5. SAFETY REVIEW

LAI's primary objective in conducting the safety review was to assess the hazards associated with an offshore LNG storage facility based on existing scientific studies and reports. Currently, there is no other offshore storage and regasification facility similar to Broadwater anywhere in the world. Therefore there is no comparable safety record for a facility that is equal to or substantially similar to the proposed FSRU. However, LNG cargo vessels have sustained an excellent safety record over the past forty years. There have been no cargo tank breaches of any type despite a number of LNG groundings. The double hull design of the LNG carrier and the stringent safety and security procedures surrounding LNG vessels in U.S. waters are partially responsible for the industry's historic safety record.

For this review, LAI evaluated the definition of hazard zones for the Project based on the Sandia Report[160] and EISs of other LNG projects in the U.S. and Canada. We researched the impact of LNG spills over water both for accidental and intentional events based on publicly available experimental and modeling studies performed to date. Finally, we extensively reviewed Resource Report 11 on Reliability and Safety in Broadwater's Application to FERC.

5.1. LNG Properties

LNG is a clear cryogenic liquid which boils at -259°F (-162.3°C). It is formed in a liquefaction process by cooling natural gas and reducing its volume by a factor of about 600. This decrease in volume is common to all gases when they are cooled and allows natural gas to be effectively and economically transported from the production site to the consumption site. LNG is less dense than water with a specific gravity of 0.423 and therefore floats on water.[161] On the other hand, cold LNG vapor is heavier than air by a factor of 1.52. If LNG spills, it forms a pool which spreads along the water surface or ground as it evaporates. Because the LNG vapor is initially colder than the surrounding air, it forms a visible (white) vapor cloud by the condensation of water. However, when the regasified LNG vapor reaches ambient temperature and pressure, it is lighter than air by a factor of 0.54 and is no longer visible.

LNG is composed mostly of methane (CH_4). Thus, the properties of methane serve as a first approximation of LNG's properties. LNG also contains ethane (C_2H_6), propane (C_3H_8), butanes (C_4H_{10}) and iso-pentane (C_5H_{12}) as well as nitrogen (N_2). However, the composition of LNG can vary widely depending on its source, as shown in Table 13, and therefore must be adjusted after regasification to meet a comparatively tight tolerance requirement regarding the chemical composition of the natural gas before it can be deemed pipeline quality.

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[160] M. Hightower, L. Gritzo, A. Luketa-Hanlin, J. Covan, S. Tieszen, G. Wellman, M. Irwin, M. Kaneshige, B. Melof, C. Morrow and D. Raglan, "Guidance on Risk Analysis and Safety Implications of a Large LNG Spill Over Water", SAND2004-6258 (Dec. 2004).

[161] Specific gravity is a dimensionless ratio of the densities of two materials with the reference material being water.

Table 13 – LNG Compositions by Source (% by volume)[162]

Origin	Nitrogen N_2	Methane C_1	Ethane C_2	Propane C_3	iso-Butane iC_4	n-Butane nC_4	iso-Pentane iC_5	LHV Btu/scf
Trinidad	0.01	96.13	3.40	0.39	0.04	0.03	0.00	1045.09
Algeria	0.32	89.57	8.61	1.18	0.13	0.18	0.01	1102.30
Indonesia	0.03	90.15	6.41	2.38	0.50	0.51	0.02	1118.00
Nigeria	0.05	90.48	5.05	2.95	0.58	0.87	0.02	1125.75
Qatar	0.09	89.18	7.07	2.50	0.46	0.69	0.01	1127.19
Abu Dhabi	0.13	85.82	12.57	1.33	0.06	0.08	0.00	1132.88
Malaysia	0.01	87.63	6.88	3.98	0.84	0.66	0.00	1155.70
Australia	0.30	86.11	9.04	3.60	0.42	0.52	0.01	1161.79
Oman	0.09	86.52	8.31	3.32	0.85	0.85	0.06	1162.33
Variation between high and low	0.31	10.31	9.17	3.59	0.81	0.84	0.06	117.24

Fuels require oxygen to burn. Therefore LNG itself is not flammable. LNG vapor, which is a mixture of LNG and air, is flammable if its concentration is between 5.5% (the lower flammability limit, or LFL) and 14% (the upper flammability limit, or UFL) by volume in air at 77°F (25°C). Figure 44 shows the flammability limits for selected fuels. It is important to note that methane's flammability range is narrow compared to hydrogen's flammability range, which has an LFL of 4.0% and a UFL of 75%.

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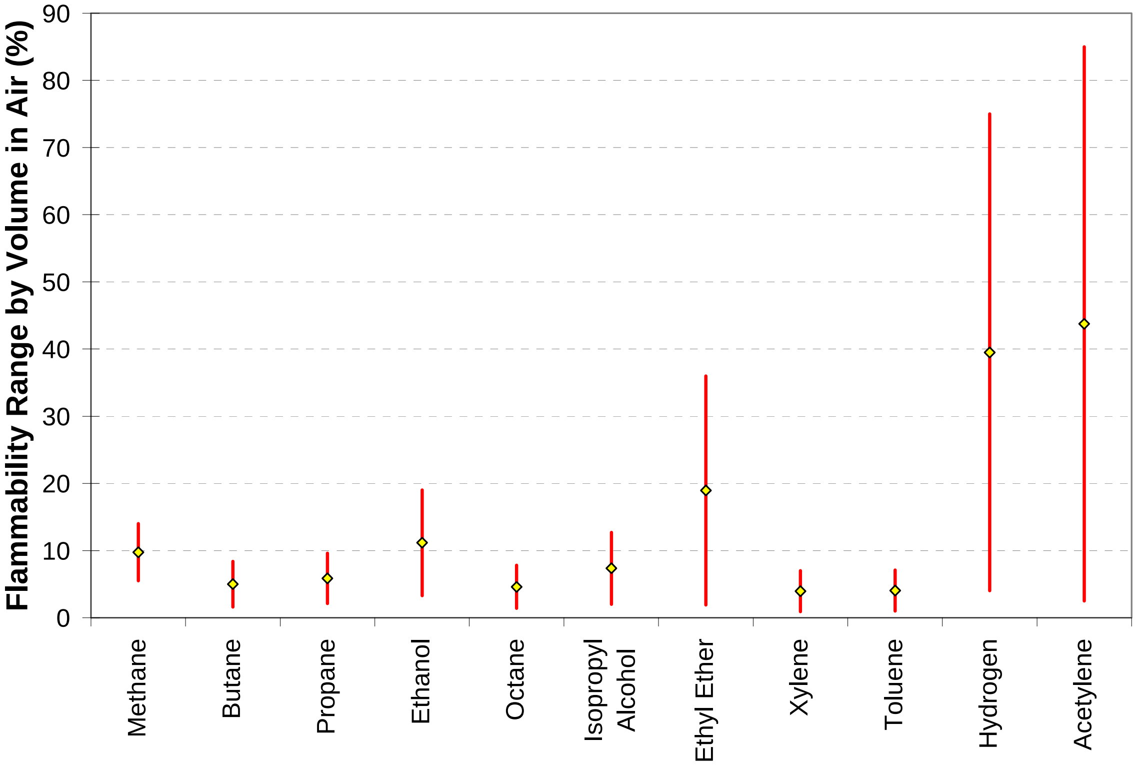
[162] Source: Solar Turbines

Figure 44 – Flammability Limits for Selected Fuels[163]



There are two general classes of explosive combustion: detonation, which is more powerful, and deflagration, which is less powerful. In order for a detonation to occur, the fuel / air mixture must be within the minimum and maximum detonation limits which are narrower than the flammability limits, and shock initiation is required.[164] Figure 45 shows that methane is a safer fuel relative to other hydrocarbons because it requires a large quantity of explosive initiator in order to detonate.

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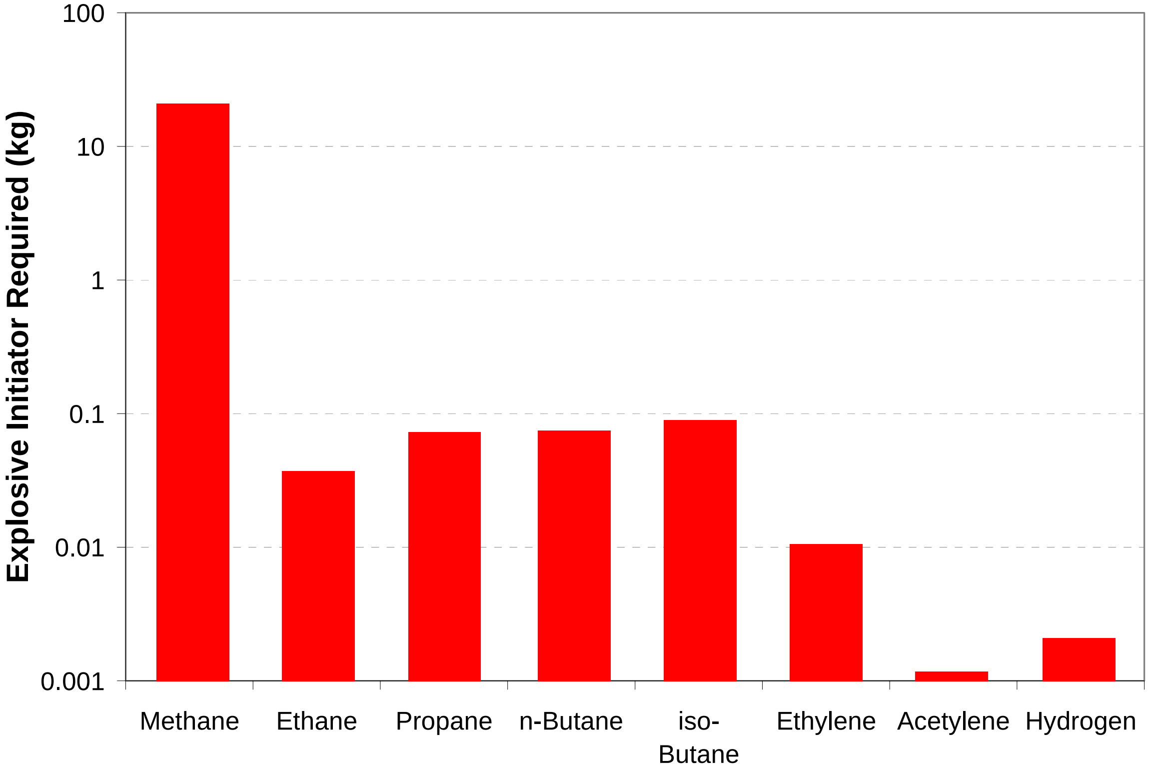
[163] Sandia Report, Table 4, p29.

[164] The detonation limits for various fuels do not seem to be publicly available and are not listed in the Sandia report with the flammability limits.

Figure 45 – Relative Detonation Properties of Common Fuels[165]



5.2. *LNG Hazards*

Several types of events can lead to an LNG spill at both onshore and offshore LNG facilities. LNG is stored in insulated storage tanks that are not under pressure, so the LNG is continuously vaporizing. The vapor is released through piping from the tank and either used as fuel for ancillary processes or recondensed. Leaks are, however, more likely to occur when LNG is under pressure for transfer or vaporization. Minor hazardous events, including leaks from low-pressure storage, from high-pressure pumps, vaporizers, metering or piping, are associated with the vaporization and storage of LNG. More serious events are associated with the LNG carrier and transfer of LNG from the carrier to the FSRU. Examples of more serious hazardous events include: an LNG carrier leak or failure, an emergency venting, and a transfer system leak or failure. Major events are associated with an intentional attack or a vessel collision between the FSRU and/or the LNG carrier and a vessel of significant mass such as an oil tanker or cargo ship.[166]

In the event of a spill from the FSRU or the LNG carrier, a pool of LNG will form on the water's surface (Figure 46). LNG is not soluble in water and is therefore not a source of seawater contamination. The liquid will vaporize into a cloud which drifts with the wind close to the

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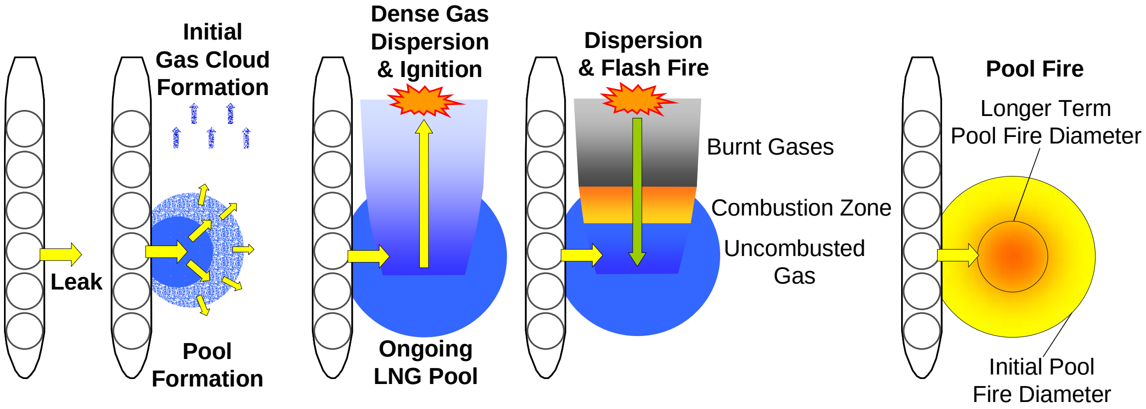
[165] Sandia Report, Figure 15, p154.

