LNG TRANSPORTATION, RISK MANAGEMENT, AND MARITIME SECURITY

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ABSTRACT: *Liquefied natural gas (LNG) was the focus of great speculation, evaluation, and facility construction in the late 1970s due to extremely high oil prices and the need for large, sustainable quantities of energy in the US. Importing natural gas in its liquefied form in special-constructed ships was necessary to meet US energy demand. However, lower prices and bringing the oil crisis under control subsequently caused the market potential for LNG to diminish during the 1980s and 1990s. Most of the vessels and facilities constructed in the US to meet the potential demand in the 1970s remained out of service for the next 20 years. However, recent changes in the global and US energy markets have put LNG in the marketplace spotlight again. There is momentum building to create an infrastructure to support the import of LNG into coastal communities around North America. Especially in the wake of the terrible events of September 11, 2001, government and citizens are apprehensive about the potential risks of transporting large quantities of LNG by ship through our coastal waters and into our ports. LNG vessels and waterfront facilities have been well regulated over the past 30 years and have an extraordinarily high safety record. This paper addresses the key issues of risk management that affect LNG import, including maritime security; existing vessel and facility regulations and practices; and risk communication messages. The security of LNG transport, transfer and storage is a critical matter that will be discussed from the generally accepted risk based analysis of consequence, vulnerability, and threat. As a consideration of consequence, is an LNG release an event that could potentially destroy an entire port area? How vulnerable are LNG vessels and facilities, and how can operators, in conjunction with Port Security Committees, evaluate and reduce the likelihood that those with criminal intent will target their vessel or facility? This paper is unique in that it adds the critical element of maritime security to the years of dialogue related to the safe transport of LNG. We are now in an environment where intentionally caused spills and releases must be factored into existing prevention, preparedness and consequence management planning.*

Introduction

Constantly available and affordable energy supplies are vital to maintaining and enhancing quality of life and promoting economic growth. The energy supplies used in the United States are predominantly non-renewable sources including oil (38%), natural gas (24%) and coal (23%), along with nuclear (8%), hydroelectric energy and other sources (7%). The United States consumes more energy than any other country in the world, estimated to be a quarter of the world's consumption (BP, 2002).

Based on current projections, demand for natural gas globally is expected to increase 2% each year in the US (EIA, 2002), and double in the world by 2010 (BP, 2001). To accommodate this increase in LNG demand, more shipments of LNG will be imported, sometimes through busy port areas, and new terminals are likely to be constructed, or old ones reactivated in rural communities. Given the events of 9/11, there is concern that these LNG shipments and terminals could become terrorism targets and represent a risky option to meet energy demand. Industry and government agencies are actively assessing the risks associated with the marine transportation and import of liquefied gases, especially LNG.

What is LNG? Liquefied Natural Gas (LNG) and Liquefied Petroleum Gas (LPG) are both imported into the United States and other countries around the world. Japan, for example, imports 100% of its LNG supply, which accounts for one-third of their primary energy needs (BP, 2001).

LPG and LNG are petroleum hydrocarbons. They are both composed of low molecular weight hydrocarbons; LNG is composed primarily of methane (approximately 65% to 99%) and LPG generally is either propane or butane. Like crude oil, their actual composition varies from place to place with geologic conditions. Both can be found either with crude oil or in discrete gas reservoirs. The majority of LPG is produced from the crude oil refining process or from "associated" fields. An increasing proportion of LNG is produced from "non-associated" fields, which are purely gas reservoirs.

LPG and LNG are gases at ambient temperatures and atmospheric pressure, but are transported in bulk as liquids to reduce the required container volume. In the case of LNG the volume is reduced by a factor of approximately 600; for LPG the volume is reduced by a factor of roughly 250. These gases can be liquefied either by low temperature, by high pressure or a combination of the two. In the case of LNG, the critical temperature is below ambient so that pressurization alone is insufficient for liquefaction and therefore cooling is necessary. This is not the case for LPG, which liquefies readily under pressure and is common in many households in this form. LNG is carried at very low temperatures near atmospheric pressure in the marine mode; LPG is usually carried in bulk, either at low temperatures at atmospheric pressure, or higher temperatures and under pressure in large ships and fully pressurized in smaller ships or barges.

Principle hazards. The principle hazard or dangerous condition associated with these gases is flammability, i.e., the vapors burn. These substances are not flammable in their liquid state. Their vapors are a safety hazard predominantly to people and property, rather than to organisms or habitats in the marine environment, because of LNG and LPG chemical and physical properties.

