Canadian Society for Chemical Engineering

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ANSWERING SAFE SITING QUESTIONS FOR LIQUID NATURAL GAS IMPORT TERMINALS

A Summary from the

Second American Institute of Chemical Engineers –
Canadian Society of Chemical Engineers LNG Technical Conference

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Jerry Havens
University of Arkansas
Conference Chair

Peter Lederman
Peter Lederman & Associates
Conference Vice-Chair

Liquid Natural Gas's (LNG's) role in delivering energy is growing world-wide, with a surge of activity in North America since the first conference in this series was held in 2005 in Vancouver. Several new LNG import terminals in the U.S. and Canada are operational, with others in planning stages. At the same time, LNG import terminal siting applications are facing serious challenges in satisfying community concerns about public safety. The traditional process for balancing risks to public safety with social benefits, made more contentious by perceived terrorist threats, grows more difficult.

The Second American Institute of Chemical Engineers (AIChE) – Canadian Society of Chemical Engineers (CSChE) LNG conference brought together experts from industry, government, consensus standards organizations, consulting organizations, and universities to take an updated look at siting challenges, both political and technical, that the LNG industry faces. The conference, held in Montreal in August 2009, aimed to identify areas of uncertainty in technical data and information required for rational decision-making and to recommend actions needed for governments to provide satisfactory assurance of public safety. This summary is intended to identify issues that, based on conference papers, seem to merit priority consideration. (Those who wish a complete record of conference presentations can find them at www.aiche.org/Conferences/CoSponsored2009/LNG/presentations.aspx.)

The conference began with an industry perspective, delivered by a representative of Shell Global LNG, who described the global nature of today's LNG business. The industry has facilities in a range of climates, from Arabia to Australia to Sakhalin Island (Russian Arctic Far East). New facilities are being developed world-wide. The speaker from Shell expects most future gas to come from offshore sources, which will present different challenges as gas is processed at sea. Significantly, proposals increasingly include unloading offshore, with transport as liquid or gas to onshore storage. Some of these proposals appear to be made, at least in part, to address public safety concerns associated with the presence of LNG carriers close to populated areas. Indeed, unloading with immediate regasification offshore appears to be gaining favor to allay public safety concerns about LNG vessels and storage of large amounts of LNG onshore.

Next, presentations by the U.S. Federal Regulatory Commission (FERC), the U. S. Coast Guard (USCG), the National Fire Protection Association (NFPA), and the Canadian Standards Organization (CSA) outlined regulatory perspectives on facility siting. The regulatory approaches differ significantly in the US and Canada.

In Canada, while the government has the lead role in enforcement, the development of regulations is primarily the responsibility of the Canadian Standards Association.

In the US, a developer/operator deals primarily with three agencies: FERC in the Department of Energy, the Pipeline and Hazardous Materials Agency (PHMSA) in the Department of Transportation, and Coast Guard in the Department of Homeland Security. There are some areas of contention regarding jurisdiction at the land/sea boundary (e.g., in cases of near-shore carrier offloading with LNG piped to shore). The regulations state that PHMSA has jurisdiction of the facility extending <u>to</u> the last valve on land while the USCG has jurisdiction of the vessels and lines <u>from</u> the last valve on land. The USCG has sole authority over the LNG ships, shipping lanes and offshore facilities, as well as affected navigable waterways.

The majority of proposed or operating facilities in North America are in the U.S.; these require approval-to-site by FERC and USCG as well as continuing operational oversight by both agencies and PHMSA. The burden placed on USCG to put in place and maintain "adequate" security for LNG carriers in transit to and from the terminals appears potentially onerous and merits careful and continuing evaluation. It is not clear how future requirements related to security will impact the overall economic performance of the industry or government. There also do not appear to be agreements in place directing the distribution of such costs among affected parties.

In the U.S., state and local authorities are pressing for larger roles in the LNG terminal siting process. States currently have "veto" power on some siting issues in some locations, and concerns for constituent's interests increasingly impact LNG import terminal siting decisions. In Oregon, for example, where three import terminals are being considered, these concerns include, in addition to public safety, potential environmental impact and secondary impacts of pipelines on land owners distant from the facility. In terms of safety, in addition to provision of safe separation distances to protect the public, states' concerns include provision of adequate fire and medical emergency services (such as burn centers), whether in rural or populated areas. Finally, while FERC may have the primary federal siting authority, state and/or local governments have final authority to grant construction/operating permits.

The conference organizers believe that their findings could be helpful in addressing a growing world-wide need for a risk/benefit procedure agreed to by all major parties for siting LNG facilities. Such a procedure should have applicability to, and be consistent with, procedures for siting any energy facility that poses risks to the public.

