Appendix C2
Review of the Independent Risk Assessment of the Proposed Cabrillo Liquefied Natural Gas Deepwater Port Project

SANDIA REPORT

SAND2005-7339
Unlimited Release
Printed January 2006

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Unlimited Release
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REVIEW OF THE INDEPENDENT RISK ASSESSMENT OF THE PROPOSED CABRILLO LIQUIFIED NATURAL GAS DEEPWATER PORT PROJECT

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ABSTRACT

In March 2005, the United States Coast Guard requested that Sandia National Laboratories provide a technical review and evaluation of the appropriateness and completeness of models, assumptions, analyses, and risk management options presented in the Cabrillo Port LNG Deepwater Port Independent Risk Assessment – Revision 1 (Cabrillo Port IRA). The goal of Sandia's technical evaluation of the Cabrillo Port IRA was to assist the Coast Guard in ensuring that the hazards to the public and property from a potential LNG spill during transfer, storage, and regasification operations were appropriately evaluated and estimated.

Sandia was asked to review and evaluate the Cabrillo Port IRA results relative to the risk and safety analysis framework developed in the recent Sandia report, "Guidance on Risk Analysis and Safety Implications of a Large Liquefied Natural Gas (LNG) Spill over Water". That report provides a framework for assessing hazards and identifying approaches to minimize the consequences to people and property from an LNG spill over water.

This report summarizes the results of the Sandia review of the Cabrillo Port IRA and supporting analyses. Based on our initial review, additional threat and hazard analyses, consequence modeling, and process safety considerations were suggested. The additional analyses recommended were conducted by the Cabrillo Port IRA authors in cooperation with Sandia and a technical review panel composed of representatives from the Coast Guard and the California State Lands Commission. The results from the additional analyses improved the understanding and confidence in the potential hazards and consequences to people and property from the proposed Cabrillo Port LNG Deepwater Port Project. The results of the Sandia review, the additional analyses and evaluations conducted, and the resolutions of suggested changes for inclusion in a final Cabrillo Port IRA are summarized in this report.

ACKNOWLEDGEMENTS

The authors received technical, programmatic, and editorial support on this project from a number of individuals and organizations both inside and outside Sandia National Laboratories. We would particularly like to express our thanks for their support and guidance in the technical evaluations and development of this report.

The U.S. Coast Guard was instrumental in providing funding, coordination, management, and technical direction. Special thanks for supporting our modeling, analysis, and technical evaluation efforts.

To support the technical analysis required for this project, the authors worked with many organizations, including industry and state and federal agencies to collect background information on proposed system design and operations, and modeling concepts and approaches in order to assess potential LNG spill safety and risk implications.

The following individuals were especially helpful in supporting our efforts, providing technical information and reviewing technical evaluations.

LT. Ken Kusano – United States Coast Guard, Deepwater Port Standards Division
Martin Eskijian – California State Lands Commission
Madhu Ahuja – California State Lands Commission
Avinash Nafday – California State Lands Commission
Andy Wolford – Risknology Inc.
Keith Clutter – Analytical and Computational Energetics Inc.

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LIST OF ACRONYMS

ACE	Analytical and Computational Energetics Inc.
CSLC	California State Lands Commission
DHS	Department of Homeland Security
DOE	Department of Energy
E&E	Ecology and Environment Inc.
FDS	Fire Dynamics Simulator
FSRU	Floating Storage and Regasification Unit
IRA	Independent Risk Assessment
kg/m^2s	kilogram per second per square meter
kg/m^3	kilogram per cubic meter
km	kilometer – 1000 meter
Knts	Knots – 0.514 m/s
LFL	Lower flammability limit
LNG	Liquefied natural gas
m	meters
m^2	square meter (area)
m^3	cubic meter (volume)
m/s	meters per second
NIST	National Institute of Science and Technology
psi	pounds per square inch
USCG	United States Coast Guard
°C	degrees Celsius
°K	degrees Kelvin

1. EXECUTIVE SUMMARY

While accepted standards exist for the systematic safety analysis of potential spills or releases from Liquefied Natural Gas (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 increased industry's and the public's attention to these activities.