If the liquefied gases are accidentally released in the usual scenarios, which are from a tank into a diked area on land, or a release of liquid onto water, vaporization begins immediately. Since the LNG and LPG liquid does not burn, the presence of an ignition source when the vapor is within its flammable limits is the significant danger. The downwind travel of a vapor cloud for LNG or LPG has been described as a long, thin cigar-shaped vapor cloud and, under certain meteorological (low wind or atmospheric inversions) conditions, it can travel a considerable distance before its concentration falls below the lower flammable limit.

The LPG vapor cloud is always heavier than air, suppressing the dispersion of the cloud; consequently, the cloud remains hazardous for a greater distance downwind than if the cloud were neutrally or positively buoyant. The result is that LPG vapors tend to hug the ground, depending upon ambient wind conditions. In these conditions it is more likely that an ignition source, from passing traffic, land or sea based, or from stationary plant, may be encountered, and the possibilities of a conflagration are much higher.

For LNG, the vapor warms by mixing with the diluting air, cooling the surrounding air in the process. With a large release, the air-gas mixture is, initially, denser than the warm air in the immediate vicinity of the release and it may be some distance from the release before the cloud is diluted below the low flammable limit. This, though, depends on local conditions such as topography and meteorological conditions.

In the case of an accidental release into a diked area the rate of vaporization of liquefied gases will be initially rapid but can decline as the impoundment floor freezes. A typical impoundment area filled with LNG, for example, might take hours to evaporate, especially if its rate of evaporation is reduced by the application of a "foam blanket."

The United States (US) Coast Guard conducted a detailed review of LNG and LPG as dangerous bulk cargoes, which was published as a summary of hazards and practices that would guide Coast Guard safety and regulatory policies (US Coast Guard, 1980). There have been unconfined LPG vapor clouds that have detonated during field tests in the US, which shows that under accident conditions LPG could detonate. However, LNG would not detonate under the same conditions.

The US Bureau of Mines investigated the behavior of LNG when spilled on water and found that LNG spreads continuously until vaporization is complete. Boiling is rapid due to the large temperature difference between the water and the LNG and the large surface area. Should an accidental release occur underwater, small-scale tests by US Bureau of Mines showed that LNG completely vaporized before any liquid could rise to the surface. However, tests in industry show that when LNG is spilled in significant quantities it can lead to a phenomenon known as "Rapid Phase Transition" (RPT), where there is a rapid change of state from a liquid to a vapor with an associated release of energy of explosive proportions. This phenomenon is dependant on a critical mix of LNG and water and may not occur in all spill scenarios. However, were RPT to occur, the resulting explosive release of energy carries the risk of severe structural damage. A RPT occurring after the ingress of water to a ships cargo tank, for example, might cause severe structural damage, thus releasing further LNG into the water and precipitating further damage and more gas release. During the experiments conducted by Gas de France, they determined that pressures in the air and water were measured to be of up 4.2 kg TNT equivalents.

The risk of RPT has to be taken into account when considering a fire-fighting medium for LNG fires; water directed in a jet onto a LNG pool fire can encourage vaporization. Secondly, it may create "explosions" due to the mixing of the liquefied gas and water in sufficient quantities causing a RPT. Trials with LPG have failed to produce the phenomenon of RPT.

Neither LPG nor LNG is toxic. While combustion remains a significant potential hazard, there is little danger from breathing in these gases for short time periods as long as asphyxiation is avoided. In high concentrations, they act as asphyxiates by diluting the oxygen concentration below that necessary to sustain life. They are inactive and not significant air pollutants. Nor are these gases water pollutants. They are insoluble in water, have very low toxicity to marine organisms, and they volatize quickly in water. Hence, the gases do not present a significant threat to the marine environment in themselves. However, an explosion in the marine environment caused by the RPT could result in acutely lethal effects to marine organisms in the immediate vicinity of the explosion, especially in near-shore and shallow waters. While it is very difficult to generalize about biological impacts, the adverse impacts of a liquefied gas explosion would probably be more localized and short term than those of a crude oil spill. This would depend upon the biological organisms and habitats, size of spill, seasonality and other variables associated with the affected area.

Because LPG and LNG are transported at very low temperatures (-163°C), contact of liquefied gas with either liquid at these temperatures will damage living tissue and the majority of metals in marine use will suffer brittle fracture, especially in the case of LNG.

