RISK ASSESSMENT/HAZARDS FOR DEEP WATER PORT LNG TERMINALS

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ABSTRACT

In December 2004, Sandia National Laboratories (Sandia) developed a guidance document providing a risk and safety analysis framework for assessing site-specific hazards and risk management approaches to minimize the consequences to people and property from a possible liquefied natural gas (LNG) spill over water.

In the summer and fall of 2005, Sandia worked with the United States Coast Guard and the California State Lands Commission to use the developed framework to assess the analysis of the hazards and consequences to the public of possible large spills from an LNG Deep Water Port (DWP) terminal off the coast of California.

This paper summarizes the approach and analytical techniques recommended for analyzing hazards and risks from a potential large LNG spill from a DWP. While the risks and hazards from any spill at a terminal are site-specific, the information presented in this paper can be used to help the public and others understand the general scale of the hazards and risks to the public and commerce from a large LNG spill at an LNG deep water port terminal along the coast of California.

INTRODUCTION

While accepted standards exist for the systematic safety analysis of potential spills or releases from LNG storage terminals and facilities on land, no equivalent set of standards exist for the evaluation of the safety or consequences of potential spills or releases over water from marine transport, handling, processing, or storage of LNG. Heightened security awareness and energy surety issues have significantly increased industry's and the public's attention to these activities.

In March 2005, the United States Coast Guard (Coast Guard) requested that Sandia support the Coast Guard and the California State Lands Commission by providing a technical evaluation of the appropriate approaches, models, assumptions, analyses, and risk management options that should be used in conducting a risk and hazards assessment of a possible large spill from an LNG Deepwater Port facility off the coast of California.

A Deepwater Port is a marine facility located more than approximately 3 miles off a coast. The Coast Guard is responsible for permitting DWP terminals and currently, only a few Deepwater Ports exist to import crude oil and LNG. There are several conceptual designs for LNG DWP terminals including gravity-based storage structures, submersible moored buoys systems, and anchored floating storage facilities. In all current designs, the LNG transported to the DWP is either regasified by specially designed LNG transport vessels while attached to a buoy, or stored and regasified at the DWP. In some designs the storage systems float and look like large ships as shown in Figure 1 for the proposed Cabrillo DWP, approximately 14 miles off the coast of Oxnard, California. At the DWP terminal the LNG is regasified and the natural gas is pumped via a subsea pipeline or pipelines to on-shore receiving facilities and the natural gas pipeline system.

Figure 1. Conceptual design of the proposed Cabrillo Port LNG DWP Floating Storage and Regasification Unit (FSRU).

LNG DWP terminals have some advantages from a public safety standpoint. Being off-shore makes the facility remote, which often helps to minimize the potential health and safety risks to the on-shore public from a potential spill. But there are some drawbacks with various DWP concepts. The remote facilities can be more difficult for surveillance and to protect from accidental or intentional events. The DWP facilities often store large quantities of LNG and potential spills can be larger than might occur with more standard and smaller LNG cargo vessels coming into an on-shore LNG facility.

Sandia was asked to evaluate the potential hazards from a DWP based on the LNG spill risk and safety analysis framework developed in the December 2004 Sandia report, "*Guidance on Risk Analysis and Safety Implications of a Large Liquefied Natural Gas (LNG) Spill over Water*". The report provides a technical framework to assess the site-specific hazards from a potential LNG spill over water and identify approaches to minimize the impact of such a spill on the safety of the public and property. The goal of Sandia's efforts with the Coast Guard was to assist them in assessing the hazards to the public from a potential LNG DWP spill during transfer, storage, or regasification operations. While the results presented use site-specific data from the proposed Cabrillo LNG DWP to provide a qualitative summary of potential hazard distances from a spill, the approach used and presented can be used to assess the hazard issues for any DWP. Also, the results discussed provide a general scale of the expected hazard distances for other deep water ports.

RISK AND HAZARD EVALUATION FRAMEWORK

Risk assessment of an LNG DWP import facility should be viewed as a system that includes the LNG tanker, the DWP terminal and location, navigational lanes, and the nearest commerce and public areas to the DWP terminal. Four classes of attributes affect the overall risks and hazards to commerce and the public and include:

- The context of the import facility – location, site specific conditions, DWP LNG storage and regasification and transmission design and operations, importance of the LNG or natural gas to the region;
- Potential targets and threats – potential accidental events, credible intentional events, and ship or infrastructure targets;
- Risk management goals– identification of levels of consequences or hazards to be avoided, such as injuries and property damage to the public, import on marine commerce, and LNG or natural gas supply reliability required; and
- Protection system capabilities – LNG tanker safety and security measures, LNG DWP terminal operations and safety and security measures, and early warning and emergency response/recovery measures.