In March 2005, the United States Coast Guard (USCG) requested that Sandia National Laboratories (Sandia) provide a technical evaluation of the appropriateness and completeness of the models, assumptions, analysis, and risk management options considered in the report, "Independent Risk Assessment of the Proposed Cabrillo Port LNG Deepwater Port Project –Revision 1"(Cabrillo Port IRA). Sandia was asked to evaluate the Cabrillo Port IRA based on the risk and safety analysis framework provided in the recent Sandia report, "Guidance on Risk Analysis and Safety Implications of a Large Liquefied Natural Gas (LNG) Spill over Water". This Sandia report on LNG spill risk analysis provides a technical framework to assess the 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 technical evaluation of the Cabrillo Port IRA was to assist the Coast Guard in ensuring that the hazards to the public and property from a potential LNG spill during transfer, storage, and regasification operations were appropriately evaluated and estimated.

Initial Review and Evaluation

Sandia was provided with three primary documents for the technical review. These included the "Independent Risk Assessment of the Proposed Cabrillo Port Liquefied Natural Gas Deepwater Port Project -Revison 1", the "Draft Environmental Impact Statement/Environmental Impact Report for the Cabrillo Port Liquefied Natural Gas Deepwater Port", and the "Cabrillo Port Security Workshop Report". Based on an initial review and evaluation of the Cabrillo Port IRA, several issues were identified by Sandia. These issues were presented at a Technical Review Panel meeting in San Antonio, Texas on April 11th and 12th, 2005. The Technical Review Panel included representatives from the USCG/Deepwater Ports Standards Division, California State Lands Commission (CSLC), Sandia, and the major contributors and authors of the Cabrillo Port IRA including Ecology and Environment Inc. (E&E), Risknology, and Analytical and Computational Energetics (ACE). The following were provided based on the initial Sandia review of the Cabrillo Port IRA:

- Suggested expanding and moving some of the information into the summary and body of the report to provide better clarification of some of the analyses conducted.
- Suggested establishing a fire and dispersion hazard analysis subgroup to address several fire and dispersion modeling analysis issues and concerns identified.
- Suggested establishing a processing and safety subgroup to consider process safety and security issues associated with LNG storage, regasification, and transmission operations on the FSRU, which is a relatively new concept relative to existing land-based LNG import facilities.
- The conclusion that the accidental breach scenarios and analyses for the FSRU were reasonable relative to the current knowledge and modeling techniques for collisions, breaches, and potential spills for double-hull vessels.
- Suggested that an evaluation of the current understanding of potential malicious threats and their associated spills be conducted to better assess hazards to people and property from an intentional event.

The technical subgroups established exchanged information, assessed process safety information, and conducted additional fire and dispersion analyses. Based on these information exchanges and analysis efforts, a second meeting with the Technical Review Panel was held at Sandia on June 14th, 2005. At this meeting, the discussions focused on modeling and analysis issues and concerns associated with the fire and dispersion hazard analyses and results. Those discussions centered on efforts to assess fire and dispersion model input parameters and assumptions, identify appropriate domain analysis grid sizes and analysis techniques, assess numerical stability, and validation of the models being utilized to ensure appropriateness.

Final Assessment and Resolution

The Technical Review Panel continued to assess the fire, dispersion, and hazard analyses through the end of September 2005. By September, all of the initial issues identified had been resolved. Based on the interactions and technical discussions of the Technical Review Panel, the following resolutions of the review of the Cabrillo Port LNG Deepwater Port IRA – Revision 1 Draft were developed.

The threat evaluations identified two governing intentional events that should be considered for spill and hazard analyses. 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 the final fire and dispersion analyses assumed full tank volume releases for these breach scenarios for conservative estimates of hazard distances.

The FSRU is still in the preliminary design phase. A final evaluation of the proposed process safety and security measures therefore is not possible, though many process safety and safety management measures were included in the conceptual design to minimize the chances that various FSRU processes and operations, including regasification and gas transmission, will not increase hazards and risks to the public and property beyond that expected from other possible threats. Several process safety and security considerations were recommended for consideration and evaluation in the final FSRU design and operational plans.

The computational fluid dynamic analyses required a thorough examination of all input variables, as well as boundary and initial conditions, and grid and domain sizes. The resolution of the fire and dispersion analyses and results became the controlling factors in the review effort. These issues required extensive interaction of the Technical Review Panel. Vapor dispersion issues were resolved by the end of August 2005 and the fire analysis issues were resolved by late September 2005. Overall, the final results for both fire and dispersion hazard distances, after incorporating the recommended Sandia changes, appear to provide reasonable estimates of hazard levels and distances for what are considered credible events. The analyses developed should provide conservative estimates of expected hazard distances.