[166] For a more detailed list of hazards see: E. Skramstad, S.U. Musaeus and S. Melbo, "Use of Risk Analysis for Emergency Planning of LNG Carriers", DNV Consulting, 2000 Gastech Conference (November 20, 2000).

water surface. The vapor cloud will likely encounter an ignition source, such as a tug or fishing boat, almost immediately. If the gas is in the flammability range (5.5-14% by volume), it will ignite and rapidly burn back to the pool. This event is called a flash fire because it travels very quickly. The pool will continue to burn as long as LNG is leaking from the FSRU or carrier.

Figure 46 – Sequence of Events Following a Spill



Because of its long range effects, the most serious LNG hazard is thermal radiation resulting from a pool fire or the ignition of a vapor cloud. Thermal radiation is light emitted from the surface of an object due to its temperature. The power of the thermal radiation per unit area, also called the heat flux, is expressed in kilowatts per meter squared (kW/m^2 – international units). For reference purposes, the average radiation from the sun reaching the earth's atmosphere is 1.4 kW/m^2. At the edge of a pool fire, the thermal radiation may exceed 220 kW/m^2. The injury to humans from thermal radiation depends both on the intensity of the radiation and the exposure time (Figure 47). Exposure to heat flux at the edge of a pool fire is strong enough to damage structures and cause death almost instantly. Table 14 shows the type of damage that occurs from different levels of heat flux based on an average 10 minute exposure time.

According to the National Fire Protection Association (NFPA), an incident heat flux level of 5 kW/m^2 is recommended as the design level that should not be exceeded in areas where more than 50 people might assemble.[167] 5 kW/m^2 is also the permissible level for emergency operations lasting several minutes with appropriate clothing. At an exposure level of 5 kW/m^2, first-degree burns would occur in 20 seconds, second-degree burns in 30 seconds and third-degree burns in 50 seconds with a 1% fatality rate.[168] No pain has been shown for thermal fluxes less than 1.7 kW/m^2 regardless of exposure time.[169] The California Energy Commission's (CEC) filing at FERC concerning the Long Beach LNG terminal expresses concern that FERC uses a thermal

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[167] NFPA standard for the production, storage, and handling of LNG - Standard 59A (2001).

P.W. Parfomak and A.M. Flynn, "Liquified Natural Gas (LNG) Import Terminals: Siting, Safety and Regulation", CRS Report for Congress (May 27, 2004).

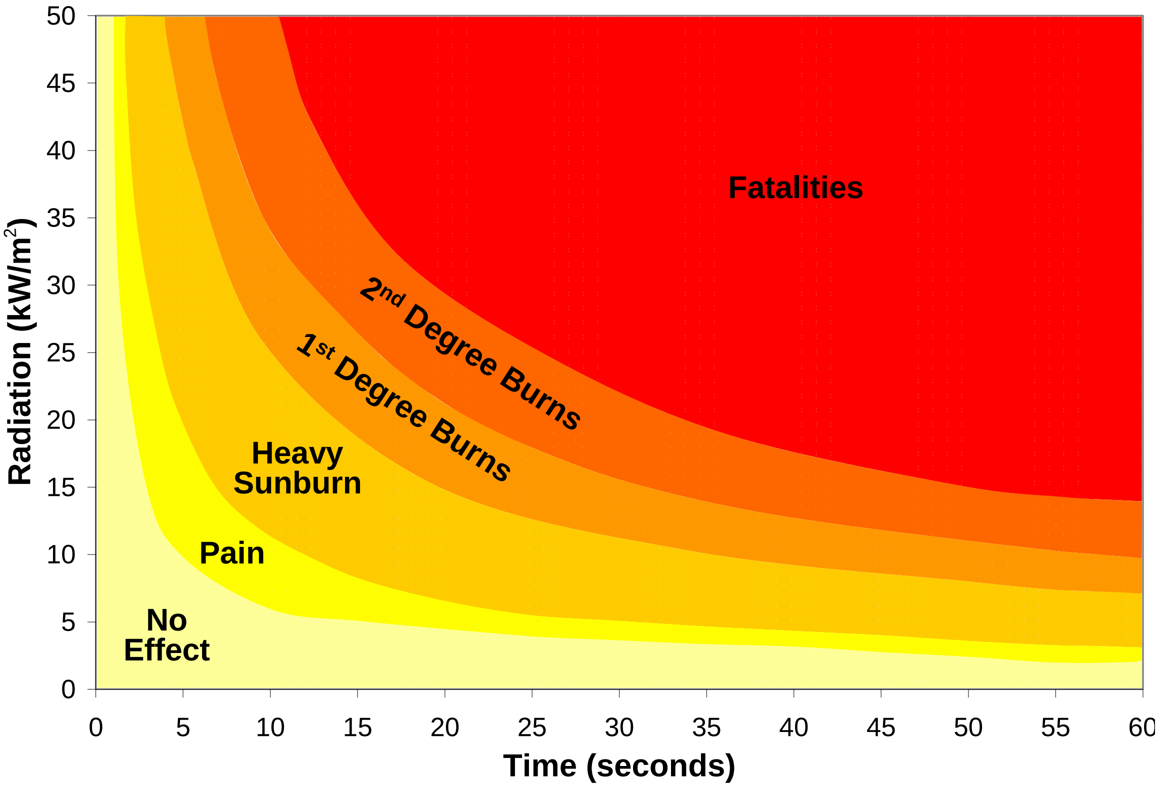
[168] California Energy Commission, December 8, 2005 filing at FERC concerning the Long Beach LNG terminal (CP04-58-000).

[169] C.L. Beyler, "Fire Hazard Calculations for Large, Open Hydrocarbon Fires", Chapter 3-11, SFPE Handbook of Fire Protection Engineering (2002).

radiation level of 5 kW/m^2 which does not ensure the safety of all populations.[170] They recommend a level of 1.4 kW/m^2 which is equivalent to the "no observable effects level" that the CEC uses in siting power plants.

FERC relies exclusively on the thermal radiation levels identified in NFPA 59A. It must be noted that in the 2005 NFPA 59A update, the proposed revision to the thermal radiation flux levels, from 5 kW/m^2 to 2.5 kW/m^2, was rejected. In Europe, the allowable thermal radiation level for "critical areas", *i.e.* areas that are difficult to evacuate on short notice, is 1.5 kW/m^2.[171] In Austria, the land use planning standard for new facilities is 2.0 kW/m^2.[172] **LAI considers 2 kW/m^2 to be the thermal flux level that should be used as the limit for calculating safe distances from an LNG pool or vapor fire**.

Figure 47 – Radiation Effects on Naked Skin[173]



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[170] California Energy Commission, December 8, 2005 filing at FERC concerning the Long Beach LNG terminal (CP04-58-000).

[171] Ibid.

[172] Ibid.

[173] ANEI Bear Head LNG Terminal Environmental Assessment, Figure 4.9 (May 2004).

Table 14 – Common Approximate Thermal Radiation Damage Levels[174]

Incident Heat Flux (kW/m^2)	Type of Damage
35-37.5	Damage to process equipment including steel tanks, chemical process equipment or machinery - third degree burns, lethal 50% of the time for a person wearing average clothing
25	Minimum energy to ignite wood at indefinitely long exposure without a flame
18-20	Exposed plastic cable insulation degrades – second degree burns, lethal 1% of the time for a person wearing average clothing
12.5-15	Minimum energy to ignite wood with a flame; melts plastic tubing
5	Permissible level for emergency operations lasting several minutes with appropriate clothing – no lethal effects, first degree burns in 20 seconds
1.7	No pain regardless of exposure time

Rapid phase transitions (RPTs) occur when spilled LNG comes into contact with warm water and explosively boils off. This rapid expansion from the liquid to the vapor state causes large overpressures. RPTs are localized in the vicinity of the LNG leak and may cause some structural damage to the LNG carrier or the FSRU. Although RPTs on their own do not involve a fire, they may increase the rate of LNG pool spreading and the size of a vapor cloud that could subsequently ignite. LNG composition is a critical parameter. RPTs are more likely to occur in LNG mixtures containing high fractions of ethane and propane.[175]

Boiling Liquid Expanding Vapor Explosions (BLEVEs) can fragment a storage tank because vapor cannot escape from the safety valve quickly enough in the event of a fire. BLEVEs are usually associated with incidents involving propane tanks since those are typically under high pressure. There has been one BLEVE incident involving an LNG truck in Europe. During this truck accident, the insulation around the storage tank failed and flames from the fire directly impinged on the tank resulting in superheating of the LNG, extremely rapid vaporization of the contained liquid and fatigue of the containment vessel. The pressure release valve either failed or was unable to handle the excessive vapor. A similar scenario might be possible in the event of a pool fire around an LNG vessel with spherical Moss tanks. However, the cargo tanks in an

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[174] Based on Sandia Report, Table 6, p. 38, and other fire safety documents.

[175] G.A. Melhem, S. Saraf, and H. Ozog, "Understand LNG Rapid Phase Transitions", ioMosaic Corporation (2005).

LNG vessel are not designed for high pressures and material failure would provide pressure relief and would limit the pressure rise to a small amount insufficient to cause a BLEVE.[176]

Other explosions due to very fast combustion (detonation and deflagration) are unlikely unless the LNG cloud mixes with air and becomes trapped in a confined area such as between ship hulls. Even then, the effects of the explosion would be localized near the spill.

The low temperature of LNG could cause cryogenic burns to FSRU personnel in the event that the LNG is spilled and comes into contact with unprotected skin. Asphyxiation of the FSRU, LNG vessel, tug or pilot boat crews is possible although not considered a major issue because radiation effects from a fire are considered the dominant effect.

5.3. LNG Accident History

The DEIS and FEIS of most LNG terminal projects usually contain a section on LNG carrier safety. LAI reviewed these report sections as well as other safety reports.[177] The U.S. LNG experience began with the opening of the Distrigas LNG facility in Everett, Massachusetts, in 1971. Since then, more than 700 cargoes have been delivered to Distrigas without major incidents. As we understand it, there have been no fatalities at or around the Distrigas facility attributable to LNG operations, including offloading cargo. As shown in Figure 48, LNG vessels are in the heart of the city when they enter or exit the port of Boston, coming within 1/8 of a mile or 200 m from shore at the closest point.[178] Logan International Airport is briefly shut down when LNG carriers enter Boston Harbor.

Figure 48 – LNG tanker in Charlestown on its way out of Boston [179]

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[176] R.M. Pitblado, J. Baik, G.J. Hughes, C. Ferro and S.J. Shaw, “Consequences of LNG Marine Incidents”, CCPS Conference, Orlando (June 29-July 1, 2004).

[177] Det Norske Veritas Technical Report (Project No. 70004197), “LNG Marine Release Consequence Assessment”, (July 2004)

[178] Boston Globe, December 21, 2004.

[179] Ibid.

Over the past 45 years, over 40,000 LNG voyages have taken place worldwide. No serious accidents involving the rupturing of a cargo tank have occurred. LAI categorized LNG carrier accidents into three categories: LNG vessel spills, LNG vessel groundings, and LNG vessel collisions / interactions.

The most noteworthy LNG vessel spills include the following:

- 1979 – Pollenger at Everett, MA
    - Spill on steel cover of cargo tank caused cracking of steel plate
- 1979 – Mostefa Ben Boulaid at Cove Point, MD
    - Valve leakage caused spill and deck fracture
- 1985 – Isabella (unknown location)
    - Cargo tank overflow due to valve failure caused severe cracking of steelwork
- 2001 – Khannur at Everett, MA
    - 100 gallons of LNG cracked the protective decking over the cargo tank dome
- 2002 – Mostefa Ben Boulaid in Algeria
    - Cargo tank overflow caused fracturing of the steelwork

The following three LNG vessel groundings are significant:

- 1979 – El Paso Kayser near the Straits of Gibraltar
    - Damage to hull and secondary membrane, deformation of primary membrane
    - No LNG released
    - LNG pumped to another vessel
- 1980 – LNG Taurus near Taboata Harbor, Japan
    - Cause: rapidly worsening weather
    - Ship waiting for pilot to board when port was closed
    - Hull damaged but no loss of cargo
- 2004 – Tenaga Lima near Mopko, South Korea
    - Cause: strong wind
    - Water entered the insulation space between primary and secondary membranes
    - Ship was re-floated and repaired

Two recent incidents involved LNG vessel collisions/interactions with other vessels:

- 2002 – Norman Lady struck by USS Oklahoma City nuclear submarine near the Strait of Gibraltar
    - Had just unloaded cargo in Spain

  - Minor damage to double hull but not cargo tanks
- 2006 – Golar Freeze broke loose from its moorings and pulled away from pier during unloading at the Elba Island, GA, import terminal
  - Cause: surge created by the chemical tanker Charleston which was passing by at too high a speed
  - Emergency shut-off was activated
  - Unloading arms came detached
  - No LNG was spilled
  - Two tugs pushed tanker back to the dock

Review of the LNG accident history to date reveals that there were relatively more accidents in the early stages of the industry (late 1970s-early 1980s). A number of minor accidents led to the development of more stringent safety measures in effect throughout the U.S.