In that regard, although the conference focused on North America, speakers from Europe and consulting organizations specializing in quantitative risk assessment (QRA) described a representative international approach. That example is a QRA-informed LNG import terminal siting at Hoek van Holland, where two LNG import terminals will be located at the mouth of the main ship channel to Rotterdam. That licensing process, divided into two parts, first studied the relationship between movement and potential consequences, which resulted in an optimized routing system to minimize risks of ship movements in the harbor. The second part of the application process included a QRA of hazards that could result from unplanned releases of LNG. The principal hazards considered were vapor cloud (gas dispersion) fire and pool fire radiant heat hazards. The scenarios studied included maximum credible accidents (MCA), maximum non-credible accident risk (MNCA), and potential "domino" effects on nearby facilities. Non-credible risks identified included terrorist acts, as well as crash of aircraft into a storage tank. The closest residences to either of these facilities are more than 1600 m distant. The risks were determined to satisfy the Netherlands' risk acceptance criteria, which are less than 1 in 1,000,000 per annum for individual risk and less than 1 in 100,000 chance of greater than 10 fatalities per annum to residents and people in surrounding plants. The QRA model identified uncertainties in determining appropriate dispersion separation distances, recognizing that no large-scale validation test results were available. For explosion effects associated with delayed ignition (vapor cloud explosion), the QRA study was based on Sandia report SAND2004-6258, which suggests that overpressures will arise only when a cloud is confined and obstacles to a propagating flame are present. In light of this, more than one presenter reminded the audience about the explosion of a cloud of light hydrocarbons such as butane in December 2005 at the Buncefield, U.K., tank farm.

In contrast to this QRA process, regulatory requirements in the U.S. presently are consequence-based, with a buffer zone distance from the LNG facility mandated to keep the public out of harm's way. There is no statutory requirement for quantitative determination of the risk (probability) of a hazardous event. Procedures for licensing LNG facilities in the U.S. do frequently appeal for consideration of the probability of a (hazardous) event's occurrence, but such appeals are not sufficient to satisfy the requirements of rigorous QRA. Instead, regulators categorize events (such as amount of LNG spilled, or the seriousness of an ensuing fire) as "high", "moderate", or "low," with no specific quantitative measures to justify these categorizations. There is reason to believe that introduction of "measures of risk" without supportable quantification may contribute to the contentiousness surrounding the determination of safe separation distances required by US regulations.

Non-governmental organizations are playing increasingly important roles in the U.S. regarding LNG siting approval. Some attendees identified potential problems in the "joint/cooperative" preparation and promulgation of standards and regulations by the U.S. Department of Transportation (DOT) and the National Fire Protection Association (NFPA). Historically, before the 1980s, there was no federal government regulation specifying safety requirements for LNG facility approval, and NFPA 59A (Standard for the Production, Storage, and Handling of Liquefied Natural Gas) was typically prescribed. In the early 1980s, DOT promulgated 49 CFR 193 (Liquefied Natural Gas Facilities: Federal Safety Standards). From that time forward, the requirements to provide assurance of public safety for LNG import terminal siting permits were specified in federal regulation, which continued to reference certain provisions of NFPA 59A. In the late 1990s, NFPA 59A was formally incorporated into 49 CFR 193.

The U.S. regulation (49 CFR 193) was developed, at least in part, in response to elements of the 1978 Energy Act regarding remote siting of LNG import terminals. The methodology chosen by DOT to meet those "remote siting" requirements was, and remains, safe separation distances between the facility and the public sufficient to keep the latter out of harm's way. The primary hazard to the public was identified as a fire resulting from unintended release of LNG, as opposed to explosion. Two fire hazards were the regulatory focus: a "pool fire" if spilled LNG was immediately ignited, or a "vapor cloud fire" if spilled LNG evaporated and formed a cloud that ignited as it drifted downwind. These two types of hazard zones, from which the public is forbidden, are defined in 49 CFR 193 as "exclusion zones." Regulation defines them as:

- Vapor cloud exclusion zone - the maximum distance, for a specified "design spill." determined with a regulation-prescribed mathematical model, that could be reached by an LNG vapor cloud before it falls below a time average concentration of 2.5% by volume (one half of the lower flammable limit concentration for methane).

- Fire radiation exclusion zone - the maximum distance, from a specified "design spill fire," determined with a regulation-prescribed mathematical model, to which a person, at ground level, would be exposed to a thermal radiation flux of 5 kW/m^2 (a thermal radiation flux, applied to bare human skin, which will cause 2nd degree burns in approximately 30 seconds).

