Managing LNG Risks: Separating the Facts from the Myths

ioMosaic

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Facts and Myths

Some parts of the US media have managed to dramatize key issues surrounding LNG transportation, facility operations, and proposed new projects. Erroneous media speculation and sensationalism, especially regarding the threat of terrorism, have created an atmosphere of anti-LNG sentiment fueled by fear and paranoia.

> ***"Erroneous media speculation and sensationalism, especially regarding the threat of terrorism, have created an atmosphere of anti-LNG sentiment fueled by fear and paranoia."***

The media are partly influenced by erroneous, so-called independent expert analysis and public statements. This has been exacerbated by political and public concerns and pressure, skepticism and doubts over recent studies and statements from LNG companies and government agencies, as well as historical and recent incidents such as Skikda.

It is becoming very difficult for the average person to separate fact from fiction because of this sensationalism and the hidden motives and private agendas of various working groups.

This paper will separate facts from myths regarding statements reported by various newspapers, working groups, and web sites.

Attractiveness of LNG Facilities and Vessels as Terrorist Targets

After the terrorist attacks of 9/11, government agencies and the public became more concerned about chemical storage and transportation facilities that are close to populated areas. Facilities handling large quantities of hazardous materials, such as LNG terminals and tankers, were initially identified as attractive terrorist targets.

> ***"LNG tankers and bulk storage tanks are not attractive targets for terrorists who seek to achieve mass casualties."***

The scenario feared by all involves a terrorist using an explosive charge (or flying an airplane) to breach and possibly detonate one or more storage tanks on a ship containing up to 125,000 m3 of LNG in a heavily populated area. The same scenario is feared for large LNG storage tanks. As a result, security and surveillance of LNG terminals/facilities and ships coming to port to unload LNG cargo have increased considerably.

In 2002, the city of Boston denied permission to an LNG tanker from entering port and unloading its much needed LNG cargo at an Everett LNG terminal, during the winter. In addition, there is significant opposition to proposals for LNG terminal expansions, and as well as proposals to build new LNG terminals. The opposition comes from both the general public as well as politicians. There is a lot of debate surrounding the potential for an LNG explosion.

"The likelihood of this scenario is equivalent to each of the authors of this paper winning the power ball or megabucks lottery several times, simultaneously."

Let us examine the issue of possible LNG explosion when the liquid and vapor are not confined. First, LNG has to be vaporized and then mixed in the right proportions with air in order to obtain a composition that can burn. Furthermore, methane is relatively insensitive to initiation as compared to heavier hydrocarbons. Available data and good understanding of explosion dynamics indicate that it is not possible to detonate LNG vapors, even with the use of an explosive charge (that is large enough) on a storage tank, unless the LNG vapors contain high fractions of ethane and propane (more than 20%). Explosion test data on methane/ethane mixtures in the vapor phase support these statements[1]. The likelihood of this scenario is equivalent to each of the authors of this paper winning the power ball or megabucks lottery several times, simultaneously.

The most likely outcome of a terrorist attack will be a large pool fire and possibly a low order deflagration/flash fire of finely divided LNG liquid droplets aerosolized by the blast force of the explosive charge. LNG pool fire hazards are localized and as a result thermal radiation effects (2nd degree burns) are typically confined to within one or two pool diameters from the edge of the flame. This significantly limits the extent of impact.

As a result, LNG tankers and bulk storage tanks are not attractive targets for terrorists who seek to achieve mass casualties.

Understand Hazards and Manage Risk

"Ultimately, it is a question of what risk level is tolerable or acceptable vs. the economic benefit derived by society / communities."

If we only managed hazards, no one would be flying an airplane or driving a car to work. When we fly or drive we are aware that we could get killed but we factor in the likelihood of that occurring and it is very low. We should and do manage risk and not just hazards. The LNG industry has a lower risk profile than airlines, and chemical and petrochemical processing facilities to name a few[2]. Risk is defined as the probability of occurrence of an unwanted event. Risk has two components, (1) a probabilistic one relating to the likelihood of occurrence of an event and (2) a deterministic one relating to the magnitude of the event.

