employees to prevent accidents. In general, a qualitative risk assessment reduces the effort and expense by focusing on only the important safety issues.[16] Because of the importance of the training, the paper will discuss the several training courses provided by the oil and gas companies.

2.2-1-1: <u>Training</u>

It is considered as the most important step before begging the carrier in any oil and gas company. Several training courses are provided for the employees where they get a comprehensive instruction about all facets of the Liquefied Natural Gas (LNG) industry. Also, the understanding of LNG facility operations from the process point of view and the reasons for the rapid expansion and advancement of the industry should be provided.[12] Several studies conclude that most workplace injuries are preventable. Companies are required to avoid any injuries to their personal to the best of their abilities.

Proper personnel training regarding their use of Personal Protective Equipment (PPE) is a crucial practice to ensure high levels of safe environment during LNG operations. In addition, most of these safety courses focus on the risk associated with the process such as the H_2S gas, LNG leak, equipment failure and many other hazards associated with the process. H_2S training courses are the most important course provided due to the important of that hazard (H_2S).

- *H_2S Gas in LNG*

As it mentioned before, hydrogen sulfide is part of the acid gas along with carbon dioxide. H_2S is the chemical symbol of Hydrogen Sulphied which has other names like sour gas, acid gas and sewer gas. H_2S gas is colorless material, highly toxic, odor of Rotten Eggs at low concentration, highly corrosive to certain materials, dissolve into any liquid, burns with a bluish flame and forms SO_2 and forms an explosive mixture with air/oxygen.[13] All of these characteristics make the sour gas as an environmental and operating safety problem that can occur in the handling of liquid sulfur produced. For example, in the workplace it is leading cause of sudden death. H_2S concentrations vary and the effect of the concentrated gas with time exposure is shown in Table 2.

Table2. H_2S Concentration and Time Exposure[13]

Material	**Concentration/ ppm**	**Time Exposure**
H_2S	10	8 hours
	15	15 minutes
	20	No time

From Table 2, for the 20 H_2S concentration, no job at this concentration without Breathing Apparatus (BA).[13] Therefore, there is a Time Weighted Average (TWA) where the workers may be exposed to acid gas on an 8 hours per day/ 40 hour per week basis without long-term health effects is 10 ppm.[13] Due to the effects of H_2S gas to health, environment, corrosive, fire and explosion several prevention steps are taken by the oil and gas companies. These preventions were listed in companies to ensure the safety regulations for the employees. Table 3 shows H_2S hazards and the right prevention steps as well as the first aid associated with each hazard.[13]

Table3. H_2S Hazards and its Preventions[13]

Hazards	**Prevention**	**First Aid**

Fire: highly flammable	No open flames No sparks No smoking	Shut off supply; if not possible and no risk to surroundings Let the fire burn itself out
Explosion: gas-air mixtures are explosive	Closed system Ventilation Explosion protected electrical equipment and lighting Connect to earth Reduced sparking hand tools	Keep cylinder cool by spraying with water
Inhalation: sore throat, coughing headache, dizziness, unconsciousness, labored breathing	Ventilation Local exhaust or breathing protection	Fresh air Rest Half upright position Transport to a doctor
Skin: frostbite, redness, pain	Cold insulating gloves	Do not remove clothes Rise skin with plenty of water or shower Transport to hospital
Eyes: frostbite, redness, pain, blurred vision	Face shield or eye protection in combination with breathing protection	First rinse with plenty of water Transport to a doctor if necessary

2.2-1-2: Personal Protective Equipment (PPE)

Personal Protective Equipment (PPE) refers to protective clothing, helmets and goggles to protect human's body or clothing from injury by electrical, heat, chemicals, and infection hazards, for job-related occupational safety and health purposes.[14] In addition, PPE can be used to protect the working environment from pesticide application, air pollution or infection from the worker. Personal Protective Equipment is the last but not the least step to protect the employees in work. However, almost every company developed PPE policy in which all their employees are required to wear proper PPE in work for safety requirement.[15] Everyone in the facility from line workers to department chairpersons should receive some level of safety training, depending on their responsibilities and presence within the various production areas.[16] The basic Personal Protective Equipment consists of head protection, hearing protection, eye and face protection, RXE prescription eyewear, respiratory protection, chemical resistant clothing, hand protection, foot protection and janitorial and site equipment.[17] Figure 5 shows a simple PPE for a chemical plant.

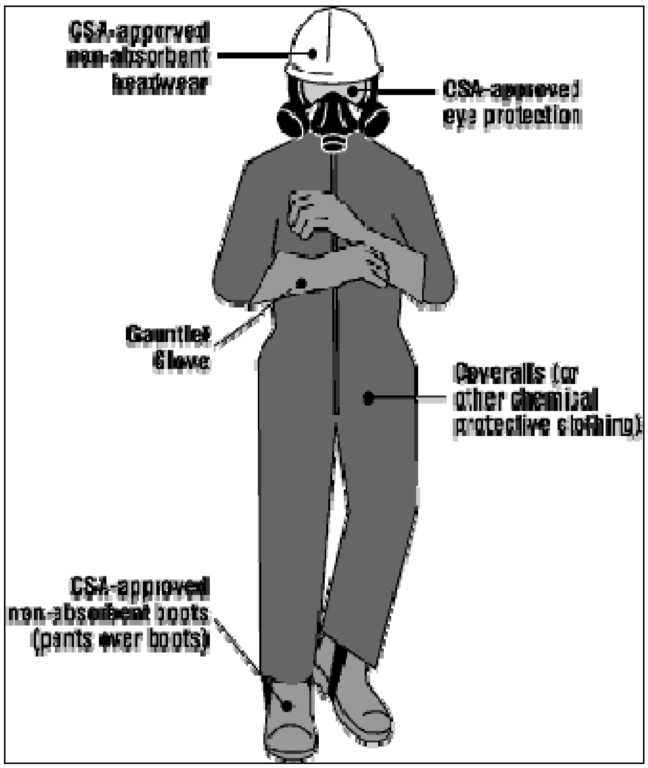


Figure5. Proper Personal Protective Equipment[16]