5.4. Sandia Report

The Sandia Report focuses on risk analysis and safety implications of a large LNG spill over water.[180] The existing standards for spills or releases of LNG over land do not apply over water. The Sandia report addresses the risk assessment of LNG spills over water, accidental and intentional LNG breaches, spills and corresponding hazard analyses, and risk reduction strategies and recommendations. Although the Sandia Report does not compare the risks of offshore and onshore facilities, other studies have concluded that overall the risks for offshore and onshore facilities are about the same.[181]

The Sandia Report emphasizes that risk from a potential LNG spill can be reduced by minimizing the three elements of the overall risk of the event:

- Probability of the accidental or intentional event,
- Probability that preventive or mitigating measures fail, and
- Consequences of the event measured in fatalities or cost.

Appendix B of the Sandia Report summarizes finite element modeling of ship collisions between a series of large ships (50,000 metric tons) and an LNG vessel. The Report finds that penetration

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[180] M. Hightower, L. Gritzo, A. Luketa-Hanlin, J. Covan, S. Tieszen, G. Wellman, M. Irwin, M. Kaneshige, B. Melof, C. Morrow and D. Raglan, “Guidance on Risk Analysis and Safety Implications of a Large LNG Spill Over Water”, SAND2004-6258 (Dec. 2004).

[181] Aspen Environmental Group, “International and National Efforts to Address the Safety and Security Risks of Importing Liquified Natural Gas: A Compendium”, California Energy Commission, CEC-600-2005-002 (January 2005).

R. Erikson, J.M. Brandstorp and E. Cramer, “Evaluating the Viability of Offshore LNG Production and Storage”, DNV Consulting, Gastech 2002 Conference, Qatar.

into the inner hull of a double-hull vessel requires a 3 m outer hull breach and impact velocities exceeding 5-6 knots.

Spill and dispersion/hazard modeling is also used to estimate how far from a pool fire the heat flux drops to 5 kW/m^2 or less. The results of the models vary depending on the assumptions of the model and the initial conditions at the time of the spill. One limitation of the spill and dispersion/thermal hazard modeling is the lack of validation against large-scale spill experimental data.

Modeling was used to estimate the sizes of LNG cargo tank breaches for accidents (defined as resulting in hole sizes less than 2 m^2) and for intentional breaches (resulting in hole sizes between 2 and 12 m^2). Sandia assumed that LNG carrier storage tanks have a 25,000 m^3 capacity and that only half of the contents of the tank, 12,500 m^3, will spill in the event of a breach. Any single accident is thought to involve releases from only two to three tanks. This cascading release of LNG was analyzed and is not expected to significantly increase the overall fire size or hazard ranges, only the expected fire duration.

Most of the modeling studies assume that a single, coherent pool fire can be maintained for very large pool diameters but this is not thought to be realistic because there would be insufficient air in the interior of a fire to sustain complete combustion. Sandia suggests that "flamelets," or multiple small pool fires would exist rather than the single large pool fire assumed by the models.

Sandia recognized that variations in location-specific conditions, such as terrain, weather, waves, currents and obstacles, can influence dispersion so a range of hazards is more important than a "specific maximum hazard guideline." Generally, a fire is likely to occur immediately and burn the LNG pool and/or vapor. However, if the vapor cloud is not ignited it could extend to 2500 m and then be ignited. The thermal radiation from the ignition of a vapor cloud can be very high within the ignited cloud and particularly hazardous to people. The experiments to date do not give a good indication of the atmospheric dispersion of a vapor cloud that would be associated with very large spills.

Sandia performed a sensitivity analysis of thermal radiation intensity level distances for credible accidental and intentional breach and spill scenarios. Using the same burn rate, Sandia calculated pool diameter, burn time and thermal radiation from spills with 1 to 3 tanks breached and hole sizes ranging from 1 to 12 m^2. The discharge coefficient and the surface emissive power were varied a little as can be seen in Table 15. From this modeling, Sandia concluded that the high hazard distance corresponding to a heat flux of 37.5 kW/m^2 was 250 m for accidental spills and 500 m for intentional spills. Similarly, Sandia concluded that the low hazard distance corresponding to a heat flux of 5 kW/m^2 was 600-750 m for accidental spills and 1600 m for intentional spills. These hazard distances form the basis for Sandia's recommended safety zones.

Table 15 – Sandia Report Thermal Intensity Level Distances[182]

Hole Size (m^2)	Tanks Breached	Discharge Coefficient	Burn Rate (m/s)	Surface Emissive Power (kW/m^2)	Pool Diameter (m)	Burn Time (min)	Distance to 37.5 kW/m^2 (m)	Distance to 5 kW/m^2 (m)
				Accidental Events				
1	1	0.6	$3x10^{-4}$	220	148	40	177	554
2	1	0.6	$3x10^{-4}$	220	209	20	250	784
2	3	0.6	$3x10^{-4}$	220	362	20	398	1,358
				Intentional Events				
2	3	0.6	$3x10^{-4}$	220	209	20	250	784
5	3	0.6	$3x10^{-4}$	220	572	8.1	630	2,118
5	1	0.6	$3x10^{-4}$	220	330	8.1	391	1,305
5	1	0.9	$3x10^{-4}$	220	405	5.4	478	1,579
5	1	0.6	$2x10^{-4}$	220	395	8.1	454	1,538
5	1	0.6	$3x10^{-4}$	350	330	8.1	529	1,652
12	1	0.6	$3x10^{-4}$	220	512	3.4	602	1,920

LAI graphically represented four of the cases from Table 15 in Figure 49 below. These curves are rough estimates of the modeled results based on three data points from Table 15 and indicative of how slowly the radiation decays from its 220 kW/m^2 value at the edge of the fire to its 5 kW/m^2 value at the edge of the low public safety impact zone.

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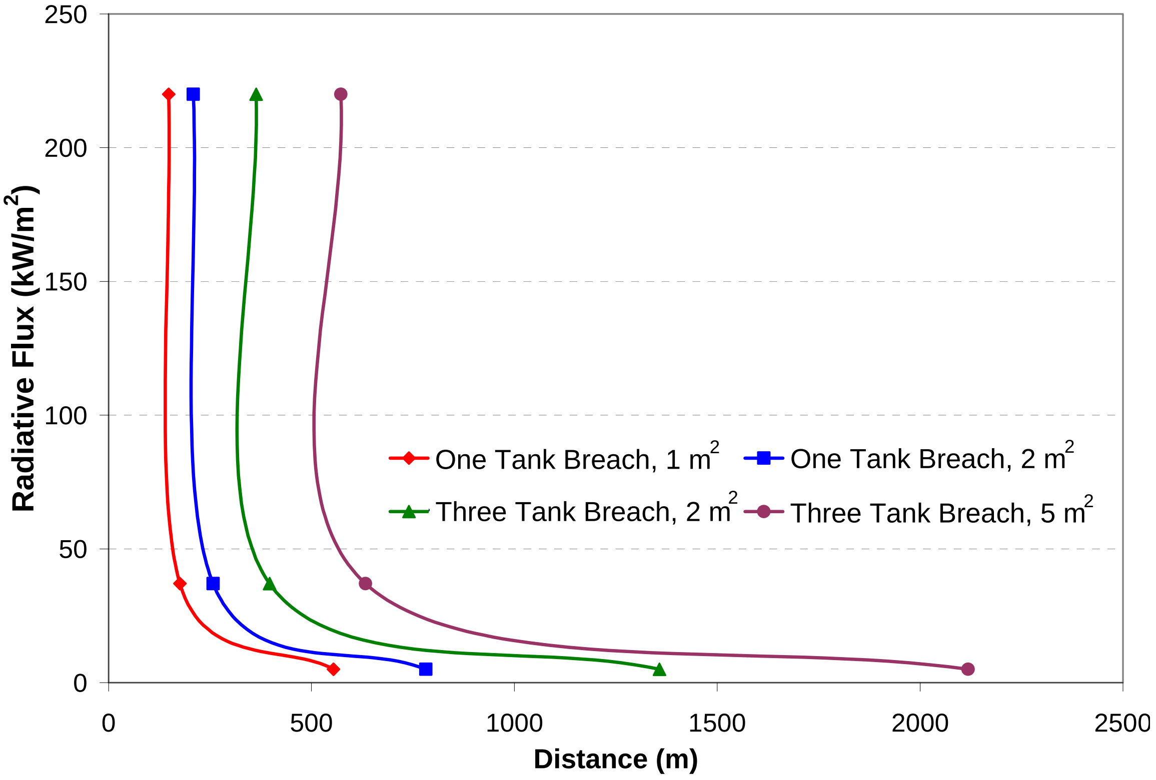
[182] This table is based on data from Table 10. Effect of Parameter Combinations on Pool Diameter in an Accidental Breach and Table 14. Intentional Breach – Effect of Parameter Combinations on Pool Diameter in the Sandia Report. Note that the Sandia report itself has inconsistencies between Tables 10 and 14 and Table 41 of Appendix D which are supposed to include the same results.

Figure 49 – Sandia Report Radiative Flux



For onshore LNG terminals, each LNG container and LNG transfer system must have a dispersion exclusion zone in accordance with NFPA 59 A Sec. 193.2059.[183] These regulations aim at minimizing the possibility that flammable vapors reach a property line that can be built upon. Part 193.2059 requires that vapor dispersion distances be calculated for a 2.5% average gas concentration, i.e. ½ LFL.[184] Calculating a distance to LFL assumes the travel of a continuously flammable vapor cloud. Due to wind gusts, pockets of flammable vapor may break away from the continuous cloud. A conservative estimate of the downward flammable distance assumes these pockets have dissipated when the cloud concentration is below ½ LFL.[185] In the EISs for onshore projects, FERC presents vapor dispersion distances to ½ LFL. It is not clear why the Sandia Report does not present distances to ½ LFL but only distances to LFL.

According to Sandia's dispersion calculations, for large accidental spills the vapor cloud could extend to beyond 1,600 m from the spill depending on atmospheric conditions. Therefore, LNG vapor dispersion analyses should be conducted using site-specific atmospheric conditions to assess the potential areas and levels of hazards to public safety. For a one tank breach, the

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[183] NFPA 59A Sec. 193.2059, "Flammable Vapor-Gas Dispersion Protection."

[184] The meteorological conditions for these calculations are (i) conditions that result in the longest downwind distances at least 90% of the time or (ii) maximum downwind distances for Stability Class F, a wind speed of 4.5 mph, 50% relative humidity and the average regional temperature.

[185] C.D. Zinn, "LNG Codes and Process Safety", Paper #109e, AIChE National Meeting Atlanta, Georgia (April, 13, 2005).

distances to the LFL were calculated to be 1,536 m with a pool diameter of 148 m and 1,710 m for a pool diameter of 209 m (Table 16).[186] The time for the LFL to be reached was approximately 20 minutes. For intentional spills, the distances to LFL were calculated to be 2,450 m for a one tank breach with a pool diameter of 330 m and 3,614 m for a 3 tank breach with a pool diameter of 572 m. The report concludes that high thermal hazards from intentional events can extend significantly from the spill location.

Table 16 – Sandia Report Vapor Dispersion Distances to LFL[187]

Hole Size (m^2)	Tanks Breached	Pool Diameter (m)	Spill Duration (min)	Distance to LFL (m)
Accidental Events				
1	1	148	40	1,536
2	1	209	20	1,710
Intentional Events				
5	1	330	8.1	2,450
5	3	572	8.1	3,614

LAI graphically represented the four cases from Table 16 in Figure 50 below. These curves are rough estimates of the modeled results based on two data points from Table 16 and assuming symmetrical wind conditions. These curves are indicative of how far the vapor cloud extends from the pool but are not an accurate representation of the shape of a vapor cloud. Clearly, the three tank spill creates a larger vapor cloud than a single tank spill. Larger holes with higher LNG spill rates result in a larger vapor cloud than smaller holes with lower spill rates.