All technical issues identified by Sandia in the Cabrillo Port IRA review and evaluation process were resolved by early October 2005. Table 1 summarizes the major issues identified by Sandia and the general resolution by the Technical Review Panel. The changes have improved the hazard analyses and provide results that adequately and reasonably represent the hazards and public safety issues associated with maritime LNG import operations at the Cabrillo Port, relative to the current understanding of large LNG spills over water. The detailed evaluations of the potential threats to the FSRU and the extent of hazards from a possible LNG spill are presented in detail in the following sections of this report.

Table 1. Summary of Issues and Resolutions Identified in the Cabrillo Port IRA – Revision 1[1]

Identified Issue	Resolution
General Issues	
1. A two-tank release appears to be the most severe event based on potential credible threats.	Hazard analyses were modified from a catastrophic three-tank release to a more credible two-tank release.
2. Evaluation of hazards to on-shore public from a spill as well as shipping, recreational boaters, etc. should be considered.	Assessment of the potential impacts of fire and dispersion hazards on shipping and other receptors will be considered.
3. Reassess intentional threats at regular intervals because of continually changing nature of threats.	CSLC and USCG are considering an appropriate interval to assess changes or escalation of credible threats.
Accidental and Intentional Breach and Spill Issues	
1. Accidental breach and spill results from a collision appear appropriate and consistent with other collision studies.	Agree with overall approach and results.
2. Credible threat analyses suggest breach sizes in the range of 7-12 m^2 should be considered for this type of facility and location.	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.
3. A simultaneous breach of all three storage tanks appears inappropriate to use for hazard analyses.	Breach and spills were reassessed for a two-tank breach and spill.
4. Risk management of the final design should include the assessment of active mitigation measures due to the remoteness of the system.	USCG will encourage and assess mitigation measures and systems in evaluating the final FSRU operational plan and design.
Fire and Vapor Dispersion Hazard Issues	
1. The analytical technique employed for dispersion calculations in the IRA is sensitive to domain scale and boundary conditions and must be carefully assessed.	Domain scale and boundary conditions were reassessed and identified problems were addressed with more detailed analysis, comparison with other numerical approaches, and validation with experimental data.
2. Initial IRA calculations for potential dispersion distances appeared to under predict hazard distances.	Dispersion scenarios were analyzed using more appropriate input parameters, computational domains, and boundary and site-specific environmental conditions. The final results obtained were consistent with results from other numerical models.
3. General application of the modeling technique used in the IRA for dispersion calculations and hazard estimates should be reviewed for appropriateness.	The selected analytical approach was carefully reviewed and evaluated against experimental data and found to provide results consistent with best available computational fluid dynamics methodologies.
4. Fire hazard evaluations were not included in the initial draft IRA. Since the likelihood of ignition of a large spill is possible, fire hazard analyses should be conducted.	Fire hazard analyses were developed using appropriate large-scale fire modeling analytical approaches. The results obtained are consistent with other large-scale LNG fire analyses for spills over water.
Process Safety and Security Issues	
1. While current processing operations appear to preclude a multi-tank breach, final system design and safety features should be carefully evaluated.	The USCG to carefully evaluate implementation of improved safety and security measures to reduce the risks and consequences of off-normal events during post-license detailed design review.
2. Final system safety analysis unable to be completed until conceptual handling, storage and regasification system design and operational parameters finalized.	The USCG to carefully evaluate implementation of improved safety and security measures to reduce the risks and consequences of off-normal events during post-license detailed design review.

2. PROJECT BACKGROUND AND SITE INFORMATION

The following information describes the project location and the general conditions and operations associated with the proposed facility and terminal. These characteristics impact the overall analysis associated with the potential for a spill, the possible size of a spill, and the extent of the hazards from a potential spill. While more specific information is available in the Cabrillo Port IRA[1] and the Cabrillo Port EIS/EIR[2], the current design is conceptual and may change in the future. Therefore, the current terminal and facility information should be updated if significant design changes occur in the future.