1 Bull, D.C., and Elsworth, J.E., "Susceptibility of Methane/ethane Mixtures to Gaseous Detonations in Air", Combustion and Flame, 35, 87 – 91, 1979.

2 Arthur D. Little Inc. and SAI Comparison of accident probabilities, 1975

Ultimately, it is a question of what risk level is tolerable or acceptable vs. the economic benefit derived by society/communities.

Whether the risk is perceived by society/individuals to be voluntary or involuntary, risk is also a key factor. The additional risk associated with smoking or driving a vehicle is a voluntary risk. Additional risk associated with siting of new facilities is usually considered involuntary risk that can only be avoided at a great cost, such as moving away from the area. Involuntary risk is much less tolerable/acceptable than voluntary risk.

"Proposed and existing LNG terminals and facilities must be scrutinized using a sound risk basis and not fear."

Communities are generally intolerant of activities that will be visually intrusive, noisy, produce offensive odors or are pollution threats. Where risk is concentrated in a local area, the potential impact of an accident will be very visible and deeply felt. This is especially true when "visible risk" is contrasted with a road accident or disease where one or more isolated individuals are affected and there is negligible concentration of risk on communities.

Ironically, society in general will expand greater efforts to reduce "visible" risk despite the fact that more lives are lost by other causes.

The magnitude of impact of a potential accident carries a lot of weight. An accident which has the potential (or is perceived to have the potential) to injure or kill a large number of people attracts more public interest than the individual incidents capable of killing or injuring the same number of people.

The likelihood of a scenario leading to the total loss of containment involving an LNG tanker or a large LNG storage tank must be considered in conjunction with the potential hazards such events pose and their impact on the public. US regulations (49 CFR Part 193) require that LNG facilities have secondary containment for LNG tanks and LNG transfer facilities. In addition, the facility must maintain exclusion zones to protect the public from potential thermal radiation and flammable vapor dispersion hazards.

Today's risk assessment methods can be used to establish individual and/or societal risk profiles or environmental impact. These methods are well understood and generally accepted by operating companies, the public, and government.

Proposed and existing LNG terminals and facilities must be scrutinized using a sound risk basis and not fear.

Historical review of LNG safety in the United States and worldwide

"The LNG industry in the United States and worldwide enjoys an exceptional marine and land safety record."

The LNG industry in the United States and worldwide enjoys an exceptional marine and land safety record. In the past thirty years, Japan has received nearly all of its natural gas in the form of LNG transported by ship. Once every 20 hours an LNG ship arrives at the busy Tokyo bay, unloads its LNG cargo, and leaves safely. In the last three decades and with more than 40,000 voyages by sea worldwide, there has not been a single reported LNG release from a ship's cargo tank. LNG tankers have experienced groundings and collisions during this period, but none has resulted in a major spill. This is partly due to the double-hulled design of LNG tankers which offers significant protection to the double walled LNG containers. During the past sixty years of LNG operations, not a single general public fatality has occurred anywhere in the world because of LNG operations.

This exceptional safety record can be attributed to several key factors: (a) The LNG industry understands the physical and chemical hazard characteristics[3] of LNG and have used that knowledge to instill and maintain an excellent safety culture in LNG operations and to advance the engineering of safety systems and standards[4] for storage and transport of LNG, (b) The LNG industry is heavily regulated[5] in the United States and worldwide, and (c) The use of multiple layers of safeguarding (primary containment, secondary containment, instrumented safety systems, operational systems, and safe separation distances) is common practice in LNG systems and operations.

Historical Accident Data

In almost all accidents involving LNG resulting in explosions, confinement of LNG vapors played a key role. Lessons learned from such accidents have already been incorporated into the design and operating procedures of LNG facilities and/or government regulations.