Risk management issues. The risks associated with LNG and LPG are the possibility and probability that an uncontrolled release of either product will result in injury, loss, market disadvantage, or destruction, such as loss of life, property destruction, and adverse impact on the viability of the market should an accident occur. Due to the perceived hazards of liquefied gases, e.g., that it will ignite and result in a large fireball explosion, many people are alarmed about having an LNG facility in their community or having vessels transport LNG and/or LPG through coastal communities. Since 9/11, the possibility of terrorist action against these facilities and vessels could result in a high number of fatalities and an interruption to the energy supply chain, is also a significant concern. While many perceived risks focus on safety issues, people are still concerned about the environmental effects of a large uncontrolled LNG or LPG release.

The gas industry, particularly the gas transportation industry, has an enviable safety record. Safety and environmental risks associated with LNG and LPG facilities and vessels can be addressed and effectively managed through various regulatory, and non-regulatory, techniques including:

- Risk communication messages, to define clearly liquefied gas properties and hazards, safety, and environmental issues and the industry safety track record;
- Risk mitigation for vessels – construction, human factors and training;
- Risk mitigation for terminals and jetties – siting and design, weather, traffic control, safe mooring, transfer contingencies, safe distances, training, review of operating practices and procedures; and
- Port security and response plans for vessels of high concern.

Risk communication. A key aspect of risk management is communicating with the individuals who might be at risk from future liquefied gas projects. To minimize potential adverse environmental and social impacts, communities that could be affected by the anticipated increase of the LNG market in the US and other parts of the world over the next decade need assurances that their concerns will be addressed. One outreach approach for addressing potential stakeholder concerns is developing proactive "risk communication" messages, whereby the industry communicates with the audience about perceived potential risks to human health and the environment from LNG shipping and waterfront storage facilities. Risk communication messages should raise the level of understanding of relevant issues and satisfy stakeholders that they are being adequately informed within the limits of available knowledge. Critical to the success of risk communication messages is dialogue, two-way communication, between stakeholders and those associated with causing the risk.

BP recently developed a risk communication video on LNG that conveys information about LNG properties and behavior. The 8-minute video shows them how LNG behaves under various conditions through a series of tabletop demonstrations. This video is especially useful in helping people relate physical and chemical properties to things that are familiar in their experience. The video is intended for use in meetings with stakeholders, to clarify and facilitate discussions about perceived risk, in addition to other issues of concern. This video is one component of risk communication about liquefied gases. Citizens and decision makers also want to know how the potential risks associated with liquefied gas facilities have been managed over time; what is the industry track record with regard to safety.

LPG transportation began with small volumes before World War II. The movement of large volumes was developed in the 1960s, with the construction of fully refrigerated ships. International LNG transportation, by sea, started in 1959 with the conversion of a small cargo ship to a 5,000-m3 LNG carrier. This was *Methane Pioneer*. This ship carried the first cargoes of LNG between Lake Charles, Louisiana in the United States and Canvey Island in the U.K.

The total sea borne trade of liquefied gases in 1999 was approximately 155 million tons, with 91 million tons of LNG, approximately 45 million tons of LPG, 12 million tons of ammonia, and 6 million tons of other chemical gases. As of December 31, 1999, a total of 30,747 cargoes of LNG have been transported since the *Methane Pioneer* first arrived in Canvey Island in 1959, representing almost 2.5 billion cubic meters or 1.2 billion tons of cargo. At the end of 1999, there were 1,063 liquefied gas carriers of all sizes in operation, of which 196 had a capacity larger than 60,000 m^3 and 113 were specialized LNG carriers.

Since 1959, not a single operating LNG or LPG ship with a capacity above 5,000 m^3 has been lost nor has there been any substantial loss of product ashore or at sea. There have been losses of small, fully pressurized, LPG carriers at sea, but the cargo in these incidents has been released in a controlled manner, despite, in some cases, the containment breaking free of the vessel. There has never been an uncontrolled release of gas following an accident to a gas carrier.

The very large financial commitments associated with liquefied gas trades require that standards of safety and reliability be maintained always at the highest practical level. This taken together with the fact that liquefied gas presents no corrosive risk to vessel tanks, means that gas tankers generally can preserve a pristine condition over a very long service life. This could extend to over forty years.