Personal protective equipment (PPE) is used to reduce exposure to hazards and reducing these exposures to acceptable levels.[14] Risks to personnel will in turn affect the output of the LNG plant. “Educating employees about the benefits of PPE empowers them to make the right choices in using protective equipment and protecting themselves from job-related hazards”.[16] Personnel training will affect a company's output postively by reducing the costs associated with workplace injuries. The cost of an injury is much more expensive than the initial medical treatment for any injured employee. Furthermore, PPE can have a positive impact on insurance premiums as well as maintaining a healthy safety culture.[16]

2.2-1-3: Emergency Response

Several steps are taken when an emergency case occurred in the process or the company. For example, employees should move to a safe area either crosswind or upwind as required. The emergency should be reported directly using one of the following: Radio to MCR, Main Control Room, Pull Manual Alarm Pullbox, red color only, or call a fire station at 7777.[13] This emergency action is for QatarGas only, other companies have different procedures but similar. The most important thing in reporting an emergency is know the exact location. For example, know the location if it is upstream or downstream, the process train number and the utility close by. Also, the nature of the emergency such as fire, gas leak, spill and accident should be specified. In addition, individual information like the employee's name, company and staff number are important information. Almost all the companies provide a safety showers and eye wash station within the facilities. In order to have the safest process and environment, all the regulation and steps should be followed to reduce the injuries and accidents.

2.3: *Safety in LNG Storage*

There are various types of LNG storage tanks, but the choice of the storage depend on the safety and operational consideration such as plant location, engineering design standards, code requirements and layout constraints. LNG storage can be classified as either aboveground or belowground storage. However, for the liquefaction plants, the aboveground classification is used where the LNG tanks can be classified into three main types; single containment tanks, double containment tanks and full containment tanks.[10] Each of these tanks has their unique characteristics. For the three types, Liquefied Natural Gas (LNG) is stored in storage tanks of around 160,000 m^3 capacity at just above atmospheric pressure.[10]

2.3-1: Above-Ground LNG Tanks

2.3-1-1: *Single Containment Tank*

There are three main types of LNG tanks. First, single containment tank can be defined as a tank comprising an inner tank and outer container designed and constructed only for the inner tank to meet the low temperature ductility requirements to storage LNG. For the single containment tank the material used in contact with LNG could be either 9% nickel steel or aluminium 5083, pre-stressed concrete.[10] The unique about this type is that it either required dike such as P.T Badak or it might not required dike such as Kenai. In addition, there is a range of concentration through bottom and the shell. Figure 6 shows a simple deign of single containment tank.

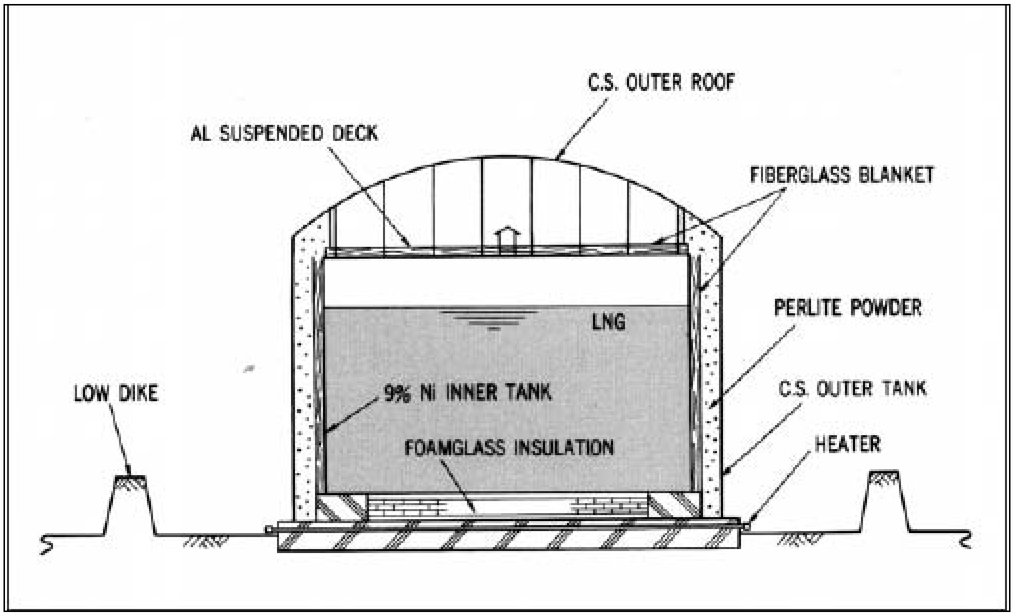


Figure 6. Single Containment Tank.[10]

There are some restrictions regarding the impoundment location of the tanks especially the single containment tanks. For example, the minimum distance from edge of impoundment to building or property line should be 0.7 times the tank diameter but not less than 100 ft. The minimum distance between storage containers should be 1/4 of the sum of the diameters of adjacent containers with minimum of 55 ft. The minimum distance to property line is calculated by the radiation levels of 5, 9, or 30 kW/m^2 and different spill rates depending on type of buildings beyond the property line.[10] Single containment tanks have operated worldwide without major incident for over 30 years in location.[18]

2.3-1-2: *Double Containment Tank*

The double containment tank is a tank designed and constructed so that both the inner tank and the outer tank are capable of independently containing the refrigerated liquid stored.[10] The tank design has a freestanding 9% nickel inner tank and an outer made either of pre-stressed reinforced concrete or poured in place reinforced concrete strengthened by an earthen or rock embankment.[18] There are some differences between the two types of tanks mentioned. For example, double containment tanks requires less plot area than single containment tanks due to outer wall material used, concrete. Also, the cost of the double tank is 40% higher than the single tanks.[18] Figure 7 illustrates a double containment tank.