Vapor Cloud Exclusion Zones

When DOT promulgated 49 CFR 193, the spill prescribed to determine the vapor cloud exclusion zone separation distance was a guillotine rupture of the largest operating line carrying LNG in the land-based facility, with full flow maintained for 10 minutes (or a shorter time if approved by DOT with demonstration by the applicant that the line could be shut down in the shorter time period). In a typical import terminal, this line is the ship unloading line (SUL) which typically flows approximately 60,000 gpm LNG. The SUL spill thus became the spill (~60,000 gpm for 10 minutes = 600,000 gallons) which determines the controlling (largest) vapor cloud exclusion zone required to protect the public. The vapor cloud dispersion exclusion zone is determined for a pool of LNG which evaporates due to heat transfer from the spill impoundment where it is captured (approximately 600,000 gallons LNG). The rate of evaporation must be entered into a regulation specified vapor dispersion model, which calculates the maximum extent of the 2.5% gas concentration in the cloud.

In 2000, DOT changed the "design spill" required under 49 CFR Part 193 to the "single accidental leakage source" specified in NFPA 59A. Speakers at the conference pointed out that, in 11 LNG Import Terminal Siting Draft and Final Environmental Impact Statements reviewed up to 2005, the "design spills" applicants proposed for analysis included, along with the guillotine SUL breakage, a variety of guillotine breakages of smaller (such as instrumentation) lines, with 10 minute spills ranging from 28,900 gallons to 812,000 gallons. This inconsistency in design spill selection, due in part to differences in transfer line lengths, diameters, flow rates and branch connections in the various applications for import terminals (but primarily due to changes from full pipe rupture to failure of small diameter pipe attachments), led to similar inconsistencies in the resulting vapor cloud exclusion zone distances.

In April 2007, the Fire Protection Research Foundation (FPRF) issued the report, “LNG Source Term Models for Hazard Analysis: A Review of the State-of-the Art and an Approach to Model Assessment.” This was followed in March 2009 by the FPRF report, “Evaluating Vapor Dispersion Models for Safety Analysis at LNG Facilities.” Both of these reports, done at the request of the National Fire Protection Association’s 59A Technical Committee, provide evaluation tools and criteria for the decision-making process for referencing models in the 59A standard.

In January 2009, the National Association of State Fire Marshals (NASFM) completed a review, funded by DOT, of the LNG Source Term and Vapor Dispersion Model Evaluation Protocols (MEP) issued by the FPRF and NFPA 59A. NASFM found that, in general, the MEP approach was “useful and valuable and will promote a global drive towards better quality modeling approaches.” However, the NASFM panel also felt that the use of the MEP required clarification and further guidance to be useful for the fire service, emergency responders, authorities having jurisdiction, and regulators. In June 2009, the NASFM issued its review of the FPRF report, “Evaluating Vapor Dispersion Models for Safety Analysis of LNG Facilities.”

The Vapor Dispersion Model MEP and the Source Term Assessment reports prepared by FPRF for the NFPA 59A Technical Committee are publicly available and were the subject of considerable discussion at the conference. A significant finding regarding evaluation of the SOURCE5 (vapor source model routinely used in vapor cloud exclusion zone determinations filed with FERC in the US for import terminal siting permits) can be summarized in the following statement from the report: “Finally, a prototypical assessment is carried out of the ... SOURCE5 source term model using the developed assessment methodology. SOURCE5 ... has limited scope, but also its scientific basis, especially for pool spreading, is quite unphysical. Furthermore the prescription of SOURCE5 that the cloud formed in a dike should not disperse or dilute at all until the pure vapour has accumulated in the dike to the level of top of the wall is unphysical and is likely to lead to very optimistic (non-conservative) hazard predictions".

<u>Fire Radiation Exclusion Zones</u>

Determining the controlling fire radiation exclusion zone is presently based on the assumption of a fire atop the primary LNG concrete full-containment vessel (increasingly the type of containment proposed). The exclusion zone thus determined is typically about 1000 feet. However, the LNGFIRE model (prescribed by 49 CFR 193) may not be appropriate for this use because it had not been verified for fires greater than about 35 meters diameter (a full-containment tank diameter could be approximately 85 meters). Additionally, the LNGFIRE model has not been verified for tank-top fires of any size, because it was developed for determining fire radiation exclusion zones for fires resulting from ignition of LNG spilled into ground level impoundments. The liquid level in such a tank (the height of the base of the fire above ground level) could be approximately 35 meters.