The risks to which the gas transportation chain is exposed are constantly changing, from the initial design phase of a terminal or gas vessel through the life cycle of the project. To this end it is necessary to review on a regular basis the operating practices and procedures that are currently in place. The international gas trade association is SIGTTO, Society of International Gas Tanker and Terminal Operators Ltd., which was formed to promote high operating standards and best practices to gas tankers and terminals throughout the world. Since the liquefied gas industry, especially the LNG industry, is expanding at such a rapid rate, SIGTTO recently compiled a single publication that lists all other publications to advise entities on the best practices that are prevalent in the liquefied gas industry and where these practices are documented. The publication also enables those involved in the industry to assess their compliance with these best practices by a means of self-assessment (SIGTTO, 2000).

Risk mitigation for vessels. The structure of both LNG and LPG ships has been designed by international regulation, so that they are able to withstand the impact of both collision and grounding without damage being incurred to the containment system. This includes the use of "double hulls" and protective location construction. The containment systems are also governed by legislation that covers insulation and the prevention of a leakage of the cryogenic liquid onto unprotected steel or other material that may not be able withstand the transport temperatures.

There are specific regulations for gas carriers concerning the construction, equipment, and operation of gas carriers. They are contained in the International Maritime Organization's (IMO) "Gas Codes." These gas codes are in addition to regulations and a survey cycle of operational fitness that apply to other sectors of the shipping industry and provide a solid base for gas shipping safety. There are three Gas Codes that have evolved with the industry.

- *The Code for Existing Ships Carrying Liquefied Gases in Bulk (Existing Ship Code -IMO).*
- *The Code of Construction and Equipment of Ships Carrying Liquefied Gases in Bulk (The GC Code - IMO).*
- *The International Code of Construction and Equipment of Ships Carrying Liquefied Gases in Bulk (The IGC Code - IMO).*

International regulation for the training of seafarers is covered by an IMO convention known as the Standards of Training and Watchkeeping 1995 (STCW95), under which there are general and specific requirements for officers responsible for cargo operations on gas carriers. The gas industry also has been proactive by "designing out" the human error with use of automated systems, such as Emergency Shut Down (ESD) systems. Where the human factor cannot be controlled by automation and mechanical systems, other steps have been taken to minimize the impact of an incident. For instance, all gas carriers built after 1976 have their cargo tanks protectively located so that in the case of a collision or grounding the containment system is protected.

Risk mitigation for terminals and jetties. There are no international regulations governing terminals. In certain countries, national rules are applied, such as those published by NFPA in the United States, the Health and Safety Executive in the UK, the Japanese Safety Bureau in Japan, CEN Standards and Standard Directives in Europe, and others. If no national regulations exist, terminals are designed, constructed, and operated consistent with internationally accepted recommendations compiled by bodies such as SIGTTO, Oil Companies International Marine Forum (OCIMF), International Association of Ports and Harbors (IAPH), Permanent International Association of Navigation Congresses (PIANC), BSI, and IMO.

Key considerations to minimize risk in siting and designing coastal liquefied gas terminals include: site selection, traffic control in the port approached and in the vicinity of the jetty, weather operating limits, safe mooring, transfer contingencies, safe distances, and terminal staff training.

When designing a terminal, the maximum credible spill should be assessed. The quantity of vapor released from the failure of a hard arm or loss of containment, for example, can be established and then the spread of the resulting gas cloud must be considered. The risk of ignition within this predicted gas cloud must be eliminated even if the gas cloud extends over a considerable distance (PIANC, 1988). Accordingly, ignition controls must reach out well beyond the immediate area. In addition, to cover any possible ignition sources on the ship itself, suitable emergency procedures should be in place. Gas cloud spread is estimated by an analysis of the dispersion of the gas resulting from a range of spills under a variety of conditions. This analysis can provide the approximate sizes of gas clouds, which principally depend on spill rate and duration. Other factors, such as climatic conditions, and wind factors are important but local topography, such as harbor structures and even the presence of the liquefied gas ship itself, can have an effect. It is now becoming increasingly common practice to have a "live" connection to a facility to predict the direction of drift of a gas cloud and advise on the necessary actions under the circumstances.

Port security/Response plans. LNG and LPG are considered high consequence cargoes by the U.S. Coast Guard, and as such will be subject to stringent security requirements. Previous sections of this paper have identified the primary risks of these materials as flammability, and possibly detonation under rare circumstances. While the gas industry has a near perfect safety record that reflects tremendous results from risk of unintentional release, we are now faced with the potential of intentional acts directed against these vessels and facilities in the post 9/11 terrorist environment.