These attributes must be evaluated to determine if the protection systems in place effectively meet the risk protection and management goals identified for a specific import terminal location and operations. If so, then the safety and security measures and operations developed for the LNG terminal are adequate. If the initial risk assessment determines that the identified protection goals are not met, then modifications in facility design and operations, safety and security measures, or emergency response and early warning measures should be considered to improve overall safety and security and meet the necessary protection goals.

This framework developed provides a performance based approach to protect the public and commerce. This allows flexibility in LNG DWP terminal operations, protection, and siting. The performance-based approach enables public safety and public officials to require more stringent operational oversight and improved safety and security measures in more sensitive or less remote areas, while also having the ability to allow facilities that may be more remote or less sensitive have less oversight and less stringent security measures as appropriate.

Since the relative protection goals of a facility can change over its operational life, marine import operations should be reviewed on a regular basis to reassess the adequacy of safety and security measures to protect the public and commerce. Changes in any number of factors including the context or role of the terminal, changes in threats or threat-levels, changes in risk protection goals, or changes in risk management and safety systems could impact the basis for the original evaluation, making reassessment of the hazards and risks to people and property of a potential LNG spill necessary. Chapter 6 of the 2004 Sandia report provides a framework for assessing the risks to the public and property from a large LNG spill over water. These elements are applicable to all LNG deepwater ports and the general considerations are presented below.

Step One - Characterize Assets

Assess he context of the LNG facility such as location, site-specific conditions, and nominal operations must be identified. Information needed includes:

- **Type and Proximity of Neighbors**
  - Distance to residential, commercial, and industrial facilities or other critical infrastructures such as bridges or tunnels, and
  - Transit operations– Near or in major ship channels or routes or remote from routes
- **Environmental Conditions**
  - Wind-driven Spill Movement & Dispersion – prevailing wind direction, speed, and variability,
  - Severe Weather Considerations – hurricanes, storm surges,
  - Tidal-driven Spill Movement & Dispersion – height, current, and influence on spill movement and dispersion,
  - Seismic issues - ground displacement, soil liquefaction, and
  - Temperature issues – ice, thermal impediment to operations
- **Nominal Operational Conditions**
  - LNG tanker and DWP terminal storage size and design,
  - Expected frequency of shipments,
  - Processing operations associated with DWP terminal – storage, LNG regasification, natural gas transmission,
  - Importance of LNG Shipments – Available storage, seasonal demands, percentage of regional or local supply, and
  - Transit – additional traffic (near other large ships, pleasure boats) and distance to it; transit near critical infrastructures, such as other terminals, commercial areas, or residential areas; number of critical facilities along transit; distance to critical facilities along transit.

Step Two – Identify Potential Threats

The potential or credible threats expected for the facility, based on site location and relative attractiveness of either an LNG tanker, DWP terminal, or other nearby targets, should be identified.

- **Accidental Event Considerations –** shipping patterns, frequency of other large ships, major objects or abutments to be avoided, processing or storage operations issues, warning systems, weather impacts on waterways or operations,
- **Intentional Event Considerations –** threat levels identified by Homeland Security, identified threats, past threats and shipping attacks, difficulty of attack scenarios for a given site, and

- **Attractiveness of Targets –** impact of an LNG tanker or DWP terminal attack, impact on facilities near navigational route, impact on other facilities near site not associated with LNG operations.

Step Three - Determine Risk Management Goals and Consequence Levels
Identify risk management goals or consequence levels for LNG DWP operations, including potential property damage and public safety (including injury limits). Setting of the goals and levels would be conducted in cooperation with stakeholders, public officials, and public safety officials. Consideration should be given to evaluating a range of potential risk management goals and consequence levels. In this way, an assessment of the range of potential costs, complexity, and needs for different risk management options can be compared and contrasted. Common risk management goals and consequence level considerations should include:

- Allowable duration of a loss of service, ease of recovery,
- Economic impact of a loss of service,
- Damage to property and capital losses from a spill and loss of service, and
- Impact on public safety from a spill – potential injuries, deaths.