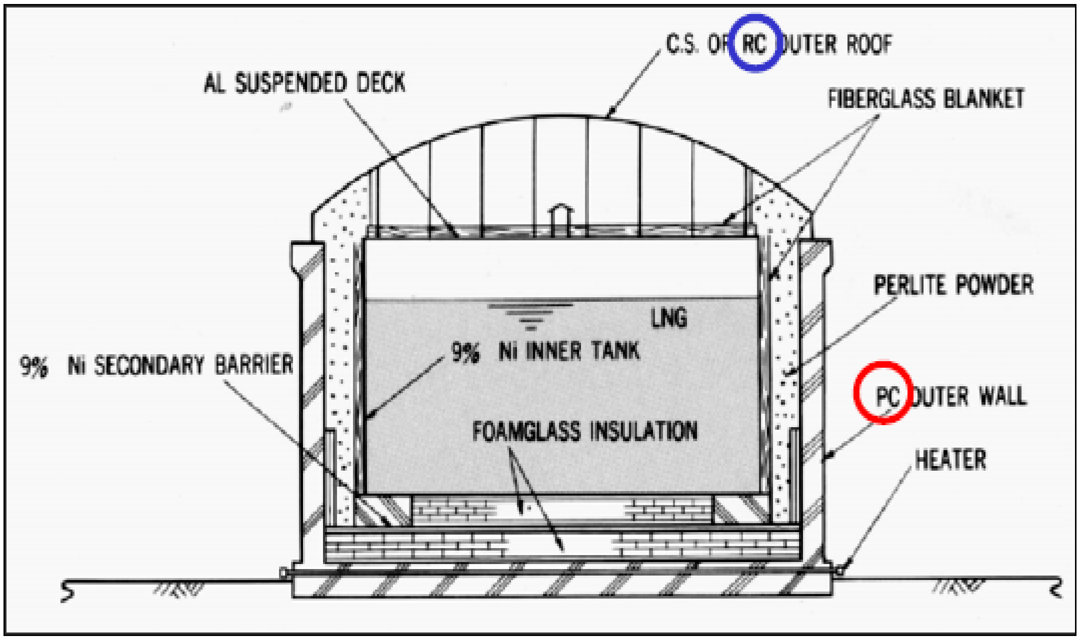


Figure 7. Double Containment Tank.[10]

2.3-1-3: *Full Containment Tank*

The final type is full containment tanks where they have almost the same design as double containment tanks except that the design added a concrete roof to the double containment tank's concrete outer walls. This type of tanks provides the greatest design integrity and allows the closest spacing between tanks and process equipments.[18] Comparing the cost of the three tanks, the full containment tanks are the most expensive design which is about 50 percentage higher than the single containment tanks.[10] Figure 8 shows a full containment tank structure.

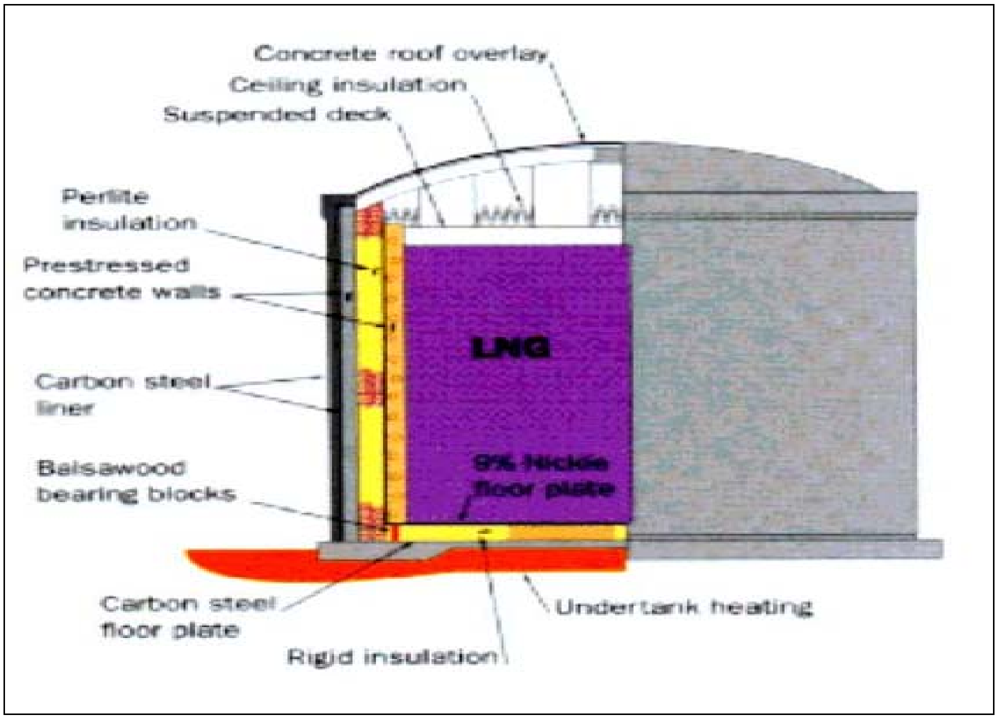
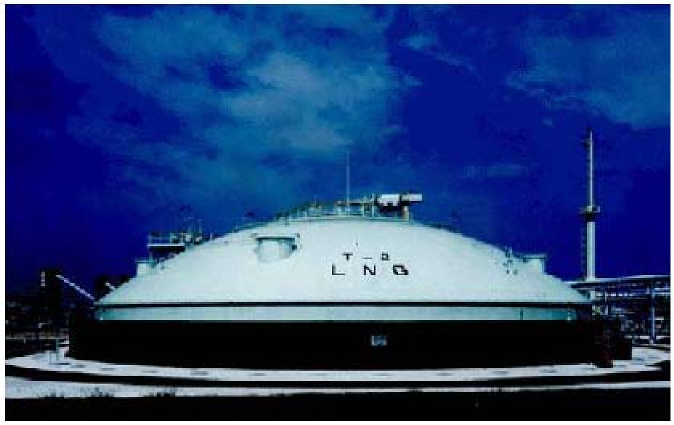


Figure 8. Full Containment Tank.[10]

2.3-2: Below-ground Storage Tanks

These types of tanks are typically more expensive than the above-ground tanks. The main benefit for locating the tanks below-ground is to create a surrounding that is more eye-pleasing. Of the many below-ground storage tanks, the in-ground storage tanks, the underground LNG storage tank, and the underground in-pit LNG storage tank are the most popular.[22]

In-ground storage tanks can be identified by its roof above the ground. Japan is particularly popular with these tanks currently having built 61 of them, one which is the largest in the world with the capacity to hold 200,000m^3 of LNG. Underground LNG tanks however are completely buried in the Earth and are well known for their concrete caps. This design allows the surrounding landscape to be adjusted to be aesthetically more pleasing (see Figure 9).[22]