The conference identified other areas of uncertainty that could potentially impact credible/acceptable determinations of exclusion zones, including:

- Data from fire test programs are limited to pool fires of approximately 20 meters diameter on water and 35 meters diameter on land. A primary result is data specifying the thermal energy flux radiated from the surface of the fire. Important uncertainty remains regarding the extrapolation of the radiative fluxes from these (small) test fires to much larger fires that are considered possible from LNG ship releases. Important uncertainty exists in the accurate quantification of the fluxes that would be experienced from the surface of such large fires, where reduction by smoke obscuration could be expected to reduce (by masking) radiation from the fire surface.
- As described above, determination of the controlling fire radiation exclusion zone is presently based on the assumption of a fire atop the primary LNG concrete full-containment vessel (increasingly the type of containment proposed), with a typical exclusion zone extent of about 1000 feet. Such a fire, if burning atop a full tank (suffering a roof collapse), could not be extinguished and would have to burn itself out -- a process that could require tens of hours. The duration of such a fire, with attendant severe exposure of the concrete tank structure, raises questions about tank survival that do not appear to have been considered.
- The unexpected catastrophic vapor cloud explosion that occurred at Buncefield in 2005 in a rather open space, hypothesized by some parties to have been caused by flame acceleration due to shrub lining a roadside, showed that uncertainties remain in the potential for damage from large hydrocarbon cloud explosions. The conference noted that FERC appears to have failed to consider important evidence (from Buncefield) regarding unconfined vapor cloud explosion potential.(Note: The FERC representatives at the conference, in reviewing this summary, stated that FERC requires applicants to address vapor cloud explosions for facilities such as NGL extraction trains and determine overpressures related to partial confinement.)

On the marine side, Sandia National Laboratory has conducted extensive analyses to establish the consequences of containment breaches from LNG carriers. LNG Carriers are becoming larger, with capacities already in excess of 250,000 cubic meters. The LNG carrier fleet utilizes two basic designs. The traditional MOSS ships typically carry LNG in 4 or more aluminum spheres (typically 25,000 cubic meters each, prior to the introduction of the larger carriers) that are supported independently from the ship's hull. The other (MEMBRANE) design uses thin stainless steel tanks that are supported by the hull structure. Sandia has carried out detailed analyses to evaluate the effects of breaches of the LNG tanks both near-shore and off-shore. Sandia's analyses indicated that a fire following rapid release of 12,500 m^3 (1/2 of one “typical” MOSS tank) through a 5 square meter area hole onto water could expose people to second degree burns (heat flux of 5 kW/m^2) approximately one mile distant from the center of the fire. Vapor dispersion distances (to 5% methane) for the same quantity spilled (but not immediately ignited) were said to be two to three miles. Sandia has updated these predictions to account for the doubling in size of ship containments now in service (the largest carriers in operation are 265,000 cubic meters). Sandia has stated that the increases in distances (predicated on rapid release of one-half of one typical tank) for the larger ships were generally less than 10%.

Since the 2005 Vancouver Conference, research required by the U.S. Congress has highlighted another potentially important area of uncertainty affecting estimates of the consequences (i.e. damage distances) for LNG spills onto water. This uncertainty centers on the potential for cascading events, i.e. "knock-on" or "domino" effects, which could damage a ship so severely that they could cause further releases, possibly resulting in complete failure and burning of the ship's contents.

Sandia described ongoing work on both the large fire radiation flux uncertainty and better quantification of the potential for cascading failures. Both programs should be completed in 2010, with reports available within an additional year. The best available information suggests that pool fires on water have been produced with diameters approaching 100 meters in diameter (the goal of the test program). Cascading failure tests are evaluating two potential ship failures: brittle fracture of structural steel due to contact with LNG, and insulation failure due to fire exposure such as could occur from the 12,500 m^3 spill already "established" by Sandia as credible.

Conclusions

LNG will be an increasing source of carbon-based fuel in the next decades as the mix of conventional and alternative sources of energy are challenged to meet the needs of ever growing demands for energy.

Notwithstanding the laudable safety record of the LNG industries, LNG import terminal operations, involving as they do concentration of immense quantities of energy in storage and in transport, are major potential hazards.

The risks attending LNG import terminal ventures pose continuing questions of low risk/high-consequence occurrences that require significant additional effort to better quantify and prevent them in a manner acceptable to stakeholders. Thus, siting and operating LNG facilities that meet the public's safety concerns will be a continuing challenge.

Here are other uncertainties the conference identified which require improved technical data and analysis techniques:

<u>Land Side</u>

- Resolving issues surrounding definition of maximum credible spills
- Resolving modeling issues for vapor dispersion, including source (evaporation rate) models that provide critical input
- Resolving modeling issues for fire radiation, including the applicability of LNGFIRE to elevated (tank-top) pool fires and satisfactorily conservative specification of the fire surface radiative fluxes (damage criteria) to be used
- The survivability of LNG tanks to fire exposures that are assumed to determine radiation exclusion zone(s)
- The limiting conditions for vapor cloud explosion.

<u>Marine Side</u>

- Correct specification of the fire surface radiative flux to be used in defining safe separation distances, similar to the Land Side issue
- Questions affecting the determination of maximum credible spill size, primarily the potential for increasing the size of credible spills by cascading failures on LNG carriers
    - due to brittle fracture
    - due to vulnerability of insulation systems
    - due to local explosions.