An explosion occurred at East Ohio Company's peak-shaving plant in Cleveland[6], Ohio on October 20, 1944. 128 people were killed and 225

3 There are more large-scale field trial data reported for LNG vapor cloud dispersion than any other industrial chemical. There have been twelve large-scale field LNG studies (three on land and nine on water) with 213 field trials (86 on land and 127 on water) reported in the open literature.

4 49CFR Part 193 LNG Facilities, 33 CFR part 127 Waterfront Facilities Handling LNG and Liquefied hazardous Gas, NFPA 59 A, NFPA 57, EN 1473, EN 1160, EEMUA 147. Also for ships, 33 CFR 160.101, 33 CFR165.20, 33 CFR 165.30.

5 In the US LNG is regulated by DOE, FERC, USCG, DOT, EPA, OSHA, U.S. Minerals Management Service, U.S. Fish and Wildlife service, U.S. Army Corps of Engineers, NOAA. Also by standards organizations including NFPA, ASME, ASCE, API, ACI, and ASTM.

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

injured. In 1943, a cylindrical storage tank was added to increase the LNG storage capacity. On October 20, 1944 this cylindrical LNG storage tank failed releasing 1.1 million gallons of LNG. The liquid rushed over the short dam around the tank. The resulting vapor cloud was ignited and the fire engulfed adjacent tanks, and a utility company building onsite. Some residences facing the fire received thermal radiation damage from the fire. After about 20 minutes into the first release, a nearby spherical storage tank (57-feet diameter) failed due to the fire. In addition to the fire, the LNG that had leaked in the sewer systems generated flammable vapors that exploded under confinement causing further damage. It is estimated that the damage due to the fire extended over an area of 0.5 miles around the cylindrical tank. This is the last time that any member of the general public was killed as a result of LNG operations.

Stainless steel was scarce during World War II and so the cylindrical tank was made from another alloy - 3.5 % nickel steel. The tank was placed in service and eventually failed catastrophically upon contact with cryogenic LNG. The 3.5 % nickel steel is no longer used for cryogenic applications. Instead 9% nickel steel, which does not embrittle at low temperatures, is now used. Also, as mentioned earlier, current US regulations require secondary containment for each LNG container to keep any potential LNG spills contained onsite.

More recently, an explosion occurred at Sontrach's LNG plant at Skikda, Algeria on January 19, 2004. 27 people were killed. It has been reported that 56 employees were admitted to the hospital. The majority of them left the hospital the same day but 5 were seriously injured. No members of the general public were injured.

"In almost all accidents involving LNG resulting in explosions, confinement of LNG vapors played a key role. Lessons learned from such accidents have already been incorporated into the design and operating procedures of LNG facilities and/or government regulations."

Preliminary findings suggest that there was a cold hydrocarbon leak that occurred at Liquefaction Train 40 and was introduced into a high pressure steam boiler by the combustion air fan. The confined gas-air mixture in the boiler firebox ignited and resulted in fire and explosion. The explosion was close enough to the immediate vicinity of the leak which triggered a subsequent larger explosion.

High-pressure steam boilers that power refrigeration compressors are not used at any LNG facility under FERC jurisdiction in the United States. The Skikda accident triggered FERC to require LNG applicants to identify all combustion/ventilation air intake equipment and distances to any possible hydrocarbon release comprising of LNG, flammable refrigerants, flammable liquids, and flammable gases. In addition, hazard detection devices must be installed to shutdown this equipment in case of a release.

Twelve LNG Facts vs. Myths

The following is a summary of several myths propagated by the media and various working groups, contrasted with common sense, factual data, and scientific evidence.

Myth No. 1

An LNG tanker holds thirty three million gallons of LNG, or twenty billion gallons of natural gas, the energy equivalent of fifty five Hiroshima bombs.

"Hazard potential depends on both the amount of energy and the rate at which it is released."

Fact

The estimation of hazard based on energy content is very misleading and erroneous.