Source: www.takenaka.co.jp

Figure 9. T-2 Tank at Fukukita.[22]

Last but not least, the underground in-pit storage tank utilizes a double metal shell for its inner and outer tank. What makes this tank unique is that dry nitrogen fills the space between the inner and outer tank to provide higher insulation between this tank and the ground. Figure 10 shows an underground in-pit storage tank.[22]

Source: SIGTTO

Figure 10. In-pit storage Tank.[22]

2.3-3: LNG Storage Potential Hazards

There are various potential hazards associated with the LNG storage tanks. First, the greatest concern for the LNG storage is with the release of a large amount of LNG or its vapor due to the mechanical failures of main tank and its equipments or the failure of various components.[10] Leakage might occur from the inner tank wall where it has a huge impact on the layout for the single and double containment types. On the other hand, liquid may impact on the outer tank in the case of LNG leakage. The liquid tightness must be guaranteed by the corner protection system as well as the polyurethane foam coating installed on the inside surface of the concrete wall.[10] The concrete outer tank protects the inner tank in case of emergency coming from the outside. The bottom heating system is installed in order to avoid frost heave.[10]

Second, the impact from "missiles" on the outer tank or which means heat from adjacent tank is another hazard. If the material used for the outer tanks is metal, it would resist to "flying object" of 50 kg at 45 m/sec where if the outer tank was made of pre-stressed concrete, it would resist to "flying object" of 1500 kg at 50 m/sec^3.[10] Third, adjacent explosion might a concern regarding the storage hazards. It is known that LNG is stored at atmospheric pressure, unless LNG is under pressure, where it is being pumped through a pipe, it will flow and evaporate if the containing vessel leaks, rather than escape as a rapidly expanding vapor cloud. LNG spilled in the open is therefore slow to mix with air into a combustible concentration. If ignited, therefore, spilled LNG will tend to burn only at the evaporating edges of the pool. The leak will cause an explosion with another tank which causes a potential hazard.

Fourth, a puncture of a bottom due to pump falling down or roof damage by pump during maintenance is another hazard associated with LNG storage tanks. Fifth, a sudden variation of atmospheric pressure is another concern. For example, when a storage tank containing LNG is filled with different-density LNG, stratification may occur. It might results in rollover accompanied by a sudden release of large amounts of BOG (Boil off Gas), which causes rapid tank-pressure rise and sometimes damage to the tank.[19] Gas accumulation between piles occurs when void under tank bottom. This hazard requires a layout of piles and shape of the tank bottom to be such that no gas accumulation can occur below tank.

Also, a tank overfilling is a potential storage hazard. When filling a tank with LNG, a balance must be struck between filling the tank to a liquid level such that there is an appropriate amount of vapor space to be pressurized as the tank absorbs heat from the environment, and there is a need to provide a sufficient amount of vapor space to allow the tank to have a sufficient holding time.[20] If the tank is overfilled, there is not enough vapor space left in the tank to allow the tank pressure to increase without venting due to heat absorption from the surroundings. It would cause the pressure inside the tank to reach the relief pressure before the predetermined hold time has expired, thus causing LNG to vent into the atmosphere through a the relief valve.[20] The final hazard but not least, sloshing is a major hazard associated with LNG storage tank. It requires a specific study to be carried out in seismic area.

2.3-4: LNG Storage Accidents

There are many accidents occurring due to the leakage of the LNG from tanks. For example, in 1944, especially in Cleveland, Ohio, a tank failed and spilled its contents into the street and storm sewer system. The resulting explosion and the fire killed 128 people. The tank was built with a steel alloy that had low-nickel content, which made the alloy brittle when exposed to the extreme cold of LNG. The resulting increase in pressure inside the tank was so fast that the concrete dome on the tank lifted and then collapsed down inside the tank killing the 37 construction workers inside.[21] Another accident happened in 1979 in Cove Point, Maryland where a natural gas leak caused an explosion

killing one plant employee and seriously injuring another and causing about $3 million in damages.[21] Several other accidents happened and most of them are reported.
Multiple safety layers are involved in safely containing LNG in side a storage tank. Figure 11 provided by SEA Consulting Inc. summarizes the safety layers in one diagram.[22]

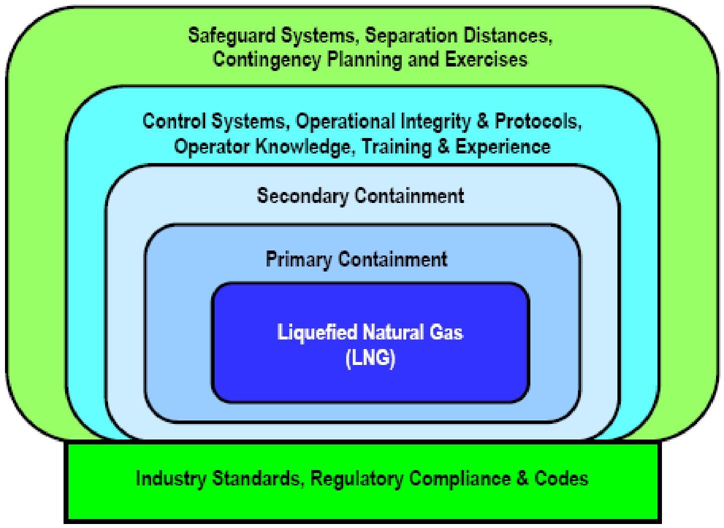


Figure 11. Multiple Safety Layers for Containments.[22]

The whole point of primary containment means the safe storage and isolation of cryogenic LNG. Primary containment requires the knowledge of materials at different temperatures and pressures. The materials that come into contact with LNG such as pipes and tanks should be able to withstand super-cold temperatures.[22] High alloy steels used to construct the inner tank of LNG tanks are normally made up of 90% of nickel and stainless steel. These alloys are necessary despite their high purchasing costs. Shell provides an illustration of a tank design and can be seen in Figure 12.[22]