Step Four - Define Safeguards and Risk Management System Elements
This includes identifying all of the potential safety and security elements and operations available on the LNG tanker, DWP terminal, or in transit. They include not only safety features but also safety and security-related operations and emergency response and recovery capabilities. These include:

- **Operational Prevention and Mitigation Considerations**
  - System operational, storage, processing, and distribution safety/security features,
  - Proximity and availability of emergency support – escorts, emergency response, fire, medical and law enforcement capabilities,
  - Early warning systems,
  - Ship interdiction and inspection operations and security forces, and
  - Ability to interrupt operations in adverse conditions – weather, wind, waves.
- **Protective Design**
  - Design for storm surges, blasts, thermal loading,
  - Security measures – fences, surveillance, exclusion areas,
  - Effective standoff from residential, commercial, or other critical infrastructures based on recommended hazard distances from an LNG spill over water, and
  - Redundant offloading capabilities.

Step Five - Analyze System and Assess Risks
The defined risk management goals and consequence levels should be compared to the existing system safeguards and protective measures. This effort would include evaluation of possible events for a potential spill that might occur for the site-specific conditions, threats, and calculated hazard distances and hazard levels. If the system safeguards in place provide protection of public safety and property that meet risk management goals, then the overall risks of an LNG spill would be considered compatible with public safety and property goals. If not, then enhanced risk mitigation and prevention strategies, changes in operations or facility location, should be considered. While many options are possible for a given site or proposed facility, approaches or combinations of

approaches should be considered that can be effectively and efficiently implemented and that provide the level of protection, safety, and security needed for LNG operations at a given location.

EXAMPLE RISK AND HAZARD ANALYSES FOR A DEEP WATER PORT

As an example of how to use the risk and hazard analysis framework presented above, we will discuss efforts conducted for the proposed Cabrillo LNG DWP. The proposed Cabrillo DWP is about 14 miles off the coast of southern California between Ventura and Los Angles Counties. The terminal includes

- An offshore LNG import terminal that would be anchored and moored to the ocean floor for the life of the project as shown in Figure 1,
- The import terminal would be a vessel-shaped, floating storage and regasification unit (FSRU), that would be specially built to transfer, store, and regasify LNG,
- The FSRU would have 3-91,000 m^3 modified Moss-type LNG storage tanks, and include a double-hull design
- The natural gas will be pumped via two subsea pipelines to on-shore receiving facilities and natural gas distribution pipelines.

The proposed terminal location is in federal waters approximately 880 meters deep. The site is also about 2.7 miles from the edge of Point Mugu Sea Range and over 2 miles from the edge of the nearest shipping lane. It is about 15 miles from the Channel Islands National Marine Sanctuary and 20 miles from the nearest boundary of the Channel Islands National Park. Information on the analysis efforts is presented in the January 2006 Sandia report "*Review of the Independent Risk Assessment of the Proposed Cabrillo Liquefied Natural Gas Deepwater Port Project*".

Threat, Breach, and Spill Analyses

Several types of accidental threats exist for this type of offshore terminal. They include collisions from other ships or LNG cargo vessels, spills during LNG transfers, or accidents associated with the storage and regasification of the LNG. The results from these accidental events could include the puncture of an LNG cargo tank from a ship collision and a subsequent fire, or a fire or combustion related explosion caused by an LNG leak or spill during the handling or processing of LNG on the FSRU. Also possible could be a leak and spill that leads to a large LNG vapor dispersion.

A range of intentional threats are also credible for this type of offshore terminal. These threats can range from insider threats to intentional attacks with a range of weapons or delivery modes such as airplanes, ships, or boats. Weapons could include such things as disabling safety features with hand tools by an insider, to the use of weapons or high explosives for other types of intentional attacks. These threats provide a range of potential breach conditions and associated spills.

Several potential accidental and intentional events were evaluated for the Cabrillo Port FSRU design to assess potential breach sizes and spill volumes. The FSRU, which has a double-hull design provides significant standoff between the storage tanks and the outer hull, even greater than current LNG vessels. This makes it particularly robust against collisions, accidents, and intentional threats. Modern numerical analysis techniques were used to calculate breach sizes based on the identified accidental and intentional threats.

LNG transfer and regasification operations were also evaluated to assess a potential breach caused from a spill during LNG transfer from an LNG cargo ship, or during regaisifcation operations on the FSRU. The analysis showed that some confinement of LNG spilled during transfer operations could vaporize, ignite, and lead to a possible breach of a cargo tank. The evaluation of the proposed processing on the FSRU, including regasification and compression, suggests that complete processing system safety and security measures have not been totally defined. While this makes evaluation of the impacts of possible off-normal processing events more difficult, it provides flexibility in adding additional safety and security measures in the final design if required. Overall, the processing system layout and safety considerations in the conceptual design suggested that the potential threats from off-normal events in the processing area would probably impact only one FSRU storage tank.