Security risk is defined as a function of consequence, vulnerability, and threat. Briefly, consequence is a measure of the severity of result if an item, system, or process at any site, facility, vessel, or infrastructure is destroyed or interrupted. Vulnerability is a measure of how well a site is physically protected by barriers, electronics, people, or processes. Threat is a measure of how likely it is that a person or group has targeted the site for penetration.

Having established that LNG and LPG are at least perceived to be high consequence materials, the next step in analyzing security risk should be a threat analysis. A threat analysis in a security risk assessment should consider all potential adversaries. These include those seeking the thrill of low consequence vandalism, or perhaps persons internal or external to the company with an ideological bent. These persons or groups may have an environmental or anti-global focus and generally would only try to disrupt the shipment of a particular material. At the high end of the scale of consequence is the terrorist, whose main focus is taking of human life and causing very high visibility acts in the process to garner attention for their cause.

Low-level threats from vandalism have always been a possibility. LNG and LPG have relatively low environmental impacts, so it is not probable that this industry should raise the ire of these groups any more than the shipment and refining of crude oil. Anti-globalists are known for violent demonstrations, but not necessarily at the risk of human life. Therefore, the biggest threat scenario must clearly be based upon the high impact terrorist act. With this threat analysis completed various terrorist scenarios can be developed to gage how vulnerable the ship or facility is from harm.

Scenario development for either vessels or facilities should be based on a careful analysis of the process where LNG or LPG is produced, shipped, and then transferred to downstream users of the material. This analysis should consider those parts of the process that will yield the most casualties and provide the best photo opportunity for the terrorist. For example, release modeling associated with accidental scenarios describe a release seeking and possibly finding an ignition source. An intentional terrorist-based scenario would most likely include that ignition source as a means to rupture the cargo containment and destroy the vessel. Once various scenarios are developed then security planners can devise ways to prevent them.

Generally, any attempt to mitigate security risk should focus on reducing consequence and vulnerability. The general public has little-to-no control over reducing threat because that is the job of our law enforcement agencies and armed forces working in concert with our intelligence services, although government entities have a very limited ability to control threat, because threat is a measure of the unknown. Of the items we are able to control, consequence is the hardest to influence. One way is by making fundamental changes to the way this industry conducts business at existing facilities or with vessels. Reducing consequence by altering the storage and transportation of LNG or LPG could adversely impact the economics or profitability of the entire process. Since the profitability of the gas industry is closely tied to the price of oil, any change would have to be carefully considered.

As a result, improvements to reduce security risk are usually tied closely to reducing vulnerability through increases in physical security hardware, people, and processes. These security improvements should be based on a thorough on-site assessment of the facility, vessel, and route of the vessel to identify weakness. The on-site assessment should yield mitigation strategies that enable a potential adversary to be detected, delayed, and responded to in the shortest amount of time. Additionally, the strategies should seek to provide defense in depth, protection for as many common vulnerabilities as possible, and not provide any path to the terrorist that is easier than others.

Security planning is a continuous process. Besides being the right thing to do in the post 9/11 environment, this need is recognized by impending federal law and regulation. Security Plans need to be updated and improved. Along with the plans, a regular exercise regime must be implemented to identify weakness and train personnel. Finally, company personnel must actively participate in the Port Security Committees already established in their area, as well as any Harbor Safety and Area Committees established by the Coast Guard. The communication and exchange of information on consequence, vulnerability, and threat that this participation yields is vital if any degree of security is to be achieved.

Summary

Liquefied gases are principally a hazard to people and property, not the environment. They are insoluble and therefore non-toxic to marine organisms. While an oil spill is visible and as such communicates its contamination; a liquefied gas cloud is invisible.

While the liquefied gas industry has a strong safety record, it is very difficult to predict exactly what would happen if there was a major uncontrolled release of LNG on the water. Tests with LNG have shown that rapid phase transition would be a serious concern if there were such a release. However, the industry has stringent construction and safety codes for vessels and terminals, and monitoring of vessel traffic, to prevent a catastrophic release on water.

A secondary tool is effective contingency planning that aims at maintaining a state of readiness and timely, appropriate procedures to mitigate emergency situations. Sound contingency planning, in addition to risk management programs, stakeholder outreach and port security plan, must incorporate the interests, expertise, and experience of the industry in LNG projects.

Biography

Ann Hayward Walker has over 20 years of experience providing technical decision support products to government and industry decision makers. Her involvement with LNG began in 1978 in looking at the risk to the Chesapeake Bay for the Virginia Coastal Resources Management Program. Most recently, she assisted BP, as executive producer, in developing a LNG risk communication video.

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