Using the same flawed reasoning relating LNG energy content to hazard potential, one can conclude that:

- 3 hours of sun shine over 10 square feet equals 3.2 lbs of TNT explosive
- A 24 gal automobile gasoline tank equals 1,225 lbs of TNT explosive
- 1,000 lbs of wood equals 3,530 lbs of TNT explosive
- 1,000 lbs of coal equals 4,470 lbs of TNT explosive

Hazard potential depends on both the amount of energy and the *rate* at which it is released. Energy release during LNG burning is relatively slow. Explosion energy is released "lightning-like" causing the formation of a shock wave that travels outwards and can cause severe damage to people and property.

Myth No. 2

LNG tankers and land based facilities are vulnerable to terrorism; An LNG potential disaster (explosion of an LNG tanker) is greater today because of the threat of terrorism. The gigantic quantity of energy stored in huge cryogenic tanks is what makes LNG a desirable terrorist target. Tankers may be physically attacked in a variety of ways to destroy their cargo or used as weapons against coastal targets.

Fact

"Any explosive charge used on an LNG ship will cause immediate ignition of the LNG vapors. The subsequent LNG pool fire will have a potentially significant impact on the immediate release area only."

As discussed earlier, LNG ships are not attractive "mass casualties" terrorist targets. Any explosive charge used on an LNG ship will cause immediate ignition of the LNG vapors. The subsequent LNG pool fire will have a potentially significant impact on the immediate release area only. This will significantly limit the extent of impact.

There are also new Coast Guard security regulations (33 CFR Part 105) for LNG tanker movements and terminals. In addition, IMO and the USCG have established stringent security requirements for vessels in international and United States waters.

Myth No. 3

An LNG tanker accident could cause the release of all five tanks LNG content. This will create a plume that would extend 30 miles. Upon delayed ignition thousands of people within the plume would be instantly killed.

"A scenario describing LNG vapor clouds impacting entire cities is "pure fiction."

Fact

LNG is not flammable until it is vaporized, mixed in the right proportions with air, and then ignited.

The measured minimum ignition energy of LNG vapors is 0.29 mJ (milli-Joules). Flammable LNG vapors are easily ignited by machinery, cigarettes, and static electricity. Static electricity discharged when one walks on a carpet or brushes his/her hair is 10 mJ, or 35 times the amount required to ignite LNG vapors. A large LNG vapor cloud cannot travel far into developed areas without igniting and burning back to the source. A scenario describing LNG vapor clouds impacting entire cities is "pure fiction".

The vapor cloud and subsequent pool fire will have a potentially significant impact on the immediate release area and downwind to the first ignition source. This significantly limits the extent of impact.

It is not realistic to imagine that all five tanks on an LNG tanker can be instantaneously released. To instantaneously remove the double hulled side of an LNG ship would require an enormous amount of explosive. The explosive used to breach the hull would cause more damage to the surroundings than the subsequent LNG spill and pool fire. To mount such an attack on an LNG ship would require the equivalent of a full-scale military operation, not a clandestine terrorist operation.

Since the early 1980s, the scientific community clearly demonstrated that a Gaussian dispersion model (the same model used to estimate the 30 mile dispersion distance) is not appropriate for LNG vapor dispersion. Dispersion estimates using a proper heavy gas model are reported in the recent Sandia study. The potential to realize major injuries and significant damage to property resulting from an intentional breach scenario extends less than ½ mile from the spill origin.

Myth No. 4

Small arms non-military weapons can rupture LNG tanker holding tanks. If an LNG tanker falls into terrorist hands, they cannot be removed without rupturing holding tanks, valves or pipelines.

"LNG vapors will not explode and will only produce a flash fire in an open space without confinement and congestion."

The LNG industry claims fire from a terrorist attack would remain near the ship because of immediate ignition caused by the weapon used by the terrorist. However, dangerous LNG cargo can be released without the use of an ignition source.