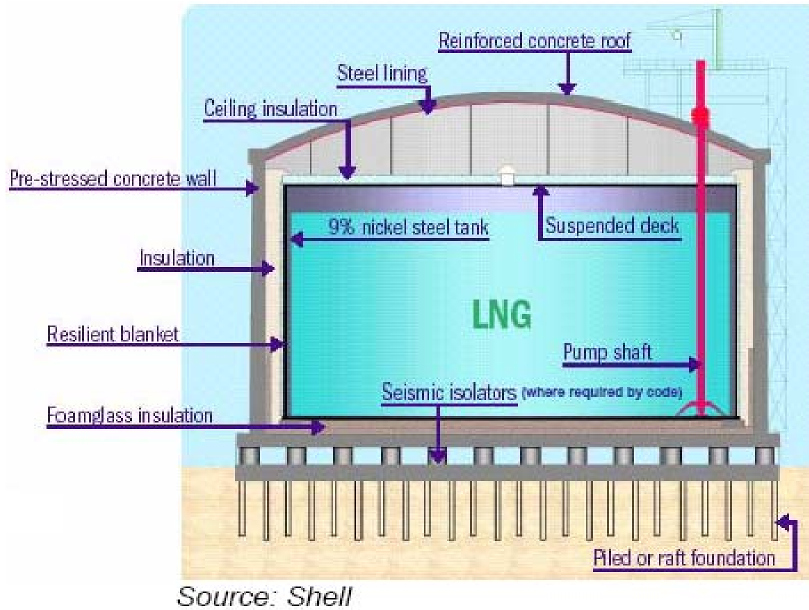


Figure 12. Basic Tank Design.[22]

An example of a primary containment includes the aforementioned single containment tanks. The inherent safety designs for pipes are located in the top of these tanks to prevent any liquid siphoning when piping systems are malfunctioning. When primary containment fails, secondary containment would take into effect to prevent any further leaks of LNG.[22]

Secondary containment includes the aforementioned double containment tanks, the aforementioned full containment tanks, dike, berm or dam impoundment to contain any leakage. Dikes are designed to contain around 110% of the total tank volume and also are designed to be high enough so the upper part of the liquid would not splash out of the dike. Due to large dikes, LNG storage facilities require massive isolated land areas for impoundments.[22]

Safeguard systems for storage tanks include detecting LNG releases such as methane detectors, fire detectors, and vapor level detectors. CCTV cameras would provide constant monitoring of any potential leakage areas.[22] Although the probability of leakage due to the use of sub-standard materials is highly unlikely, fire-fighting systems (such as foam systems and nitrogen purging) should be installed throughout the surrounding tank areas to contain any resulting pool fires.[22] All on-site personnel should be adequately trained to help activate any emergency protocols required to avert any potential disaster.

The separation distance policy an important part of the safety layer and is described in detail in the Locating section.

2.4: _Safety in LNG Shipping_

Tankers that carry LNG are ships that possess double-hulls designed and insulated specifically to contain LNG safely and efficiently. The containment system aboard these ships allows LNG to be stored at atmospheric pressure and cryogenic temperature while preventing any leakages in the event of an accident.

2.4-1: *Overview*

Modern standards reveal three major designs for LNG ships and they are the spherical Moss Rosenberg tanks, membrane tanks and the structural prismatic design (see Figure 13).[23] Traditionally, LNG ships employ the use of the Moss Rosenberg design and can be easily identifiable with their massive top half sphericasl shaped protruding out of the ship's deck. Nowadays, membrane design is beginning to take their place as the market-leading ship in the LNG shipping sector.[23]

Figure 13. Three Main LNG Ship Designs[26]

In 2002, the Moss Rosenberg design account for 52 percent of the total LNG ships in the world. However, this fraction decreased to 44 percent by 2006 (see Figure 14).[23]

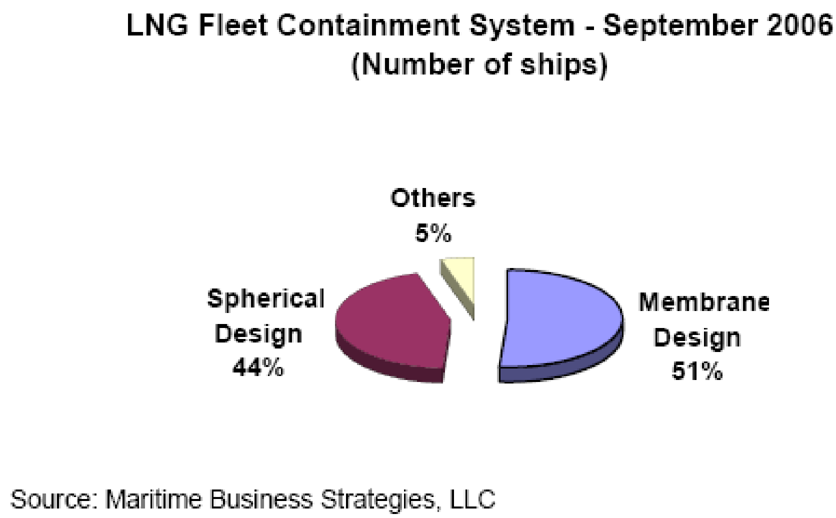


Figure 14. LNG Fleet Containment

The number of orders by 2010 also serves as prove that the shift towards membrane design is occurring (see Figure 15).[23]