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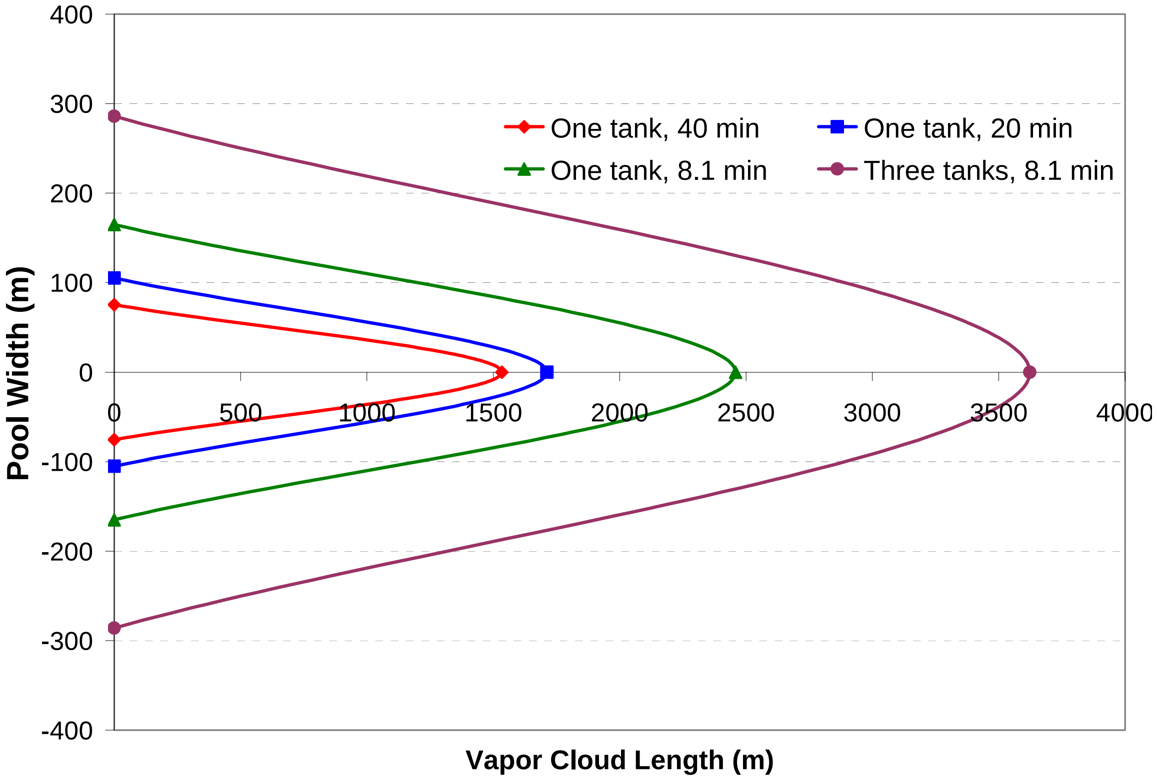
[186] The Sandia Report does not specify what site-specific conditions were used in these calculations.

[187] This table is based on data from Table 11. Dispersion Distances to LFL for Accidental Spills and Table 15. Dispersion Distances to LFL for Intentional Spills in the Sandia Report.

Figure 50 – Sandia Report Vapor Dispersion Distances to LFL



5.4.1 LNG Spill and Dispersion Experiments

The DOE and the Gas Research Institute sponsored two sets of experiments on LNG spills, which were conducted jointly by the Lawrence Livermore National Laboratory (LLNL) and the Naval Weapons Center (NWC). The experiments studied pool spreading, vaporization rates, RPT occurrence, vapor dispersion, detonation, pool fires and vapor cloud fires. The object of the "Burro" experimental series in 1980 was to determine vapor dispersion from LNG spills over water.[188] For the Burro field experiments, wind speed and direction, gas concentration, temperature, humidity and heat flux from the ground were recorded. The object of the "Coyote" experimental series in 1981 was to study RPTs and vapor cloud fires.[189] For the Coyote experiments, vapor cloud size and environmental variables such as wind speed and direction were related to the destructive potential of the fires.

Appendix C of the Sandia Report presents an overview of the LLNL and NWC spill testing data.[190] Sandia used the experimental data to validate a variety of models. However, the

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[188] R.P. Koopman, R.T. Cederwall, D.L. Ermak, H.C. Goldwire, W.J. Hogan, J.W. McClure, T.G. McRae, D.L. Morgan, H.C. Rodean and J.H. Shinn, "Analysis of Burro Series 40-m3 LNG Spill Experiments", *Journal of Hazardous Materials*, 6, pp. 43-83 (1982)

[189] H.C. Rodean, W.J. Hogan, P.A. Urtiew, H.C. Goldwire, T.G. McRae and D.L. Morgan, "Vapor Burn Analysis for the Coyote Series LNG Spill Experiments", UCRL-53530 (1984).

[190] Sandia Report Table 33, p. 105.

experimental data has limitations. The spill sizes ranged from 0.8 m^3 to 66.4 m^3 for vapor dispersion experiments and from 3 m^3 to 238 m^3 for pool and vapor cloud fires. The sizes of these experimental spills are two orders of magnitude smaller than spills from a typical LNG carrier with a capacity of 125,000 m^3. Furthermore, most of the LNG spill experiments over water were performed at the NWC, in China Lake, CA. The water test basin at China Lake has an average diameter of only 58 m with an average water depth of 1 m and an average water level about 1.5 m below the surrounding ground level.[191] LNG pool size at China Lake is limited by the size of the water test basin and was not measured in most cases.

In these experiments, the downwind distance to the LFL is 380 m for the 20.6-66.4 m^3 spills.[192] No ice formation was observed for unconfined spills. Experiments indicate that boil-off rates increase by a factor of 1.5-2 when either ethane or propane is added to the methane to alter the composition to a 97% methane mixture. LNG has a higher boiling rate than pure methane on a bound-free surface. During later stages of the spill, there appears to be a decrease in the rate of vaporization due to the changing composition of the pool.

Experiments found that there is a correlation between water temperature and RPT occurrence: RPTs occurred when the water temperature was above 17^oC (62.6^oF). Time of year would therefore be an important factor in determining whether RPTs would occur if there is an LNG spill in Long Island Sound. There is also a correlation between spill rate and RPT occurrence: 15 m^3/min is the critical spill rate above which the strength of the explosive yield increased by five orders of magnitude at the spill rate of 18 m^3/min. LAI believes that these are very probable spill rates for hole sizes between 2-12 m^2 or for unloading rates of 10,000 m^3/hr (163 m^3/min).

5.4.2 Recent LNG Spill Modeling Review

Appendix A of the Sandia Report presents an overview of LNG spill modeling studies. Most models for the spread of LNG on water assume that spreading is driven only by gravity and ignore the effect of waves, currents, preferential boiling and pool break-up. Each of the four studies discussed – Lehr, Fay, Quest and Vallejo – examines a different scenario with different assumptions. There are significant differences in thermal hazard estimates and reality must encompass this range of results. Specifically, if we compare the distance required for an object to receive a radiant flux of approximately 5 kW/m^2, the Quest study calculates a distance of 490 m, Vallejo calculates 1,290 m and Fay calculates 1,900 m. For these three studies, which all had very similar spill volumes of 12,500-14,300 m^3, the fire duration ranged from 3.3 min to 28.6 min, almost a factor of 10. The area of the fuel spill ranged from 9,503 m^2 to 200,000 m^2, a factor of 10. It appears that when waves are modeled, they decrease the pool radius by a factor of four and increase the vaporization flux by 27% due to the increase in surface area.

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[191] R.P. Koopman, R.T. Cederwall, D.L. Ermak, H.C. Goldwire, W.J. Hogan, J.W. McClure, T.G. McRae, D.L. Morgan, H.C. Rodean and J.H. Shinn, "Analysis of Burro Series 40-m3 LNG Spill Experiments", *Journal of Hazardous Materials*, 6, pp. 43-83 (1982)

[192] The pool radius for this spill is not available.

Other studies support the conclusion that the varying results are due to the differences in modeling assumptions and the modeling tools used to calculate the hazard distances.[193] There are significant deviations between studies and these reduce to some extent when the same modeling assumptions are used. Nevertheless, for the same hole size, for example, pool fire results and dispersion results can vary up to a factor of two.

5.4.3 Sandia Report Recommended Safety Zones

Sandia's guidance on risk management for accidental and intentional spills defines three types of safety zones (Table 17), which are graphically depicted in Figure 51. The 500 m safety / security zones that have been established for most offshore LNG projects are based on Zone 1 for intentional spills.

Table 17 – Sandia Report Safety Zones[194]

	Accidental Spills	**Intentional Spills**
Zone 1 Severe negative impact from thermal radiation	~250 m (273 yds)	~500 m (547 yds)
Zone 2 Less severe negative impact from thermal radiation	250-750 m (547-820 yds)	500-1,600 m (547-1,750 yds)
Zone 3 Minimal risk from thermal radiation	>750 m (820 yds)	>1,600 m (1,750 yds)

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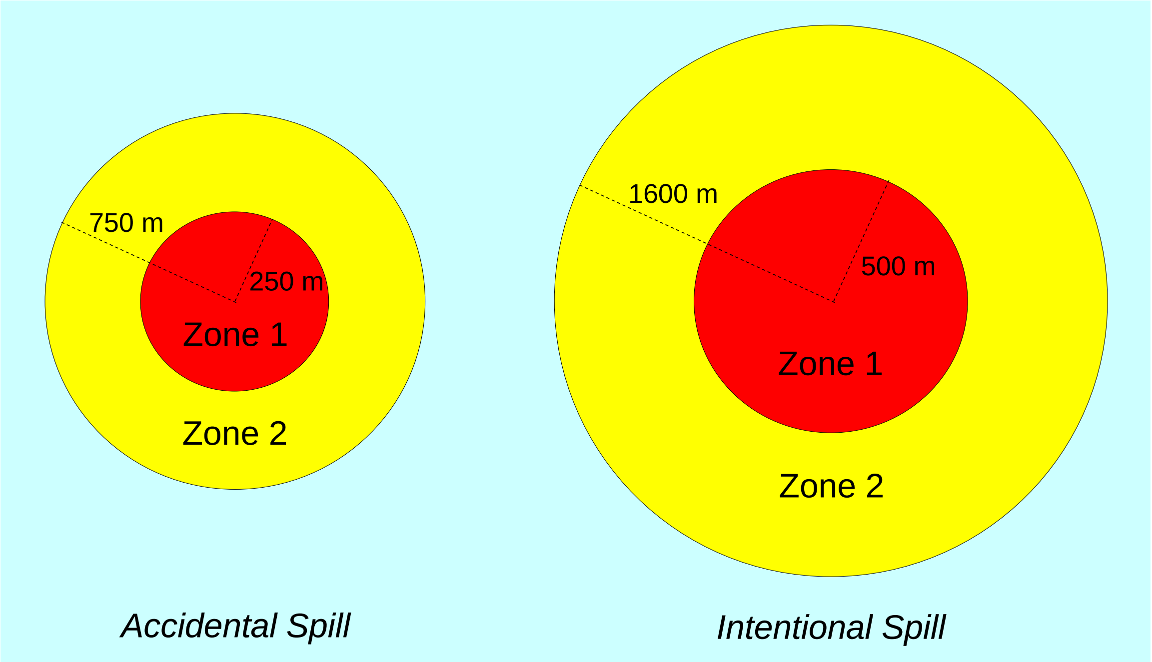
[193] J. Baik, V. Raghunathan, M. Witlox, "Consequence Modeling of LNG Marine Incidents", American Society of Safety Engineers, Middle East Chapter, 7th Professional Development Conference & Exhibition, Kingdom of Bahrain, March 18-22, 2006.

[194] Sandia Report Section 1.3.1, p. 22.

Figure 51 – Sandia Report Safety Zones



5.5. *Safety and Security Implementation*

Safety and security for an offshore LNG project can be implemented at several levels with one or more of the following: Safety Zone, Precautionary Area, Area to be Avoided (ATBA), and No Anchoring Area (NAA).

Pre-2006, the Safety Zone for offshore projects was usually 500 m or 547 yards. No traffic unrelated to Port operations is authorized in this area. The USCG has primary responsibility for monitoring, patrolling, and enforcing the law in the Safety Zone.[195]

A Precautionary Area is printed on new NOAA nautical charts and serves as a notice to mariners of potential LNG carriers and other port operations in the area. The Precautionary Area has recommendations for vessel speed and direction but otherwise does not restrict vessels.

An ATBA is similar to a Precautionary Area with respect to nautical charts, vessel speed and direction. Typically, the maximum speed for an ATBA is 10 knots (19 km/hr). It can be recommendatory or mandatory. Restrictions to vessel movement are enforceable if the ATBA is mandatory.

A NAA can be recommendatory or mandatory. Fishing vessels are excluded if it is mandatory.

Table 18 summarizes the proposed or actual safety implementation for other offshore LNG terminals. Sandia's recommendation for Zone 1 has been applied in these cases. The following

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[195] Final Environmental Assessment of the El Paso Energy Bridge Gulf of Mexico, LLC, Deepwater Port Application (November 2003) USCG-2003-14294.

subsections present a brief overview of the hazard analysis for each offshore project except Cabrillo Port which is analyzed in detail in Section 5.6.

Table 18 – Safety Implementation for other Offshore Projects

Offshore Project	Safety Zone	Area to be Avoided (ATBA)	Precautionary Zone
Main Pass Energy Hub	500 m (547 yds)	3.2 km (2 miles)	
Cabrillo Port, CA	500 m[196] (547 yds)	3.7 km (2.3 miles)	
Excelerate Energy, Gulf of Mexico	500 m (547 yds)		1.0 km (0.62 miles)
Gulf Landing, LA	500 m (547 yds)		3.2 km (2 miles)

5.5.1 Gulf Landing Hazard Analysis

The Gulf Landing Deepwater Port project proposes two gravity-based structures located 61 km south of Cameron, Louisiana, at a water depth of 16.8 m. The project's FEIS discusses LNG accident modeling, which consisted of evaluating three scenarios from the literature.[197]

- DOE Worst-Case Reassessment (Quest Study):
  - Distance to LFL ranges from 0.5 to 2.5 miles for a 25,000 m^3 spill
  - Distance to 5 kW/m^2 of 0.54 km (0.34 miles) for a 25,000 m^3 spill
- Ronald P. Koopman[198]: distance to LFL ranges from 0.4 to 2.8 miles for a 25,000 m^3 spill
- James A. Fay[199]: distance to 5 kW/m^2 of 1.1 km (0.68 miles) for a 14,300 m^3 spill

5.5.2 Gulf Gateway Hazard Analysis

The Gulf Gateway Deepwater Port is located at a distance of approximately 116 miles from the Louisiana coast in 280 feet of water. The project was constructed in 2004-2005 and includes an STL buoy, a gas metering platform and an Energy Bridge Regasification Vessel. For this

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[196] The safety zone is 500 m from the stern of the FSRU which means about 800 m from the mooring tower.