Fact

A release of LNG cargo caused by a terrorist without the use of a weapon that can cause immediate ignition will be similar to actual design scenarios already used in hazard assessments.

LNG vapors are easily ignited when diluted between 5 and 15 percent by volume in air. A large vapor cloud resulting from an intentional release of cargo cannot travel far into developed areas without igniting. LNG vapors will not explode and will only produce a flash fire in an open space without confinement and congestion.

A flash fire will burn back to the source and produce a pool fire. The flash fire and subsequent pool fire will have a potentially significant impact on the immediate release area and downwind to the first ignition source. This will significantly limit the extent of impact.

Several federal agencies oversee the security of LNG shipping, import terminals and peak-shaving plants. Following 9/11 the U.S. Coast Guard (USCG) and the Department of Transportation (DOT) have introduced additional security measures:

- 33 CFR Part 127: Security measures for marine aspects (USCG) (existing)
- 33 CFR Part 105: Facility Security (USCG) (new)
- 49 CFR Part 193: Sub-part J covers Security (DOT) (existing)

In 2002, the DOT Office of Pipeline Safety (OPS) required LNG facilities to prepare security plans and to revise their security procedure manuals to incorporate additional security measures to coincide with Homeland Security alerts. Shortly after September 11, 2001, the Coast Guard began to systematically prioritize protection of ships and facilities, including those handling LNG, based on vulnerability assessments and the potential consequences of security incidents.

The Coast Guard temporarily suspended LNG shipments to Everett for several weeks after the terror attacks to conduct a security review and revise security plans. The Coast Guard can inspect ships, provide escorts, and set exclusion zones for other vessels. LNG tankers can be disabled in case of hijack (by damaging ship engines or steering) prior to the tanker coming close to shore.

Myth No. 5

The LNG industry claims that tankers are sufficiently safe because they have double hulls. A small terrorist boat rammed and pierced the double hulled French oil tanker Limburg causing a massive fire.

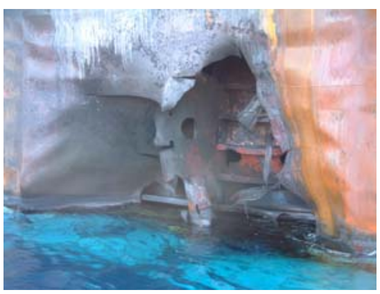
"ioMosaic calculates the thermal radiation hazard zone (greater or equal to 5 kW/m2) to be no more than 0.4 miles from the release point."

The double hull safety claim is suspect and intended for the naïve.

Fact

Membrane tankers have four barriers: outer hull, inner hull, primary LNG container, and secondary LNG containment.

The terrorist attack on the Limburg left an 8 meter hole in the outer hull and much smaller holes in the inner hull [equivalent to a 1 meter hole (see picture)].



LNG flow will be restricted by the 1 meter hole.

The explosive charge used will cause immediate ignition of the LNG vapors.

The subsequent LNG pool fire will have a significant impact on the immediate release area only. This will significantly limit the extent of impact.

Using proven and validated liquid release and pool fire models, ioMosaic calculates the thermal radiation hazard zone (greater or equal to 5 kW/m2) to be no more than 0.4 miles from the release point.

Myth No. 6

The energy industry avoids discussing the 1944 Cleveland, Ohio disaster which devastated one square mile.

Since 1944, both government and industry have made impressive technological and engineering breakthroughs in cryogenics.

Fact

Many lessons were learned from the 1944 Cleveland incident.

Nickel was scarce during World War II and so the cylindrical tank was made up from an alloy [3.5 % nickel steel] that was not suitable for LNG service. 9% nickel steel is used now and does not embrittle at low temperatures.

LNG storage tanks are now provided with full capacity secondary containment, a requirement of NFPA 59A.

Tanks are now spaced to prevent a fire in one tank from causing failure to an adjacent tank or other equipment, also a requirement of 49 CFR Part 193 and NFPA 59A.

After the Cleveland incident in 1944, industry stopped LNG activities until the early 1960s.