The evaluations identified two governing events that were considered for spill and hazard analyses. These are noted in Table 1 along with the expected breach and spill sizes for a number of controlling events. One event includes the possibility of the breach of two tanks with up to a 7 m^2 hole in each tank. The other event suggests the possibility of a breach of one tank of up to 12 m^2. These events may not lead to the full release of all the LNG from each tank, but for conservative estimates of hazard distances, full tank volume releases were assumed.

Table 1. Suggested FSRU Breach and Spill Scenarios

Storage Tanks Breached	Event	Total LNG spilled (m^3)	Area of breach per tank (m^2)
Accidental Events			
1	Collision with large ship at speeds approaching 20 knts, puncture of single LNG storage tank, assuming no plugging of puncture with vessel	100,000[a]	20
1	Collision with large ship causing circumferential rupture of single LNG storage tank	50,000	1013
1	Collision with large ship at speeds of 20 knts, puncture with plugging by vessel	50,000	5
Off-normal Processing Events			
1	Off-normal processing event that causes breach of LNG storage tank near deck level	50,000	10
Intentional Events			
1	Single large intentional event	100,000[a]	12
2	Multiple large intentional events	200,000[a]	7

[a] rounded up from 91,000 m^3 per tank for conservative estimates

Table 1 includes some large potential spills, but not a single simultaneous catastrophic release of all three storage tanks. Current threat information and assessments suggest that this event is not realistic. For each type of breach considered, the storage tank contents assumed to be released are noted. Additionally, each tank was assumed to be totally full. These assumptions make the estimated volume of LNG spilled conservative and therefore the calculated fire and dispersion hazards associated with these spills are expected to be conservative.

Fire and Dispersion Hazard Analyses

From the results shown in Table 1, the intentional two-tank release was expected to be the governing spill for hazard distances because of the total volume assumed spilled over a relatively short time span. Sandia assessed the potential LNG pool sizes for these events and calculated both the potential hazards from both a pool fire and from a potential vapor dispersion. For the fire calculations, the Moorhouse correlation was used for flame height and a surface emissive power of 220 kW/m^2, as well as a burn rate of 3×10^{-4} m/s, and a transmissivity of 0.8 were used. The Moorhouse correlation and view factors can be found in the Society of Fire Protection Engineering Handbook on Fire Protection Engineering, 2nd edition. The parameter assumptions made are reasonable given the current knowledge of the required input parameters and experimental testing and should provide a conservative estimate of thermal hazard distances. The hazard distance results calculated are presented in Figure 2 as a function of heat flux level.

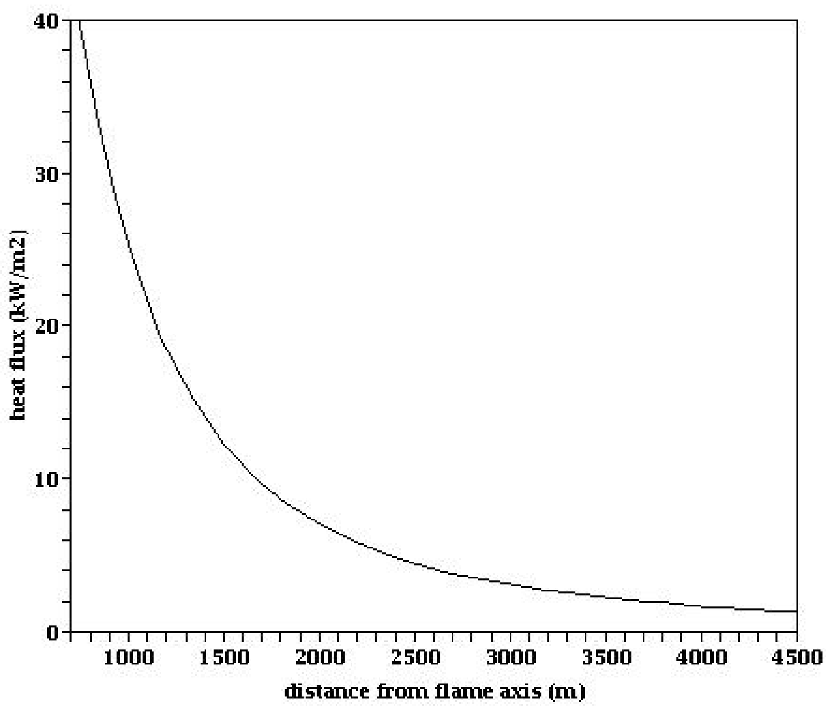

Figure 2: Calculation of pool fire hazards for a 200,000m^3 spill from the Cabrillo Port FSRU.