[197] FEIS for the Gulf Landing LLC Deepwater Port License Application (November 2004) USCG-2004-16860-58.

[198] Dr. Koopman is Special Projects Manager for the Chem / Bio National Security Program at Lawrence Livermore National Laboratory. Dr. Koopman has 32 years of experience in applied physics at LLNL, including positions as Manager of the Safety Engineering and Analysis Section of the AVLIS Plant Project with responsibility for Nuclear Criticality Safety and Integrated Safety Programs; Associate Energy Program Leader for Program Development; and Leader of the Liquefied Gaseous Fuels Program which created the Spill Test Facility at the Nevada Test Site and conducted major field test programs with industry using hazardous chemicals.

[199] Dr. Fay is Professor Emeritus in the Department of Mechanical Engineering at the Massachusetts Institute of Technology.

project, the LNG accident modeling in the Final Environmental Assessment relied on the DOE Worst-Case Reassessment (Quest Study):[200]

- Distance to LFL ranges from 0.5 to 2.5 miles for a 25,000 m^3 spill
- Exposure at 300 m from a pool fire would cause pain within 60 s
- Modeled two types of spills
    - 5 m hole took 37 min to burn the spilled LNG
    - 1 m hole took 64 min to burn the spilled LNG

5.5.3 <u>Main Pass Energy Hub Hazard Analysis</u>

The Main Pass Energy Hub Deepwater Port is proposed to be located 16 miles southeast of the Louisiana coast in water depth of 210 ft. The project includes modifying existing offshore facilities and constructing two LNG storage platforms with a total capacity of 145,000 m^3. The LNG hazard analysis presented in the USCG's Environmental Assessment focuses on worst case modeling scenarios with a maximum hazard radius of 5 miles.[201]

5.6. Analysis of Revised Cabrillo Port DEIS (March 2006)

The Revised DEIR for the Cabrillo Port LNG project was analyzed in terms of the safety and security issues that were noted by the Maritime Administration (MARAD), the USCG and Sandia.[202] The USCG and the California State Lands Commission (CSLC) retained Ecology and Environment Inc. to write the EIS / EIR. Specifically, the thermal and dispersion exclusion zone issues were studied for both accidental and intentional breach scenarios. It is important to note that this is the most relevant EIS / EIR available since it would consist of an FSRU with a capacity of 273,000 m^3, similar to Broadwater. Cabrillo Port is different from Broadwater in that it would be moored 14 miles off the California coast where the ocean depth is about 2,900 ft (884 m). Furthermore, Cabrillo Port is proposed as a spherical Moss LNG carrier type, whereas the Broadwater FSRU would have a membrane storage tank construction.

The Cabrillo Port FSRU would be permanently moored via a turret system that would allow it to rotate around a fixed point. It would be shaped like an LNG vessel with a double-sided and double-bottomed construction and displace 193,050 metric tons of water. LNG ships would unload their cargo in a side-by-side arrangement onto this structure which would be 971 ft (296 m) long and 213 ft (65 m) wide and contain three Moss spherical tanks. Each tank would therefore be capable of storing 91,000 m^3 of LNG and in the event of an accident could

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[200] Final Environmental Assessment of the El Paso Energy Bridge Gulf of Mexico, LLC, Deepwater Port Application (November 2003) USCG-2003-14294.

[201] Final Environmental Assessment of the Main Pass Energy Hub Deepwater Port Application (September 2006) USCG-2004-17696.

[202] Revised Draft Environmental Impact Report for CabrilloPort Liquified Natural Gas Deepwater Port, CSLC EIR No. 727 (March 2006).

potentially spill this much LNG. This project would require a 200 ft (60.9 m) permanent right-of-way in the offshore area where the pipelines would be laid.

5.6.1 Public Safety: Overview

The public safety issues that were raised during public meetings have been addressed in this DEIS. Potential hazards and incident scenarios were evaluated by experts at a Hazard Identification (HAZID) workshop and at a multi-day Security and Vulnerability Assessment (SVA) workshop conducted by the CSLC, the USCG and MARAD.

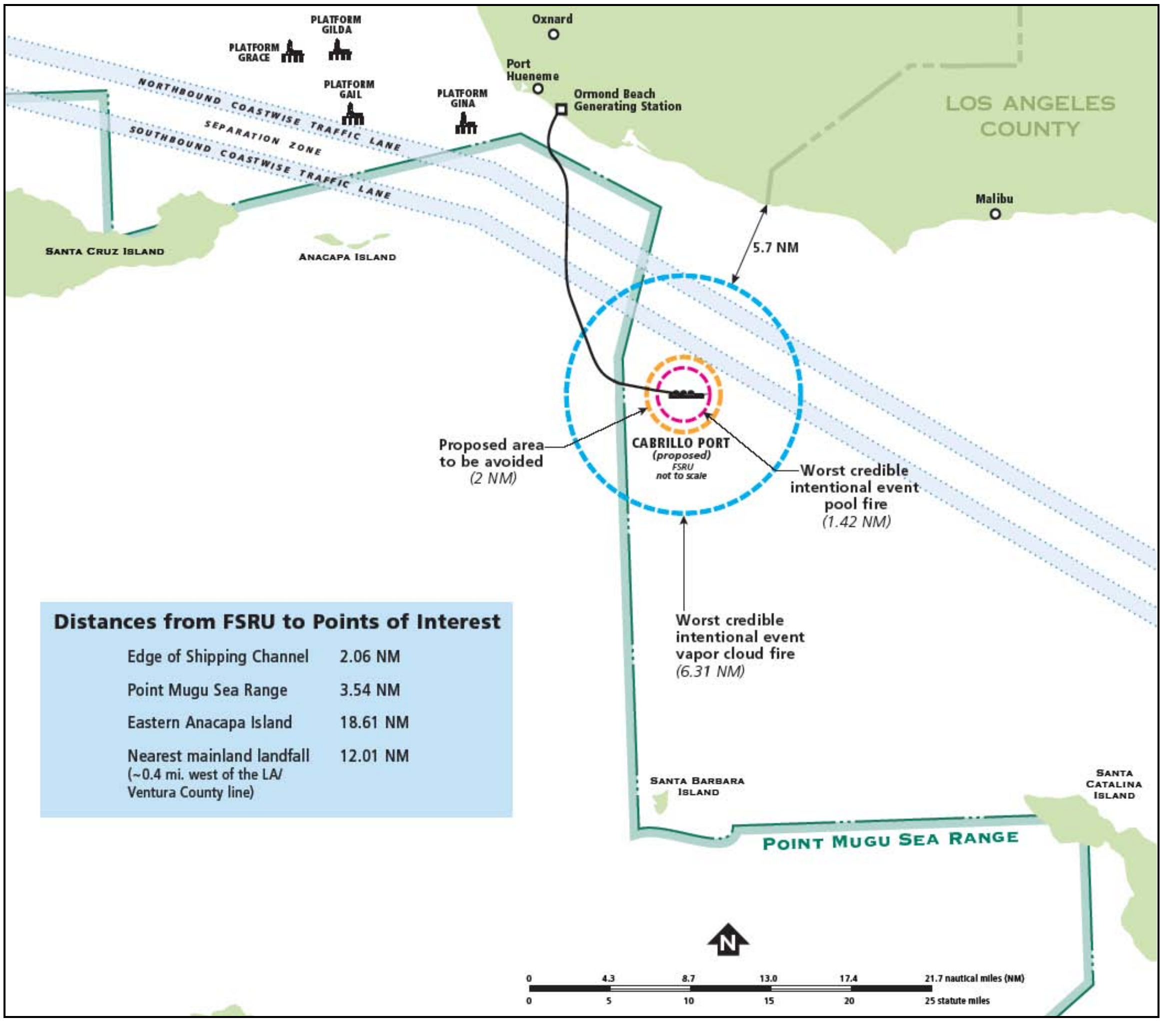
In order to address the public's concerns about the safety of the project, an Independent Risk Assessment (IRA) was conducted which evaluated the worst-case consequences associated with this project. The IRA was conducted by Risknology, Inc. with additional analytical support from Analytical and Computational Energetics, Inc. (ACE) and other consultants. The original IRA included an event-tree analysis which uses inductive logic and a graphical depiction to represent the various events that may follow from an initiating event. However, since the IRA contained sensitive security information, it was not publicly available and only the results were summarized in the DEIR. In the revised DEIR, the IRA is included as Appendix C1. The revised IRA was independently reviewed by the authors of the December 2004 Sandia Report and incorporates Sandia's recommendations.

In the revised DEIR, the USCG extended the Safety Zone around the FSRU from a 500 m radius around the mooring point to a 500 m radius from the stern of the FSRU. Since the FSRU is 296 m long, this in effect makes it an 800 m (½ mile) Safety Zone around the mooring point.

The IRA defines and evaluates representative worst credible cases which would affect one, two, or all three tanks of the FSRU. However, Sandia's review found that a three-tank simultaneous release was not credible. Accidents at the FSRU would be rare and would not reach shore, even in the case of a worst credible release such as a terrorist attack. However, recreational boaters, fishermen and commercial ships in the area and outside the Safety Zone could be affected. The potential release of LNG due to an operational incident or natural cause would not be expected to affect more than a single tank.

The impact distances from accidental releases and intentional events are much less than the distance to shore and range from 1.56 to 7.27 miles, as shown in Figure 52, with details in Exhibit 9. The coastwise shipping lane is about 2.4 miles away. The hazard to the shipping lane would occur about 30 minutes after the initiating event and the exposure time within the shipping lane would last for about another 30 minutes. An average of three commercial vessels would be exposed to this hazard based on marine traffic estimates. It is important to note that LNG carriers would not present risks or hazards to the general public while in transit to the FSRU because they would use routes that are farther from shore than the FSRU.

Figure 52 – Cabrillo Deepwater Port: Consequence Distances[203]



Distances from FSRU to Points of Interest

Edge of Shipping Channel	2.06 NM
Point Mugu Sea Range	3.54 NM
Eastern Anacapa Island	18.61 NM
Nearest mainland landfall (~0.4 mi. west of the LA/ Ventura County line)	12.01 NM

The USCG would respond to emergencies at the FSRU or an LNG carrier. Two tug vessels would be on continuous standby in the vicinity of the 500 m Safety Zone surrounding the FSRU.

5.6.2 Independent Risk Assessment

The hazardous events that were identified during the HAZID were:

- LNG spill overboard,
- Loading arm failure,
- Presence of an ignition source in the SCVs,
- Ship collision with the FSRU,

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[203] Source: Cabrillo Port FEIS.

- Ballast system malfunction, and
- Fire on LNG carrier or FSRU.

Based on the initial Sandia review, additional threat and hazard analyses, consequence modeling, and process safety considerations were suggested by Sandia.

Based on the HAZID and the SVA, six scenarios were considered.

- Scenario 1: accidental explosion in hull void
- Scenario 2: accidental explosion in moss tank
- Scenario 3: accidental/intentional marine collision
- Scenario 4: accidental explosion between the FSRU and the docked tanker
- Scenario 5: intentional two Moss tank breach
- Scenario 6: accidental/intentional cascading multiple (two or three) Moss tank release

The modeling of the LNG release, spread, and eventual burning was conducted using the Fire Dynamics Simulator (FDS) which is a public domain computer program. The FDS was calibrated to the Burro 8 test data. The IRA concluded that wind speed and orientation (gradient normal to the ground) are the parameters that most strongly control the distance to the LFL. The pool fires were represented using the right circular cylinder model since it is applicable to all heat fluxes.

The following assumptions were made in the IRA modeling.

- LNG releases were modeled as pure methane
- LFL is 0.0276 on a mass fraction basis or 0.05 on a volume basis
- No material was lost during the pool formation process and all such material was available for either the pool fire or vapor dispersion calculations
- The pool was assumed to be fixed in size and the recession process was conservatively ignored
- The ocean temperature was set at 50^{o}F and the air temperature at 70^{o}F
- Tidal or wave action was not considered and their exclusion will produce more conservative results
- Temperature inversion effects were not modeled
- The LNG evaporation rate was set to be 0.028 lb/ft^2/s (0.135 kg/m^2/s)
- The edge of the fire has an average emissive power of 220 kW/m^2
- The atmosphere has an average transmissivity of 0.8

- Flame height was found using the industry standard Moorhouse correlation which was developed using large LNG pool fires[204]
- Thermal radiation thresholds were 5.0, 12.5 and 37.5 kW/m^2
- Two LNG loading operations take place per week, each one lasting 20-24 hours
- Relative vessel movement during loading operations is limited to 2.8 m
- Submersible pumps in Moss tank can be maintained without taking the tank out of service
- A 500 m safety zone is set around the FSRU

The following sections contain a more detailed discussion of Scenarios 3-6. Scenarios 1 and 2 will not be discussed here in detail since they are specific to the Moss LNG carrier type. However, Scenario 1 and 2 could apply to the LNG carriers that service the Broadwater FSRU since they could have either spherical Moss or membranes storage tanks.