LNG facilities restarted with stringent regulations, codes, and standards to ensure safety.

Since 1944, both government and industry have made impressive technological and engineering breakthroughs in cryogenics.

Myth No. 7

The LNG industry claims that newer LNG facilities are safe. The 2004 Algerian Skikda explosion destroyed more than just an LNG facility; it destroyed the LNG industry's myth that LNG is safe.

> ***"High pressure steam boilers that power refrigeration compressors are not used at any LNG facility under FERC jurisdiction in the United States."***

Fact

The Skikda incident is under investigation and lessons will be learned.

It is suspected that a cold hydrocarbon leak was pulled into a high pressure steam boiler in Unit 40 by an air fan.

After confinement in the steam boiler, the hydrocarbons ignited; the steam boiler exploded and triggered a larger explosion in the immediate vicinity of the leak

High pressure steam boilers that power refrigeration compressors are not used at any LNG facility under FERC jurisdiction in the United States.

FERC now requires all LNG applicants to identify all combustion/ventilation air intake equipments and distances to any possible hydrocarbon release comprising of LNG, flammable refrigerants, flammable liquids, and flammable gases.

Unit 40 was not a new or upgraded unit because Sonatrach had planned to scrap the unit.

There were no offsite fatalities.

Myth No. 8

Actual LNG spills conducted by the United States Coast Guard and the Bureau of Mines show that LNG spills on water will explode.

"Only a very small fraction of spilled LNG has been observed to undergo an RPT in field trials.

RPT explosion damage is highly localized."

Fact

The explosion observed in the Bureau of Mines test is a physical explosion, often referred to as a Rapid Phase Transition (RPT).

An RPT does not involve combustion.

An RPT is caused by rapid heating from the spill surface.

The explosion is created from the rapid vaporization and sudden expansion of LNG liquid.

RPT energy is 1,500 times smaller than combustion energy.

Only a very small fraction of spilled LNG has been observed to undergo an RPT in field trials.

RPT explosion damage is highly localized.

Un-ignited, LNG vapors will eventually warm and disperse harmlessly into the air [as shown in later field trials by the Bureau of Mines].

Myth No. 9

There are no test data for LNG spills of sufficient size and scale to support scenario development and hazard estimates reported in several studies published by operating companies and the government.

"There are more large-scale field trial data reported for LNG vapor cloud dispersion than any other industrial chemical."

Fact

There have been twelve large-scale field LNG studies (three on land and nine on water) with 213 field trials (86 on land and 127 on water) reported in the open literature.

There are more large-scale field trial data reported for LNG vapor cloud dispersion than any other industrial chemical.

The credible scale relevant to industrial LNG projects is approximately 35 times larger than the existing large-scale field data.

The LNG hazard development processes are well understood and documented.

The physics of these processes are well understood and documented.

We can with confidence establish prudent and safe upper bound estimates of the extent of LNG hazards for the industrial scale of interest.

Myth No. 10

The government is hiding and keeping secret critical documents relating to LNG risks.

Access has been restricted to more than 90,000 documents. LNG is obviously so dangerous they can't tell us about the results, and as a result LNG is too dangerous for our communities.

Fact

Since September 11, 2002, open internet access to critical energy infrastructure information (CEII) including LNG facilities' safety-critical documents was restricted.

These documents describe LNG facilities' design details, siting and layout.

These documents also include LNG facilities' security plans and security details.

Restricting public access to LNG facilities' safety-critical documents is needed to prevent access over the internet by terrorist groups.

This is simply a prudent practice to protect our nation and its citizens.

Myth No. 11

If we import LNG, we will be more dependent on more foreign fossil fuel and make the United States more vulnerable to market manipulation by foreign countries. Investing billions of dollars into LNG importation schemes will only delay the investment into American renewable energy.

"If natural gas is not imported, there will be a natural gas deficit of 376 billion cubic meters (13.3 Trillion cubic feet) in 2020."