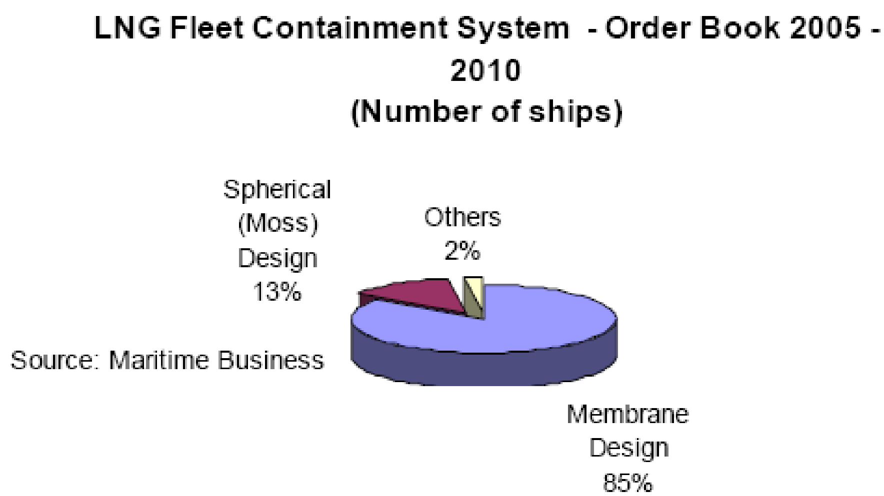


Figure 15. LNG Fleet Containment Order Book by 2010

Traditionally also, LNG carriers carry about 125 kilo cubic meters (KCM) of LNG that can provide about 3.0 billion standard cubic feet of natural gas. These 900-feet ships generally cost $160 million to build are sized about the same as a typical nuclear-powered aircraft carrier and much less polluting due to their propulsion system.[23]

Membrane tanks' interiors are composed of primary and secondary thin plates called membranes that are rigidly supported by an insulation system. These membranes are cannot support themselves although they provide for liquid containment and subjected to many kinds of dynamic fluid loadings. This type of insulation simplifies hull design to allow for thermal expansion because both the hull and tank are integrated together to increase efficiencies. Korea is the leader in LNG ship construction due to their ability to design this type of ships.[26]

Moss Rosenberg spherical shells provide liquid containment provides for external insulation and carries no liquid load. The extruded stainless steel skirt at equator between the hull and shell serve as transfer for the load. The external shell further protects the tank's insulation from various external elements. This design has a taller structure than the other two designs and would mean certain sailing restrictions under bridges and higher taxes through the Suez Canal. Nonetheless, the design is very cost-competitive with membranes.[26]

The structural prismatic or semi-prismatic tanks are self-supporting tanks within a ship's hull. These carriers are constructed using conventional methods and would mean higher building costs. The interior aluminium shell provides for the liquid containment and the insulation is not subjected to local liquid impact. A very sophisticated interface design allow for the insulation to accommodate load transfer between interior shell structure and the hull. This inefficient design is getting less popular by 2010. Figure 16 shows the three types of tank designs.[26]

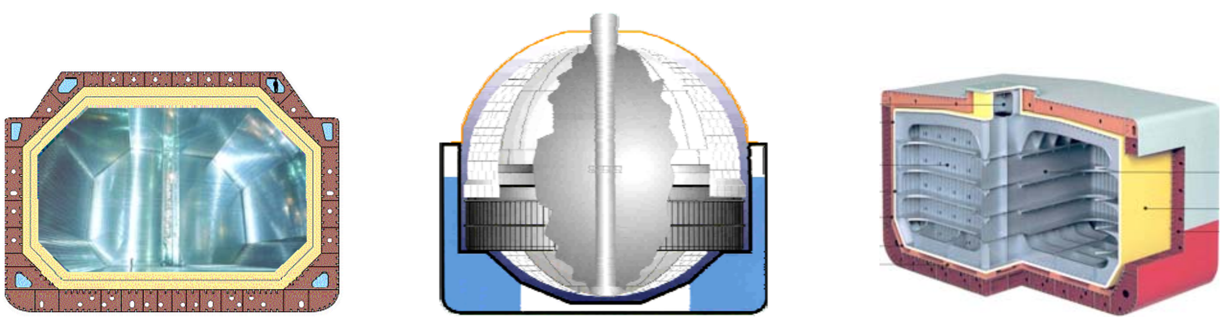


Figure 16. Three LNG Tanks (from L-R: membrane, Moss Rosenberg, & Prismatic)[26]

Typical requirements for all LNG ships in the market must be able to reach Japan and obey Japanese maritime laws including any environmental concerns, yet be flexible enough to accommodate different types of receiving terminals around the world. To increase the efficiency of the steam turbine drive system, the LNG ship boil-off gas is used as fuel to the ship's boilers. As stated before, conventional LNG ships are in the range if 130 to 150 KCM and cost reduction is possible if larger ships can carry around 200 to 250 KCM. Studies by ExxonMobil and their Korean counterparts indicated that the scale-up of membrane tanks is much more feasible and safer than the other two designs due to the membrane's internal insulation and structural integrity. However, this called up for new ship-building methods and the Koreans excelled in meeting market requirements. This resulted in the design and constructions of Q-Flex Membrane LNG ships and the Q-Max Membrane LNG ships that could carry 200 KCM and 250 KCM respectively (see Figure 17).[26]