5.6.2.1 Scenario 3: Accidental / Intentional Marine Collision

This scenario is defined as a large marine vessel colliding with the FSRU with sufficient energy to breach a storage tank. A tanker or a container ship traveling at 13.5 or 16.5 knots respectively could result in a 10 m^2 hole in the FSRU.[205] The hole size will double to 20 m^2 with a 0.5 knot increase in speed. It is important to note that there are no speed limits for ships at sea but rather the speed of a ship should be determined by weather/sea and traffic/safety considerations. Container ships typically have a cruising speed of 25 knots (29 mph) while tankers have a cruising speed of 16 knots (18 mph). The estimated frequency of collision with a tanker is 1.7×10^{-8} (about 1 in 60 million) and with a container 5.9×10^{-7} (roughly 1 in 2 million).

Both a pool fire and vapor dispersion with subsequent vapor cloud fire are investigated. It is assumed that an instantaneous spilling of one half the contents (45,500 m^3) of a storage tank will occur and lead to a pool fire with a radiative flux of 5 kW/m^2 at a distance of 2,970 m. If immediate ignition does not occur and the vapor cloud disperses down wind, the distance to LFL will vary with the wind speed. For a wind velocity of 2 m/s, the maximum distance to LFL is 5.3 km. If the vapor cloud were to ignite, the radiation distance must be added to the vapor cloud distance. For a radiative flux of 5.0 kW/m^2 a distance of 1.3 km must be added to the LFL limit.

5.6.2.2 Scenario 4: Accidental Explosion Between the FSRU and the Docked Tanker

This scenario investigates an explosion due to a spill occurring during off-loading and resulting in a flammable cloud that fills the entire space between the FSRU and the LNG carrier. If this vapor cloud were to ignite, it would burn rapidly in a deflagration mode. The report estimates

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[204] Moorhouse concluded that the cylindrical flame representation is best for thermal radiation calculations.

J. Moorhouse , “Scaling Criteria for Pool Fires Derived from Large Scale Experiments”, I.Chem. E. Symposium Series No. 71 (April 14-16, 1982)

[205] Cabrillo Port DEIR, Figure E.4 in Appendix D of Appendix C1.

the confined volume between the carrier and the FSRU to be only 6,800 m^3 although it appears to be 6 x 60 x 130 = 46,800 m^3. The 6,800 m^3 volume of methane-air mixture can result from only 1.0 m^3 of LNG which is a less than the capacity of the loading arms. The carrier and FSRU are assumed to not move or deform over the explosion time event and the ignition source is set at the physical center of the cloud. The CFD model calculates a maximum overpressure at Tank 2 (the middle tank) of 3.5 psi (24 kPa) and a maximum blast pressure between the ship and the carrier of 13.5 psi (93 kPa). The effect of the blast load profiles on the FSRU was found to be negligible, causing only a small inclination of the FSRU and increasing the separation between the two vessels by about 4 feet. There is the possibility of fire or blast-induced damage to the mooring lines connecting the vessels, but no structural analysis was conducted using the predicted explosion loads. The initiating event frequency for this event tree is the joint probability of exceeding a wave height of 2.8 m at the FSRU and continuing the loading operations. Ignition sources can come from the loading arm decoupling, sparks, static electricity and machinery onboard either vessel. The estimated frequency for this type of event is 4.81 x 10^{-5}, or roughly 1 in 20,000.

5.6.2.3 Scenario 5: Intentional Two Moss Tank Breach

This scenario investigates the consequences of an intentional attack which produces a 7 m^2 hole in two adjacent storage tanks. The entire contents of both tanks (91,000 m^3 x 2 = 182,000 m^3) were assumed to spill. A frequency estimation cannot be conducted for intentional scenarios. The maximum pool diameter was 650 m. In the event of a pool fire, the distance to 5 kW/m^2 would be 2.6 km. In the event of a vapor cloud, the distance to LFL would be 11.2 km for a wind speed of 2 m/s and 9.4 km for a wind speed of 4 m/s. After reaching the maximum downwind distance, a flash fire analysis was performed. For the 2 m/s wind speed case, the distance to 5 kW/m^2 was 11.7 km and the distance to 2 kW/m^2 was 12 km. For the 4 m/s wind speed case, the distance to 5 kW/m^2 was 10.9 km.

5.6.2.4 Scenario 6: Accidental/Intentional Cascading Multiple (two or three) Moss Tank Release

This scenario investigates the consequences of cascading tank failures through primary fire events resulting in damage to the storage tanks. An initial storage tank is breached by either an accidental or intentional event and spills its entire contents via a 7 m^2 hole. Immediate ignition causes a pool fire which results in the failure of one or two of the other tanks 25 seconds later with the release of 100,000 m^3 of LNG (Table 19). No vapor cloud formation was considered due to the immediate ignition. After the LNG pool reaches its maximum size, radiative flux distances were calculated assuming that the LNG pool burned the entire time it formed.

Table 19 – Summary of Consequence Distances[206]

	Number of Tanks (Hole Sizes)	Distance to 5 kW/m^2
Case 1	2 tanks (7 m^2, 7 m^2)	1.32 km
Case 2	2 tanks (7 m^2, 1,300 m^2)	2.51 km
Case 3	3 tanks (7 m^2, 1,300 m^2, 1,300 m^2)	3.23 km

5.6.3 Sandia Review of Independent Risk Assessment

Sandia reviewed the Cabrillo Port IRA.[207] LAI presents highlights from this review that are the most relevant and applicable to Broadwater.

Although the 40 year history and safety record of marine LNG import vessels is important and has some bearing on LNG safety, it should not be used as a default for this new facility concept. The FSRU covers a much broader spectrum than simply LNG off-loading by including LNG storage, regasification and pumping gas to shore. There are safety questions about the existence, position and capabilities of barriers between processing areas and the LNG storage tanks. If such barriers do not exist and efforts to fight a process-based fire fail, then propagation and failure of storage tanks may ensue.

Sandia points out that more credible threats exist than are imagined in the IRA, and may be more likely than the catastrophic total release scenario originally considered in the Cabrillo Port IRA. The threats can range from insider threats to intentional external attacks with a range of weapons or delivery modes such as airplanes, ships or boats. The potential threats from off-normal events in the processing area would probably impact initially only one FSRU storage tank. Detailed information on the credible threats was not publicly available.

Sandia found a number of problems with the initial LNG dispersion calculations. Some of these problems are presented here to give a glimpse of how complex the modeling is and how incorrect assumptions for input parameters or boundary conditions can critically change the modeling results.

- An incorrect value to identify the LFL was used in the input file.
- The methane is released into a flow field which is in a transitional state and has excess mixing. Sandia recommended a different boundary condition at the side boundaries parallel to the wind and at the top domain which provide a power-law wind profile uniformly across before the methane is released.
- The reduced temperature of the LNG pool was not correctly reflected. USACE used a “reaction” flag in the input file which assumes a combustion process and increases the methane temperature above atmospheric temperature.

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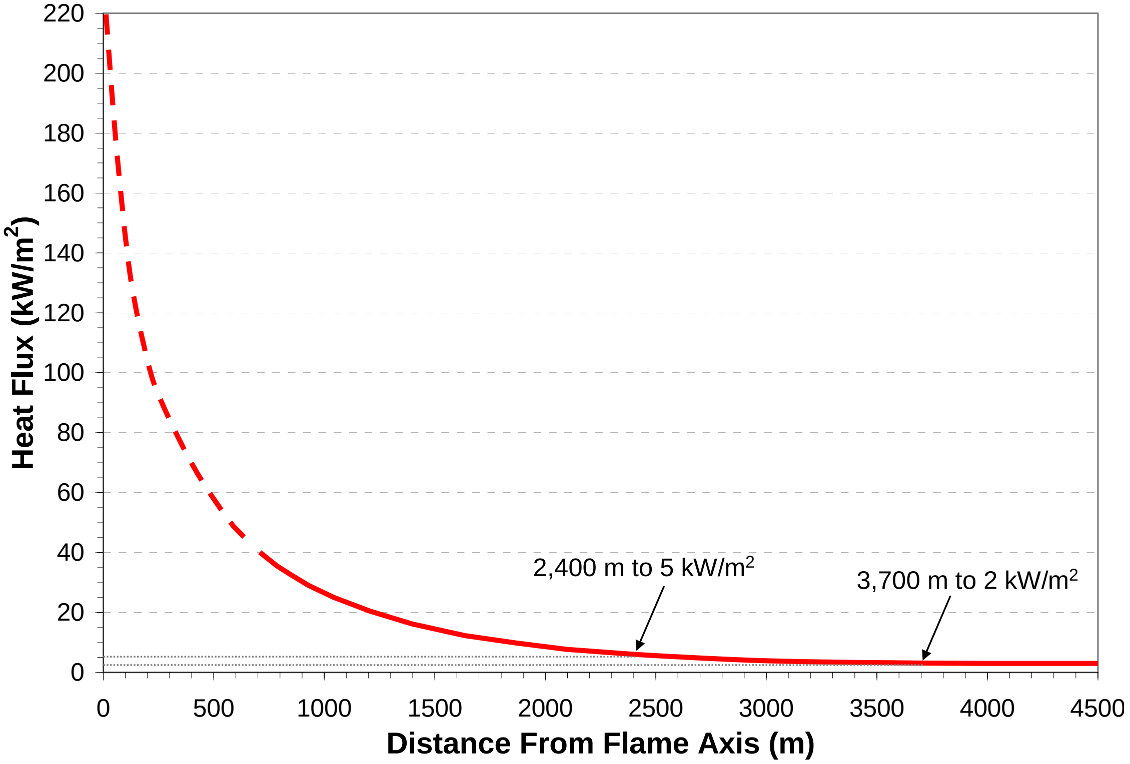
[206] Cabrillo Port Revised EIR, Appendix C1, Independent Risk Assessment, Table 3.8 or Table ES-3.

[207] Cabrillo Port Revised EIR, Appendix C2, Sandia Review of Independent Risk Assessment.

- The mesh size can change the maximum distance to LFL by almost a factor of 2: USACE found 11 km with 20 m width cells while Sandia calculated 7 km with 10 m width cells. Lower resolution simulations result in longer distances to LFL because the extent of turbulent mixing is under resolved.

Sandia's pool fire results were in close agreement with the ACE results. Sandia's modeling results were presented in graphical form (Figure 53) and show how slowly the heat flux decays as a function of distance from the pool. In this case, a minimum distance of 2.4 km (1.5 miles) is required for the heat flux to drop to 5 kW/m^2. Of special importance from LIPA's vantage point, an additional 1.3 km (0.8 miles) is required to reach a more protective level of 2 kW/m^2.[208]

Figure 53 – Sandia Calculation of Pool Fire Hazards[209]



Sandia's review of the IRA concludes that a credible scenario is that of a two tank breach. Credible threat analyses suggest breach sizes in the 7-12 m^2 range should be considered for this type of facility and location. However, no credible consequences (to a radiative flux of 5 kW/m^2) extend more than 11.7 km or 7.3 miles from the FSRU.

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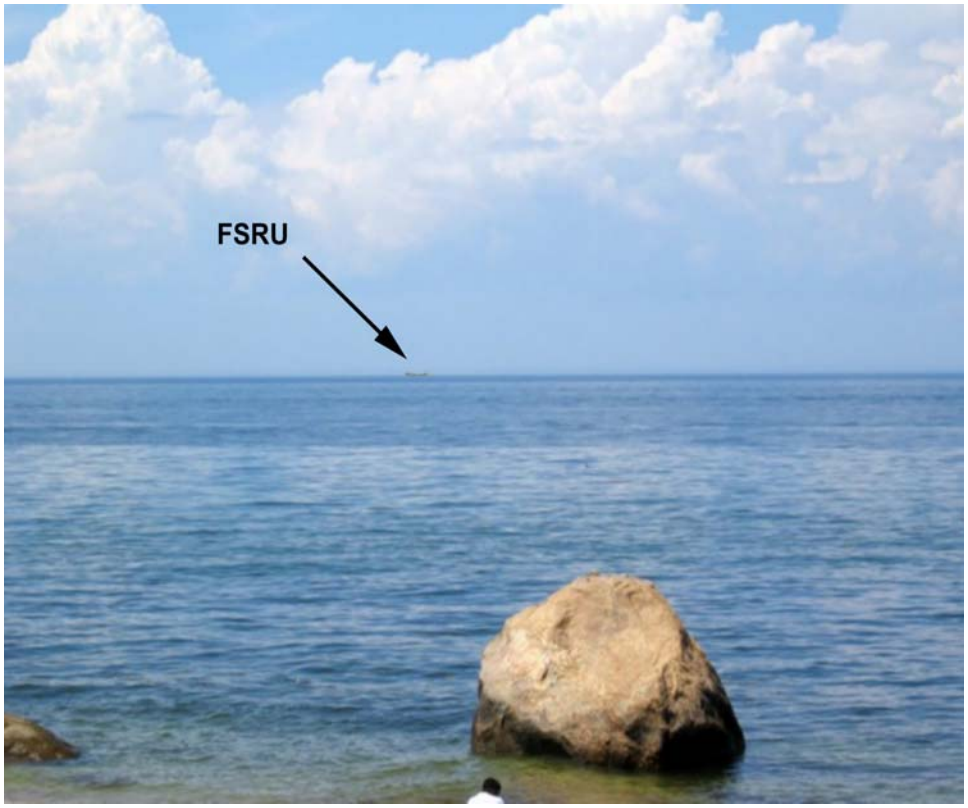
[208] The extrapolation to 2 kW/m^2 was done on the original Sandia figure, not on Figure 53.