Fact

If natural gas is not imported, there will be a natural gas deficit of 376 billion cubic meters (13.3 Trillion cubic feet) in 2020.

To meet short term demands for natural gas, it is necessary to have LNG import terminals.

LNG helps us diversify from middle-east oil dependency since, unlike oil, LNG sources are distributed more globally.

Researchers continue to work on developing alternative energy sources such as wind, power, and hydrogen systems. Today, none can substitute for the huge energy gap that can only be filled by LNG or even greater oil imports.

Without LNG, more imported oil would be needed until alternative energy sources can become technically and economically feasible.

Renewable energy should be developed vigorously, but it cannot take over for our huge appetite for fossil energy today or in the near future (20 yrs).

Myth No. 12

The required infrastructure to distribute LNG's natural gas using industrial pipelines is very dangerous. Industrial sized pipelines (up to 50 inches in diameter) at high pressure (up to 1300 psig) can explode and rupture due to human error, metal fatigue, manufacturing defect, flooding, corrosion, earthquake, and terrorist sabotage. Gas pipeline blasts have been reported to reach 50 stories high and the heat is so intense that sand would turn to glass and concrete to powder.

"Currently 1/4th of the U.S. energy needs are provided by natural gas"

Fact

For decades, natural gas (LNG vapor) has been transported through pipelines and although there are occasional gas leaks and fires, our society is not asking us to stop using natural gas.

Our society is not asking us to stop using high voltage electric lines which can become very dangerous when damaged in freezing weather or by earthquakes.

Our society is not asking us to stop using automobiles which are involved in thousands of fatalities each year in the United States.

Currently 1/4th of the U.S. energy needs are provided by natural gas.

We use natural gas (LNG vapor) burners safely in millions of homes and businesses everyday.

We need natural gas to generate electric power, cook our food, and heat our homes and offices.

We need energy and we learn to handle it safely through regulations, codes, and standards so that society is well-protected from its inherent hazards.

Most LNG facilities introduce vaporized gas into existing gas pipelines.

Conclusion

In summary, then, it is clear that there is a significant resurgence in proposed projects to import LNG into the United States.

Along with this renewed interest it is understandable that there is increasing concern regarding the safety associated with large scale LNG importation. It is legitimate for an inquiring and concerned public to ask pertinent questions and by the same token it is legitimate for those well versed in LNG safety to answer those questions. It is totally inappropriate for segments of the media and groups of citizens to engage in fear-mongering and initiate campaigns of mis-information.

In this paper we have drawn upon the vast amount of field measurements and data, operational and engineering information regarding LNG gathered over the last 60 years to candidly address the safety issues associated with large scale LNG importation. We have taken into account the new threats that have emerged in the form of terrorism in our evaluations as well.

The overall conclusion is straightforward. In the highly unlikely event of a very large scale release of LNG on land or water, significant impact will be felt in the vicinity of the release. The zone of impact will be moderate but will not extend anywhere close to the 30 miles predicted by some ill-informed groups. As long as the LNG vapor cloud is unconfined, it will not explode. If the cloud encounters populated areas it will quickly find an ignition source before covering large populated areas and burn back to the spill site.

If mass casualty is the goal of any terrorist group, then LNG facilities and tankers are not good targets.

Finally, since the Cleveland accident of 1944, the LNG industry has amassed 60 years of transportation and operational experience world wide without a single casualty being inflicted on the general public.

About the Authors

Dr. Georges A. Melhem is president and chief executive officer of ioMosaic Corporation. Since 1988, Dr. Melhem has lead and participated in many LNG studies. These studies focused on issues associated with LNG facility siting, LNG transportation, LNG hazard and risk assessments, and LNG public testimony.

Dr. Melhem is an internationally known pressure relief design, chemical reaction systems, and fire and explosion dynamics expert. In this regard he has provided consulting and design services, expert testimony, and incident investigation support and reconstruction for a large number of clients.