A heat flux level of about 35 kW/m^2 for 10 minutes is often considered the hazard criteria for infrastructure exposure since this level and duration will begin to damage steel. This suggests major damage could occur to ships or structures within about 800m or one-half mile of the center of the pool fire. Likewise, 5 kW/m^2 for 30 seconds is considered by the National Fire Protection Association as the hazard criteria for human exposure. This suggests a hazard range for people of about 2400m or about 1.4 miles from the center of the pool fire. Other heat flux level hazard criteria can be used, and Figure 2 provides hazard distances for a range of different heat flux levels.

For most large intentional events, an ignition source is likely and an LNG spill is expected to burn as a pool fire, with the hazard distances identified above. In the event that an ignition source is not present, the spilled LNG might disperse as a vapor cloud. To address this possible hazard scenario, distances to different methane concentrations were calculated for a 200,000 m^3 LNG spill that might disperse as a vapor cloud and are presented in Figure 3. The calculations were based on site-specific wind conditions for the Cabrillo Port DWP for nominal wind and atmospheric conditions. The analyses were obtained using Vulcan, a Sandia computational fluid dynamics code validated for LNG dispersion modeling. The lower flammability limit (LFL), which is 5% methane by volume, is commonly considered as the basis to identify vapor hazard distances based on possible ignition of the vapor and a subsequent fire. Based on this value, a nominal maximum dispersion distance of about 5500m or 3.3 miles from the edge of the pool spill could occur. Since other methane concentrations can be used for hazard distance criteria, they are included in Figure 3. For calmer wind and more stable atmospheric conditions, the distance to a 5% methane concentration could approach 7500m or 4.5 miles based on the analyses conducted by Sandia with Vulcan.

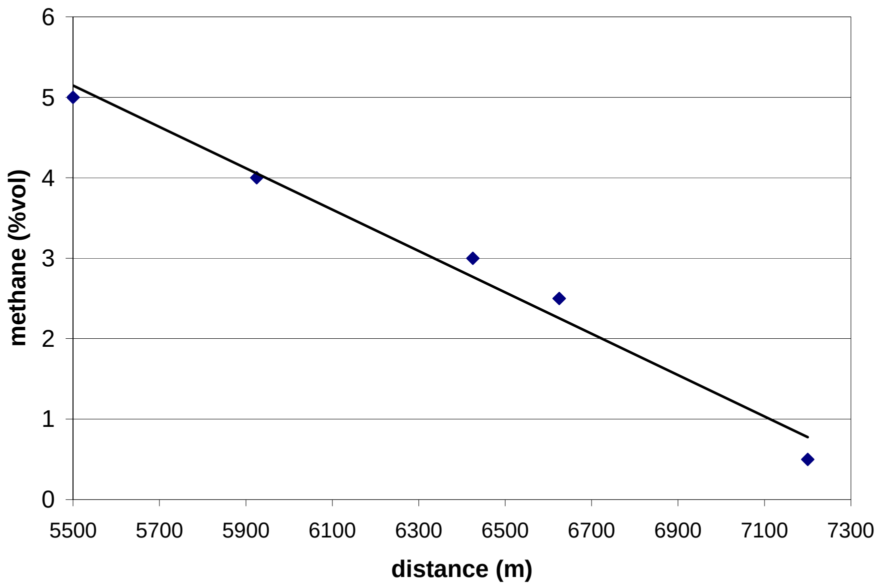

Figure 3: Maximum distance to various methane dispersion concentration levels for a 200,000m^3 spill from the Cabrillo Port FSRU.

CONCLUSIONS

This paper provides on overview of the risk and safety analysis framework developed for assessing site-specific hazards and risk management approaches to address the safety and security of the public from possible large LNG spills over water, including from an off-shore LNG deep water port. The risk and hazard analysis results obtained using the developed framework were presented for the proposed Cabrillo Port DWP to provide an example of the approach and the methods necessary to conduct a good risk and hazard analysis. The proposed Cabrillo Port DWP is a floating, off-shore, LNG receiving and regasification terminal in southern California and the hazard and risk analysis results presented are specific for this site. But, the results presented in this paper do provide a general scale of the potential hazard distances and risks to the public and commerce from a possible large LNG spills at LNG deep water ports off the California coast.