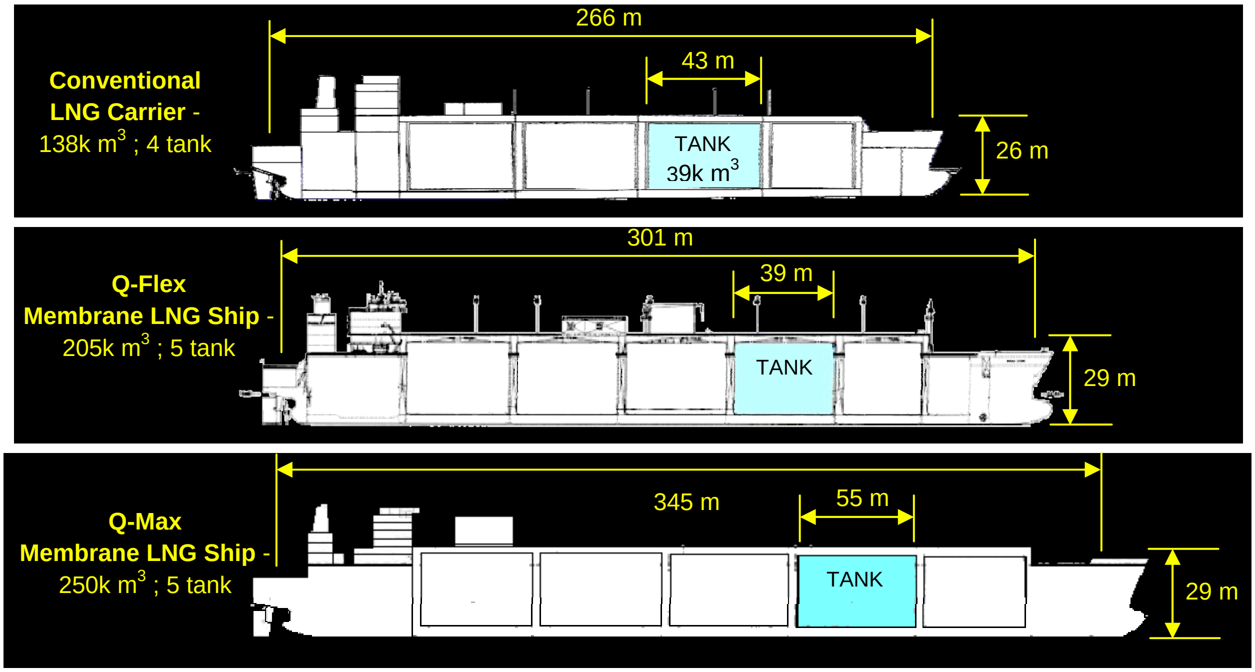


Figure 17. Size Comparison of LNG Ships[26]

Efficiency can be achieved not only by increasing containment size, but also by aiming for a cleaner propulsion system and its fuel. Fuel accounts for around 15% for LNG shipping cost alternate propulsion systems such slow-speed diesel or dual-fuel diesel with electric motor provide 40% and 50% higher thermal efficiency respectively. Steam propulsion also consume the boil-off gas, the gas the boils continuously due to the heat transfer through tank insulation and is required to avoid over-pressuring the tanks. A typical 10000 nautical mile trip will lose 3% of its cargo due to boil-off.[26]

To ensure 100% cargo delivery, reliquefication process is integrated into the ship's hull to refrigerate boil-off gas to turn back to LNG and the tank pressure can be controlled by a newer control system instead of relying on boil-off gas to occur. This system would mean that steam turbines can be replaced by the more efficient slow-speed diesel (despite consuming 10% more heavy fuel than steam turbines, this is offset by the savings of the boil-off gas).[26]

2.4-2: *LNG Cargo Tank Risks, Hazards and Safeguard*

A scenario regarding safety during shipping can be when there is a breach LNG tank due to collisions with other vessels or accidental tank breaches (which is highly unlikely). The breach of LNG tanks can be influenced by four factors, namely: impact type, location and energy; vessel geometry; tank type; and LNG characteristics. If a puncture were to occur in a Moss Rosenberg tank, LNG, under its own weight, will flow out to fill the void beneath the sphere before going out into the sea (see Figure 18).[25]

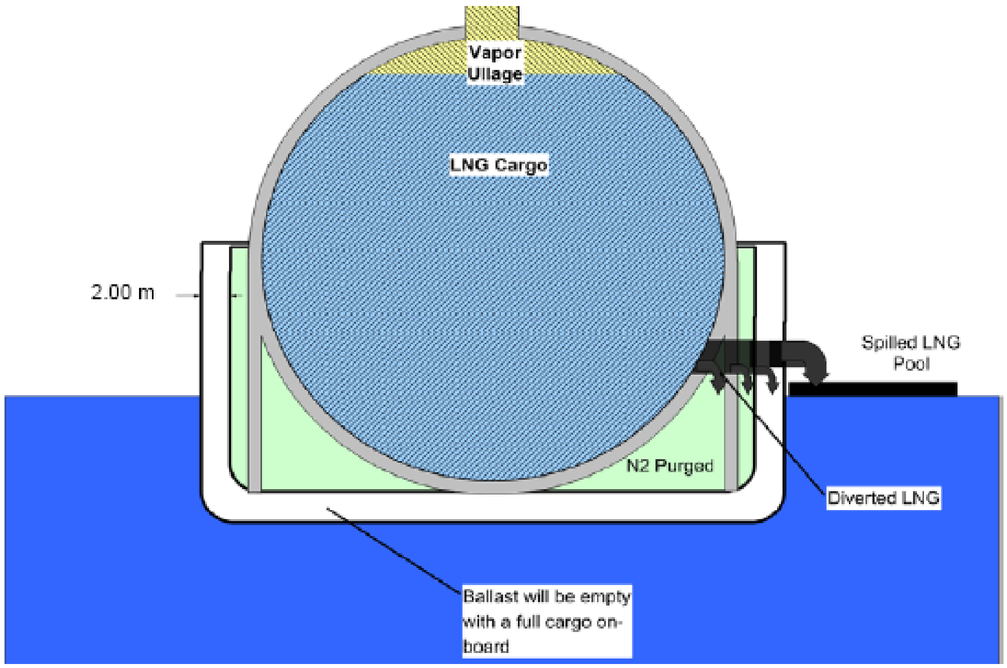


Figure 18. LNG Spill over Water from a Moss Rosenberg Tank[25]

The dispersion analysis of LNG is a huge topic and will not be discussed in this topic. As a summary, depending on the scenario, LNG can be expected to spill on the ship's deck, inside the ship or to the open water or both. The wide range of potential hazards from an LNG spill over water can be asphyxiation, cryogenic burns, structural damage, thermal damage, fireballs, air explosions or rapid phase transitions (RPT).[25]

LNG, which is largely methane, has low toxicity content but also can be an asphyxiant. Massive cryogenically-cooled release of liquid LNG would begin to vaporize into the atmosphere. Assuming that no ignition occurs, the high LNG concentration in the atmosphere should be enough to asphyxiate ship personnel due to oxygen deficiency. However, the probability of such event is overshadowed by the probability of fire concerns due to the flammability limits of methane.[25]

The same cryogenically-cooled release of liquid LNG would also mean that cryogenic burns are possible upon contact with the human skin. Also, this very low temperature liquid can affect the ship's structural integrity such the metal welding. A weak structural integrity could cause the ship to break apart into pieces and may sink the ship along with its crew and precious cargo.[25]

A fireball occurs when a vapor cloud will cause the vapor to burn back to spill source and this happens at subsonic velocities. This means that a fireball is a type of deflagration, where rapid combustion occurs through mixed air and fuel in the atmosphere at subsonic velocities. Supersonic velocity combustion is called detonation. However, if the mixed air and fuel vapor cloud is trapped between the ship hulls or in any enclosed space, a high pressure ignition could cause a rapid acceleration in combustion that can be defined as an air explosion. An air explosion is normally localized and would less probable in causing extensive structural damage.[25]