[209] Figure based on Figure 4 (from the Cabrillo Port Revised EIR, Appendix C2, Sandia Review of Independent Risk Assessment). The dashed line is an extrapolation to 220 kW/m^2 at the edge of the pool fire and is not exact since the location of the pool axis relative to the pool edge is not reported.

5.7. Resource Report 11 – Safety and Reliability

Broadwater's Resource Report 11 describes the potential effects of project component failures on the public and on the supply of natural gas to customers.[210] These failures could be due to natural catastrophes, accidental failures or intentional harmful events. Broadwater's location, about nine miles from the closest shore, minimizes the hazards to the public associated with either an accident or a catastrophe at the FSRU. On a clear day, the FSRU would barely be visible from either the New York or Connecticut shoreline (Figure 54). Table 20 compares the proximity of populations at existing onshore LNG terminals to the Broadwater location.

Figure 54 – View of FSRU from Roanoke Landing (Riverhead, NY)[211]



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[210] Resource Report 11 includes the following appendices:

- A. Historical Climatological Information
- B. Minutes of Meeting New York State Fire Administrator
- C. LNG Carrier Route Analysis
- D. HSSE Management System Framework Document

[211] Source: Broadwater Energy.

Table 20 – Populations in Proximity to LNG Terminals

LNG Facility	Estimated Population within 10 miles
Broadwater (NY)	3,443
Everett (MA)	1,745,898
Cove Point (MD)	49,014
Elba Island (GA)	154,193
Lake Charles (LA)	136,825

5.7.1 LNG Safety

Federal Port and Waterways Safety regulations (33 Code of Federal Regulations, "CFR," Part 160) mandate that LNG carriers give a Notice of Arrival 96 hours prior to arrival, giving their position, last port of call, next port of call, crew roster, cargo manifest, time of arrival and reporting any equipment casualties that could affect safety. The rules further establish safety and security zones in harbors, around vessels carrying hazardous cargoes, including LNG, in specified areas.[212] Safety zones provide buffers around enclosed sites or vessels for safety or environmental protection while security zones are for the protection of the enclosed sites or vessels against terrorist acts or accidents. Both zones can be either stationary or move along with a vessel.

5.7.1.1 FSRU

Broadwater contends that the results described in the Sandia Report are applicable to the proposed FSRU since it is similar to an LNG carrier in construction, and its hull should behave like the hull of an LNG carrier in the event of an accidental or intentional breach. Even though the FSRU storage tanks are larger (45,000 m^3) than those of the LNG carrier (25,000 m^3) considered in the Sandia Report, it can be reasonably assumed that LNG release rates and durations similar to those postulated in the Sandia Report are applicable to the FSRU.[213] The USCG questioned this premise and Broadwater commissioned Det Norske Veritas (DNV)[214] to prepare a response to the USCG questions.[215] A review of this report can be found in Appendix 6 of our report and supersedes information presented in Resource Report 11. The main points from this report are summarized below.

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[212] 33 CFR Part 165.

[213] The 200,000 to 250,000 m^3 LNG vessels in the production queue today have storage tanks that are approximately the size of the Broadwater storage tanks (45,000 m^3).

[214] DNV is a worldwide classification society headquartered in Norway which currently classifies more than 5,100 ships (16% of the world's fleet).

[215] Broadwater's response was dated December 21, 2005.

- Larger LNG carriers or the FSRU will experience smaller breach sizes given the same impact energies because of the larger distance between the outer and inner hull. Therefore, the Sandia Report breach sizes are conservatively applicable to the proposed Broadwater FSRU and larger LNG carriers.
- The FSRU release volume will be 35,560 m^3 and the LNG carrier release volume will be 27,300 m^3 compared to the Sandia Report release volume of 12,500 m^3.
- For the largest hole size of 2.52 m, the distance to LFL for a one tank FSRU spill increases to 3.32 km compared to its value of 2.45 km for the Sandia report.

Broadwater completed two HAZIDs in order to identify potential hazards associated with the project. Based on these studies, Broadwater incorporated various measures to protect the public and the environment from potential accidents including:

- Hull and containment system;
- Collision avoidance: radar beacon, radar system and navigational aids;
- LNG spillage containment from unloading and process areas;
- LNG offloading system – linked to an Emergency Shutdown which will automatically stop the cargo transfer when abnormal conditions (such as high tank levels or pressures, fire detection, loss of electrical power or instrument air pressure, detection of high pressure or low temperature within the unloading arms) are detected on the carrier or FSRU or in the event of an LNG carrier mooring failure;
- Thermal and flammable vapor dispersion exclusion zones – zone dimensions are determined by USCG;
- Hazard detection – including a Distributed Control System and an Instrumented Protective System;
- Fire suppression: a fire water system, a dry powder chemical system, a high expansion foam system, a low expansion foam system, a carbon dioxide fire protection system, a water spray system and a water mist system;
- Emergency shutdown – in the event of a total power failure, the emergency generator will start automatically; and
- Emergency response – a Preliminary Emergency Response Plan will identify the resources required and coordination requirements between Broadwater, the USCG and onshore emergency responders.

In order to protect the FSRU against natural catastrophes such as hurricanes, severe winds, tornadoes and lightning strikes, the yoke mooring system was designed to accommodate the most severe weather that can credibly occur in the area. *i.e.*, a 100 year storm event. Specifically, the yoke mooring system was designed to withstand wave heights of 5.7 to 7.0 m and winds of 50.2

to 56.8 m/s (112.3 to 127 mph).[216] In the event of a severe storm, Broadwater may reduce the manning level of essential personnel, cease natural gas deliveries, while accelerating the scheduled depletion of inventory aboard the FSRU.

Broadwater has developed a menu of terrorism threat scenarios that describe the vectors that could possibly be used to attack the FSRU and the LNG carriers. In order to minimize the risk from these scenarios, Broadwater intends to design appropriate operational procedures and mitigation measures. Broadwater has prepared a Preliminary Security and Vulnerability Assessment (PSVA) as required by the USCG. The PSVA documents the potential security threats to Broadwater operations and an analysis of the consequences that could result if such threats were successful. Finally, Broadwater prepared a Preliminary Facility Security Plan (PFSP) for the FSRU. Both the PSVA and the PFSP are “living” documents not available to the public that will be modified over the course of the FSRU design and construction. After commissioning, Broadwater would conduct a number of security operations on a regular basis.

5.7.1.2 LNG Carriers

Instead of addressing the safety issues associated with potential cargo releases from an LNG carrier during transit or unloading, Broadwater refers the reader to the following three reports:

- Consequence Assessment Methods for Incidents Involving Releases from LNG Carriers – ABS Consulting[217]
- LNG Marine Release Consequence Assessment – DNV[218]
- Guidance on Risk Analysis and Safety Implications of a Large LNG Spill over Water – Sandia National Laboratory[219]

According to Resource Report 11, there are four types of accidental events that could result in the release of LNG from a carrier:

- Vessel collision with an inbound LNG carrier
- Inbound LNG carrier collision with the FSRU or mooring tower
- Vessel collision with a moored LNG carrier
- Grounding of an LNG carrier

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[216] Resource Report 11, Table 11-9.

[217] American Bureau of Shipping, “Consequence Assessment Methods for Incidents Involving Releases from Liquified Natural Gas Carriers, GEMS 1288209, May 13, 2004).

LAI also examined the notice from FERC Docket No. AD04-6-000, “Notice of Availability of Staff’s Responses to Comments on the Consequence Assessment Methods for Incidents Involving Releases from Liquified Natural Gas Carriers”, June 18, 2004.

[218] DNV Technical Report (Project No. 70004197), “LNG Marine Release Consequence Assessment”, (July 2004).

[219] M. Hightower, L. Gritzo, A. Luketa-Hanlin, J. Covan, S. Tieszen, G. Wellman, M. Irwin, M. Kaneshige, B. Melof, C. Morrow and D. Raglan, “Guidance on Risk Analysis and Safety Implications of a Large Liquified Natural Gas (LNG) Spill Over Water”, SAND2004-6258 (Dec. 2004).

Only one LNG carrier will approach, berth, unberth and depart Long Island Sound at any given time. When the vessels enter the Long Island Sound through The Race, they will be about 1 mile from Fishers Island. The population on Fishers Island is 275-300 people in the off-season and approximately 6,000 during peak summer weekends. During the remainder of the voyage into the Sound, the vessel will be about 2 miles from the closest shore at one point in time. The USCG will determine the final route of the LNG carriers into Long Island Sound and the nature of the safety and security zone around it. Since the LNG carrier will be traveling at 12 knots, the approximate duration of a traveling safety and security zone at any single point would only be approximately 15 minutes. At approximately 12 knots, LAI observes that there should not be significant marine traffic bottlenecks.

In addition to double-hull construction, there are a number of safety features to minimize LNG spills, including:

- Vessel traffic management,
- LNG carrier procedures,
- Shipboard safety systems,
- Enhanced navigation equipment,
- Crew training, and
- Inspection by USCG and classification societies.

A letter of recommendation from the USCG is required for the project to commence operations and will probably have conditions that must be incorporated within a Vessel Management and Emergency Plan. Broadwater will provide an adequate number of tugboats (one to four) with a bollard pull capacity of 60 metric tons and fire-fighting equipment for each LNG carrier operation. The maximum sea states and other relevant weather conditions that are permissible during LNG carrier transit, berthing and unloading are shown in Table 21.

Table 21 – Weather and Sea Condition Limits for LNG Carrier Transit

Wind	33 knots (17.0 m/s)
Tidal currents	0.9 knots (0.45 m/s)
Waves	6.6 feet (2 m)

5.7.1.3 Post application Safety Filing

On February 16, 2006, the USCG requested thermal radiation results for accidental and intentional breaches of the FSRU and LNG cargo tanks. On March 14, 2006, Broadwater sent the USCG a report by DNV in which thermal hazard zones from pool fires due to immediate ignition are presented. An overview of this report can be found in Appendix 7. The FSRU pool fire distances to 5 kW/m^2 calculated by DNV range from 606 m to 1,211 m compared to 554 to 1305 m in the Sandia report for the same hole sizes. DNV does not find the effect of wind speeds and stability class to be significant. However, hole size is a significant variable: doubling the hole size will double the calculated distance to 5 kW/m^2. The duration of a pool fire depends on hole size, release rate, burning rate and volume released. Sandia used a lower burning rate so DNV repeated their calculations with Sandia's lower burning rate and found an increase in hazard distances.

5.8. Other Technical Experts on LNG Safety

Dr. Jerry Havens is the developer of the DEGADIS computer model that is recommended by the Department of Transportation regulations (49 CFR Part 193, LNG Facilities: Federal Safety Standards). He states that: "in my judgment, a large LNG pool fire – on water, and therefore uncontained – is of the highest concern."[220] He also states that: "the scientific consensus on the scope of an LNG-on-water fire involving an entire tank of LNG (6 million gallons or 23,000 m^3) is that it would be at least a half-mile in diameter… from the edge of the fire to about another half-mile out, people would receive second-degree burns on unprotected skin within about 30 seconds. Obviously, larger fires would result from larger spills."[221] However, Dr. Havens recognizes that models can not yet predict accurately how the fire size will scale with the quantity of spilled LNG.

Dr. James Fay, Professor Emeritus in the Department of Mechanical Engineering at the Massachusetts Institute of Technology, has expressed concern that there exists no relevant industrial experience with fires of the scale that would be involved in a worst-case scenario. Dr. Fay developed a mathematical model for the spills and fires from LNG vessels. He states that: "… the floating LNG pool will burn vigorously. The time to burn spills of the size mentioned (25,000 m^3) can be less than five minutes. Fires that burn thousands of tons of fuel in a few minutes are extraordinarily large."[222] Dr. Fay calculates a distance to an average heat flux of 5 kW/m^2 of 1,100 m or 3,600 ft.[223]

5.9. Safety Review Issues

5.9.1 Safety Parameter Modeling Issues

Exclusion zones for protection of people are calculated by a number of different models. These models have been validated by limited data from pool fire, vapor cloud dispersion and vapor cloud fire experiments involving small LNG spills on the order of 1-100 m^3. These experimental spills are orders of magnitude smaller than the spills contemplated in the event of an LNG accident or terrorist event, where each of the multiple storage tanks is between 25,000 m^3 and 50,000 m^3.

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[220] Havens, J., "Terrorism: Ready to blow?", Bulletin of the Atomic Scientists, Vol. 59, No. 4, pp. 16-18, July/August 2003.

[221] Havens, J., "LNG: safety in science: careful study of the consequences of spill fires can settle terminal siting questions", Bulletin of the Atomic Scientists, Vol. 60, No. 1, pp. 30-31, Jan/Feb 2004.

[222] Fay, J., "Model of spills and fires from LNG and oil tankers", Journal of Hazardous Materials, Vol. B96, pp. 171-188, (2003).

[223] Fay, J., "Spills and fires from LNG tankers in Fall River (MA)", August 2003.