Dr. Melhem was president of Pyxsys Corporation; a technology subsidiary of Arthur D. Little Inc. Prior to Pyxsys and during his twelve years tenure at Arthur D. Little, Dr. Melhem was a vice president and managing director of Arthur D. Little's Global Safety and Risk Management Practice and its Process Safety and Reaction Engineering Laboratory.

Dr. Melhem holds a Ph.D. and an M.S. in Chemical Engineering, as well as a B.S. in Chemical Engineering with a minor in Industrial Engineering, all from Northeastern University.

Dr. Melhem is the author/co-author of four books, more than seventy technical papers/presentation, and more than 300 technical reports. He is a member of the American Institute of Chemical Engineers and the American Chemical Society.

Dr. Ashok S. Kalelkar is a Principal Consultant of ioMosaic Corporation. He brings very progressive experience in the area of LNG safety, hazard, and risk management as it applies to LNG Peak Shaving facilities, Import Terminals, Ocean transport and overland shipments by truck.

Prior to joining ioMosaic, Dr. Kalelkar was a senior executive with the firm Arthur D. Little, Inc. where he led numerous engagements concerning existing LNG facility safety and operability, proposed new LNG import terminals, state-of-the-art handling of LNG seagoing tankers as well as overland shipments by truck.

The ultimate purpose of most of his work was the sound risk management of the operations being analyzed. He has testified numerous times in public hearings regarding LNG facility siting and tanker transport.

Dr. Kalelkar received his undergraduate and graduate degrees in Engineering from MIT and obtained his PhD in Engineering from Brown University.

Dr. Sanjeev Saraf is a Partner of ioMosaic Corporation. Dr. Saraf's areas of specialty include process safety management, reactivity analysis, molecular modeling, and consequence analysis. He is skilled in using LNGFIRE, DEGADIS, and consequence analysis models available in ioMosaic's SuperChems software.

He has a Ph.D. from Texas A&M University where he worked for the Mary Kay O'Connor Process Safety Center (MKOPSC). He is a member of the American Institute of Chemical Engineers (AIChE), American Chemical Society (ACS), North American Thermal Analysis Society (NATAS) and the DIERS Users Group.

Mr. Henry Ozog is a General Partner of ioMosaic Corporation. Prior to joining ioMosaic, Mr. Ozog was a consultant with Arthur D. Little, Inc. for twenty one years, where he managed the process safety consulting business. He also worked for seven years at the DuPont Company as a process and startup engineer.

Mr. Ozog is an expert in process safety and risk management, process hazard analysis (HAZOP, FMEA, FTA), and process safety auditing. He has helped numerous companies and governmental agencies identify process risks and implement cost effective mitigation measures. He teaches courses in each of these areas and is also an instructor for the American Institute of Chemical Engineers' Educational Services.

Mr. Ozog has a B.S. and M.S. in Chemical Engineering from the Massachusetts Institute of Technology. He is a member of the American Institute of Chemical Engineers and serves on various sub-committees for them.

About ioMosaic

Founded by former Arthur D. Little Inc. executives and senior staff, ioMosaic Corporation is the leading provider of safety and risk management consulting services. ioMosaic has offices in Salem, New Hampshire and Houston, Texas.

Since the early 1970's, ioMosaic senior staff and consultants have conducted many landmark studies including an audit of the Trans-Alaska pipeline brought about by congressional whistle blowers, investigation of the Bhopal disaster, and the safety of CNG powered vehicles in tunnels. Our senior staff and consultants have authored more than ten industry guidelines and effective practices for managing process safety and chemical reactivity and are recognized industry experts in LNG facility and transportation safety.

ioMosaic Corporation is also the leading provider of pressure relief systems design services and solutions. Its pressure relief system applications are used by over 250 users at the world's largest operating companies. It holds key leadership positions in the process industries' most influential and active pressure relief system design, and chemical reactivity forums, and plays a pivotal role in defining relief system design, selection, and management best practices.

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