Another type of hazard that would not cause structural damage is the rapid phase transition (RPT). This occurs when the cold liquid would enter its superheat limit and progressing to a spontaneous and explosive boiling of the very cold liquid. Overpressure releases due to RPT occur when a super-cold liquid such LNG comes into contact with warmer liquid such as seawater. Damage from this event tends to be very limited near to the spill area.[25]

Prevention and mitigation of these hazards are possible. Prevention is action to avoid an accident while mitigation is an action to reduce the aftermath of an accident. Figure 19 summarizes the prevention and mitigation strategies while Figure 20 summarizes examples of prevention and mitigation strategies for potential threats to LNG ships.[25]

PREVENTION	MITIGATION
ISOLATION ▪ physical separation (distance) ▪ physical barriers ▪ keep-out or exclusion zones (buffers) ▪ interrupted operations (aircraft, bridge traffic)	RECOVERY OPERATIONS ▪ plans in place & current ▪ equipment & people in place & ready ▪ drills ▪ evacuation plans
VOID SPACES WITH INERT GAS	MAINTAIN MOBILITY (tanker + towing)
INERTING OF VOID SPACES	LIMIT SPILL AMOUNTS & RATES
VARIED TIMES OF OPERATIONS	SECURITY EMERGENCY RESPONSE FORCES
INTELLIGENCE ▪ communication links in place & ready ▪ timely updates ▪ interagency communication links	FIRE-FIGHTING CAPABILITIES ▪ leak detectors ▪ deluge systems ▪ radiant barriers (high-pressure high-density foam systems) ▪ backup fire fighting capabilities
INCREASED MOBILITY (tugs)	REDUNDANT MOORING & OFFLOADING CAPABILITIES
ARMED SECURITY ESCORT (boat, aircraft or on-board)	OFFSHORE MOORING & OFFLOADING CAPABILITIES
SWEEPS (divers, sonar, U.S.CG boarding)	SPEED LIMITS
SURVEILLANCE (on-ship, on-land, underwater & aerial)	CRYOGENICALLY-HARDENED VESSEL
EMPLOYEE BACKGROUND CHECKS	SHIP ARMOR, ENERGY-ABSORBING BLANKETS
TANKER ACCESS CONTROL PROGRAM	MISSILE DEFENSE SYSTEM
STORM PREDICTION & AVOIDANCE PLANS	REDUNDANT CONTROL SYSTEMS
SAFETY INTERLOCKS	BACKUP FUEL SOURCE (oil)

Figure19. Prevention and Mitigation Strategies[25]

SCENARIO	TARGETS	MECHANISM	POTENTIAL CONSEQUENCES		RISK REDUCTION MEASURES	
			LOCAL	CASCADING	PREVENTION	MITIGATION
Ramming	Fixed targets afloat or ashore	Mechanical distortion	Fire & ship damage	Large-scale fire	▪ Control of ship ▪ Increased mobility ▪ Tug escort	▪ Absorbing barriers on fixed targets ▪ Fire-fighting capability
Triggered Explosion	Fixed targets afloat	Pre-placed, coordinated explosion	Ship damage	Large-scale fire, blockage of waterway	▪ Early interdiction and surveillance ▪ Sweeping ▪ Intelligence ▪ Control of ship	▪ Emergency response force ▪ Evacuation plans ▪ Towing option
Insider Takeover or Hijacking	Fixed targets afloat or ashore	Standoff & negotiation, or explosion	Elevated public concern or fire & ship damage	Public demands to cease operations or large-scale fire	▪ Early interdiction & searches ▪ Control of ship ▪ Employee background checks	▪ Emergency response force ▪ Evacuation plans
Terrorist	Target afloat	Vessel carrying explosives	Fire & ship damage	Large-scale fire and blockage of waterway	▪ Security zones ▪ Safety halo around ship ▪ Intelligence	▪ Emergency response force ▪ Evacuation plans ▪ Towing option

Figure 20. Prevention and Mitigation Strategies Specific to LNG Ships[25]

Terrorism is a risk that cannot be controlled and is very different from other risks such that it is much unexpected. In the United States at least, safeguard exists against terrorism to protect LNG facilities especially the very vulnerable LNG ships. Due to the high energy requirements to penetrate the double-wall of a storage tank or the double-hull of an LNG ship, fire is the main concern as the resulting damage, not an explosion. [22]

An example of terrorism is when an airplane crashes into an LNG ship. The impact will cause a fire on the ship due to the onboard airplane fuel ignited. This fire consequently may ignite the LNG, causing a bigger fire on the ship. Emergency fire-fighting protocols should be able to contain the fire on the ship and the separation distance of on-shore storage tanks should almost eliminate any danger to the public. Other preventive measures for terrorism in the seas include constant sea-inspections, emergency communications system, well-trained on-board security team, emergency protocols for security breach, and excellent intelligence gathering. [22]

Conclusions

The excellent safety record of LNG does not stop current research and development to constantly improve the safety of LNG facilities. For more than 40 years, there have been more than 50,000 LNG ship cruises without any major release of LNG anywhere in the world[22]. The safety record of LNG clearly indicates that LNG as a fuel is much safer than its competitors given those only seven major incidents occurred worldwide since the 1980s[22]. LNG risks and hazards are controllable given the amount of engineering and effort put into making this process very safe. Based on the understanding on the properties of LNG, the technologies and operating practices applied to creating LNG is inherently safe.

From the various sections on the value chain of LNG, it can be deduced that LNG storage either on- or off-shore is the main challenge in the safety and security of the LNG industry. Hence, the LNG storage tanks and the LNG ships inherently have primary containment, secondary containment, separation protocols and safeguard practices to ensure the highest safety measures are taken. Although preventive and mitigation actions can be taken if inherent safety measure fails, this does not mean that safety measures belong to only the automated systems. Just like in any HSE departments in all over the world, safety is everyone's responsibility and the LNG industry is no exception.

"On my honor, as an Aggie, I have neither given nor received unauthorized aid on this academic work"

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