The distances required for an object to receive a radiant flux of approximately 5 kW/m^2 calculated by the various published models can vary by up to a factor of 4 for a given spill size. This is not surprising because the calculation depends on the assumptions and approximations used in the model. Although waves are expected to reduce the spread of the LNG pool, the effect of waves is very difficult to quantify and is not included in most models.[224] There is very little friction between the LNG pool and the water so the LNG pool will be more responsive to winds than to ocean currents. However, the effect of wind is also difficult to model accurately.

It is well known that confinement of an LNG vapor cloud in the flammability range could result in an explosion (detonation or deflagration). However, buildings and/or obstacles leading to confinement are not treated in any of the models.

Since LNG vapor must be in the flammability range in order to burn, the vapor cloud needs to mix with air. In the case of a very large spill, it is unlikely that one giant fire would occur but rather a breakup into multiple flamelets. This effect is not currently modeled and would lead to a decrease in the radiative flux. Therefore, the distance to a safe radiative flux level would decrease if flamelets are considered. Although LNG's initial composition is mostly methane, as the pool spreads and evaporates, it becomes enriched in the heavier components. This change in the LNG pool's composition over time would change its vaporization and burning behavior; this phenomenon is not currently modeled.

5.9.2 Cascading Event Analysis

Both the Sandia Report and the Cabrillo Port revised DEIS discuss the possibility of a cascading event scenario. The scenario would be similar for the LNG carrier or the FSRU following an LNG cargo tank breach. An initial loss of LNG containment could cause cascading failures of additional LNG storage tanks through two mechanisms:

- A primary fire event resulting in damage to support structures or the insulation of neighboring tanks, or
- The embrittlement and brittle failure of structural components from direct contact with LNG.

The inventory of additional tanks would not be released simultaneously with the contents of the initial tank. The Cabrillo Port IRA assumed an accidental or intentional breach in an initial storage tank causing a 7 m^2 hole and spilling 100% of the LNG in the tank. Furthermore, the IRA assumed ignition of the pool of spilled LNG and subsequent failure of one or two additional tanks. The release of the contents of the second and/or third tank is assumed to occur 25 seconds after the first tank breach with only half the contents of the additional failed tanks released. No vapor cloud was formed but the additional tank failures increased the expected fire duration and the hazard range.

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[224] H. Kytomaa and F. Gavelli, "Studies of LNG Spills Over Water Point up Need for Improvement", Oil and Gas Journal, p. 61-65 (May 9, 2005).

5.9.3 LAI Extrapolations to Worst-Case Scenario

LIPA asked LAI to define a worst-case scenario for the Project because no worst-case scenario was presented in Broadwater's Resource Report 11 Safety and Reliability. In addition, LIPA asked LAI to estimate the distance to a radiative heat flux of 2 kW/m^2 in the event of a worst-case scenario involving the FSRU. Selection of 2 kW/m^2 as a safe radiative flux is based on discussions with fire safety engineers and review of engineering literature.[225]

LAI based the worst-case scenarios on review of the literature on both accidental and intentional threats. There is considerable debate concerning the worst-case scenario versus the maximum credible event approach for defining hazard zones.[226] To date, sea-borne terrorist attacks have not involved LNG carriers. Moreover, there is minimal public information on terrorist attacks on U.S. ships. The October 2000 attack on the USS Cole in Yemen is one incident that provides an estimate on the size of a hole created by an intentional attack. The hole in the outer hull created by the attack on the USS Cole was estimated to be 60 feet wide by 40 feet high or approximately 200 m^2.[227] The Sandia results have been extended to larger holes to account for a terrorist event such as the USS Cole attack and result in a vapor cloud and fire that would extend 3 miles from the vessel.[228] DNV has reviewed the range of LNG marine incidents from collision, grounding, operational error and terrorism.[229] Their maximum credible accidental release from a 0.75-m wide hole has a pool fire hazard range of 440 m. With an associated dispersion and flash fire hazard range to 5 kW/m^2 of 920 m. DNV's calculated maximum credible intentional release from a 1.5 m wide hole has a pool fire hazard range to 5 kW/m^2 of 750 m. DNV assumed that no vapor cloud would propagate since immediate ignition is almost certain in an intentional event. DNV qualifies its dispersion results with the statement "actual distances could be larger or smaller at most by a factor of two."

LAI considered two types of worst case scenarios. The first scenario is a cascading event with sequential rather than simultaneous breaches of all the storage tanks. No vapor cloud hazard is considered for cascading events since the escalation of the hazard is attributed to a pool fire. The second scenario is a vapor cloud which is assumed to encounter an ignition source within a 3.2 km (2 miles) radius around FSRU.

The distance to 5 kW/m^2 for a pool or vapor cloud flash fire depends on the hole size, the number of tanks involved, the event sequence, the weather conditions and the wave height. LAI estimated the following range of distances to 5 kW/m^2.

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[225] C.L. Beyler, "Fire Hazard Calculations for Large, Open Hydrocarbon Fires", Chapter 3-11, SFPE Handbook of Fire Protection Engineering (2002).

[226] R. Pitblado, J. Baik and V. Raghunathan, "LNG Decision Making Approaches Compared", DNV Consulting (2005).

[227] http://archives.cnn.com/2000/US/11/02/uss.cole.02/index.html

[228] L.A. Husick and S. Gale, "Planning a Sea-Borne Terrorist Attack", Foreign Policy Research Institute (March 21, 2005) http://www.fpri.org/enotes/20050321.americawar.husickgale.seabornedterroristattack.html

[229] R.M. Pitblado, J. Baik, G.J. Hughes, C. Ferro, and S.J. Shaw, "Consequences of LNG Marine Incidents", CCPS Conference, Orlando (June29 – July 1, 2004).

- For a pool fire: 2.5 - 3.2 km (1.6 - 2 miles)
- For a vapor cloud flash fire: 3 - 5 km (1.9 - 3.1 miles)

LAI extrapolated the 5 kW/m^2 results to 2 kW/m^2 based on pool fire calculations from the Cabrillo Port revised DEIS (see Figure 53).

- For a pool fire: 3.8 – 4.5 km (2.4 - 2.8 miles)
- For a vapor cloud flash fire: 4 – 6 km (2.5 – 3.7 miles)

5.10. Safety Review Findings

Highlights of LAI's safety assessment include the following:

- Broadwater's location, about nine miles from the closest shore, minimizes the hazards to the public associated with either an accident or a catastrophe at the FSRU. Broadwater's homeland security experts assert that the FSRU is likely an unattractive terrorist target because any incident would cause few casualties and would not be very accessible for extensive media coverage. Arguably, the FSRU is a difficult terrorist target with a comparatively low probability of success. Nonetheless, we note that the maximum number of crew on board the FSRU at any one time would be approximately 30 individuals. In the event of a catastrophe, we believe that the FSRU is too far from either shoreline to affect the Long Island or Connecticut population.

- Based on the history of LNG vessel accidents and review of safety reports, the most likely serious event is a grounding of the LNG carrier due to rapidly worsening weather. However, Broadwater's operating procedures will not permit an LNG vessel to enter the Sound unless there is a 24-hour weather window corresponding to wind speeds less than 33 knots and waves less than 6.6 feet. Therefore, unless there is a very sudden and negative change in weather, the probability of an LNG vessel grounding in the Sound is extremely low.

- The risk of an accident while the LNG carrier is transiting The Race appears very low although the consequences would be high. Elsewhere in the U.S., LNG carriers have regularly transited both high and low density population centers without event for decades. In Boston, for example, LNG carriers come within a quarter mile or less of the city's waterfront when they enter the harbor, and the 10 mile radius around the Everett terminal includes a population of 1.7 million. Although the Broadwater LNG carrier route comes within approximately one mile of land at The Race, an experienced pilot familiar with the route will have boarded the FSRU before it enters the Sound. The USCG will then escort the carrier to the FSRU. Both the USCG and Broadwater are eager to schedule passage during periods which avoid conflict with commercial and recreational vessel traffic, in particular, late night. Furthermore, the LNG carriers will not enter the Race unless there is a favorable 24-hour unloading weather window within the operating limits corresponding to wind speeds less than 33 knots and waves less than 6.6 feet.

- Safety zones for offshore LNG projects are based on modeling of LNG spills over water. To date, there have been neither any significant accidental spills nor any intentional LNG spills over water. LNG spill experiments conducted by scientists in the U.S. have been limited to volumes ranging from 1 m^3 to 238 m^3. Minor events such as an operational spill lasting 10 minutes would release about 1,670 m^3 of LNG (FSRU loading rate is 10,000 m^3/hr). The breach of one cargo tank on the FSRU or LNG carrier could release anywhere from 12,500 m^3 to 35,560 m^3. Exclusion zones for injury to people calculated by the various models vary by up to a factor of 4 for a given spill size because of differences in input parameters and model assumptions. When reviewing hazard analyses, the approximations in the modeling results and the uncertainties in the weather conditions at the time of a spill should be taken into consideration.

- Minor hazardous events such as LNG leaks on the FSRU or the LNG carrier are likely to occur from time to time. The FSRU and tugs would be equipped with firefighting equipment, and we expect that the FSRU and LNG carrier crew would be highly trained to handle such emergencies. Nevertheless, cryogenic damage to crew or equipment could take place. Escalation of minor hazards is conceivable under extremely sudden and difficult weather conditions, but improbable with Broadwater's emergency shutdown system and the type of emergency response training that is required.

- More serious hazardous events, such as release during LNG transfer events, are unlikely. If such a hazardous event were to occur, a pool fire or a minor vapor cloud could ensue. However, LNG transfers would not be scheduled unless weather conditions were within operating limits. Furthermore, Broadwater's emergency shutdown system would be activated if the motion between the FSRU and the LNG carrier exceeded threshold tolerances. Other critical process upsets such as loss of electrical power, high LNG tank pressure, fire detection or high pressure in an unloading arm will also trigger the emergency shutdown system and will limit the size of a spill and minimize the probability of escalation.

- In the event of a spill on deck, LNG's cold temperature could cause cryogenic damage to the FSRU or LNG carrier. Additionally, it could cause cryogenic burns to personnel on either vessel if it comes into contact with unprotected skin. Asphyxiation of the FSRU crew and the tug / pilot boat crews is also possible during a large spill.

- The most serious hazardous event would involve a collision between a vessel transiting Long Island Sound and the LNG carrier or the FSRU. The USCG has proposed a Safety Zone around the FSRU with a 1.1 km radius (0.68 miles). The USCG has also proposed a moving Safety zone around the LNG carrier while it transits the Sound which extends 3.7 km (2.3 miles) in front of the carrier, 1.85 km (1.15 miles) behind, and 0.69 km (0.43 miles) on either side. These Safety Zones will increase the navigational safety and reduce the likelihood of an accident or intentional attack. Furthermore, most of the vessels transiting Long Island Sound are neither large enough nor traveling with the speed required to penetrate the double hull of the FSRU or the LNG carrier.

- In the event of a pool fire, the thermal radiation could result in loss of life on the FSRU and might harm vessels and occupants in the area surrounding the FSRU. A pool fire could cause escalation to a multiple tank release, but it would take hours for all the LNG to be released. A worst-case scenario involving the total loss of the FSRU is conceivable, but all the LNG on board would not be instantaneously released. In the event of a worst-case scenario, the existing body of scientific knowledge indicates that the inhabitants of Long Island and Connecticut are far enough away to avoid burns through exposure to high levels of thermal radiation.

- Explosive combustion, such as a detonation or deflagration, is unlikely to occur unless the LNG vapor cloud is within the flammability range (5 to 14% by volume) and becomes trapped in a confined area such as between ship hulls. As such, these events are limited to the vicinity of the LNG carrier or FSRU.

- Unignited vapor clouds are extremely unlikely to travel more than 2 miles without encountering an ignition source, such as a recreational, commercial or fishing boat. Near the FSRU, an unignited vapor cloud could lead to asphyxiation of crew members or other emergency personnel. Any *intentional* initiating event will almost certainly provide an ignition source and therefore not lead to a diffusing vapor cloud. Once the vapor cloud is ignited, the flash fire will burn back to the spill source, *i.e.*, presumably the hull of the FSRU.

- A secondary hazard that could damage the FSRU is an RPT. This type of explosion is caused by LNG pouring into warm seawater and vaporizing very quickly due to heat transfer. This rapid expansion from the liquid to the vapor state causes large overpressures. RPTs are localized in the vicinity of the LNG leak and may cause some structural damage to the LNG carrier or FSRU. Although rapid phase transitions on their own do not involve a fire, they may increase the rate of LNG pool spreading and the size of a vapor cloud that could subsequently ignite.

- BLEVEs are unlikely to occur at the FSRU or LNG carrier in the event of a fire. The LNG storage tanks are not designed for high pressures and failure of the tank material would limit the pressure rise to a small amount insufficient to cause a BLEVE event.

- LIPA asked LAI to estimate the impact zone to 2 kW/m^2 since a radiation flux of 5 kW/m^2 is only a permissible level for emergency operations lasting several minutes with appropriate clothing. Discussions with fire safety engineers and a review of the engineering literature led to the choice of 2 kW/m^2 as a “safe” level of radiative flux. LAI found that the impact zone to 2 kW/m^2 would extend 6 km (3.7 miles) around the FSRU for a credible worst-case scenario. Therefore both shorelines would effectively be buffered by approximately 5 miles.