Identifying Information

Facility:	Cabrillo Port LNG Deepwater Port
Location:	Approximately 22 km offshore of Oxnard, CA in federal waters
Terminal Design:	Floating storage and regasification unit (FSRU)
Capacity:	3-91,000 m^3 modified Moss-type LNG storage tanks
Technology:	Vessel shaped, nonpowered, double-hull conceptual design
Period of operation:	40 years starting in 2008/2009

Project Background

The proposed Cabrillo Port is a marine LNG import facility about 22 km off the coast of southern California between Ventura and Los Angles Counties. The project would have several facilities:

- An offshore LNG import terminal that would be anchored and moored to the ocean floor for the life of the project (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 natural gas would be pumped via two subsea pipelines to on-shore receiving facilities and pipelines.

Figure 1. Conceptual design of the FSRU.

Site Information

The proposed terminal location is in federal waters approximately 880 meters deep and approximately 22.25 km off the coast of Oxnard, California. The site is also about 4.5 km from the edge of Point Mugu Sea Range and 3.7 km from the edge of the nearest shipping lane. It is about 23.6 km from the Channel Islands National Marine Sanctuary and 32.8km from the nearest boundary of the Channel Islands National Park.

FSRU Characteristics and Nominal Conceptual Operations

The FSRU conceptual design has the following operational capabilities:

- Non-powered, vessel-shaped terminal facility with stern thrusters for heading control only, a turret system for pumping the regasified LNG into the pipeline network,
- Three Moss-based LNG storage tanks, each holding approximately 91,000 m^3,
- 296 m long by 65 m wide double-hull design,
- Includes LNG regasification system to transfer the natural gas at approximately 1200 psi pressure into two subsea gas pipelines,
- Designed to receive and handle 2-3 LNG shipments per week by docking with LNG cargo vessels, and
- Regasification of about 23 million m^3 of natural gas per day.

Site Environmental Conditions

The site wind conditions are presented in Figures 2 and 3. These conditions influence hazard issues such as potential dispersion conditions and directions of a possible spill. The data were taken from the nearest weather buoy, which is located about 14km from the proposed site. The data in Figure 2 show the maximum wind speed in the area, the mean wind speed in the area of about 6-7 knots, and plus and minus one standard deviation from the mean wind speed, or the most common wind speeds of approximately 2-12 knots. Figure 3 shows wind direction data from the area for the past ten years. The most common wind direction in the area is from the west and northwest. For comparison, 1 knot = 0.514 m/s.

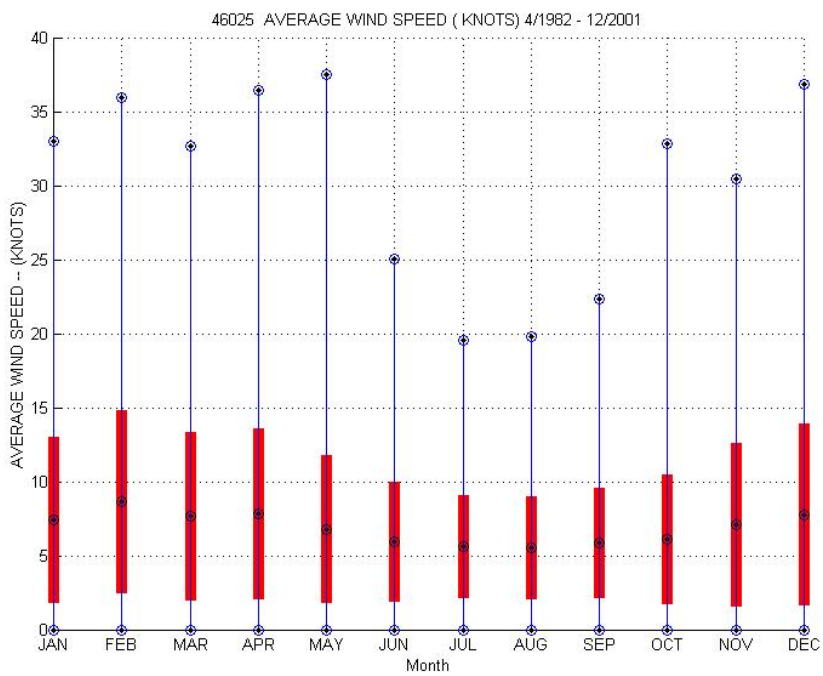

Figure 2: Wind speed data collected from a buoy 14.1 km from the FSRU site.

(Location of FSRU: 33°51'52" N 119°02'02" W. Location of Buoy: 33°44'42" N 119°05'02" W.) The weather data from this buoy can be found at http://www.ndbc.noaa.gov/station_history.php?station=46025

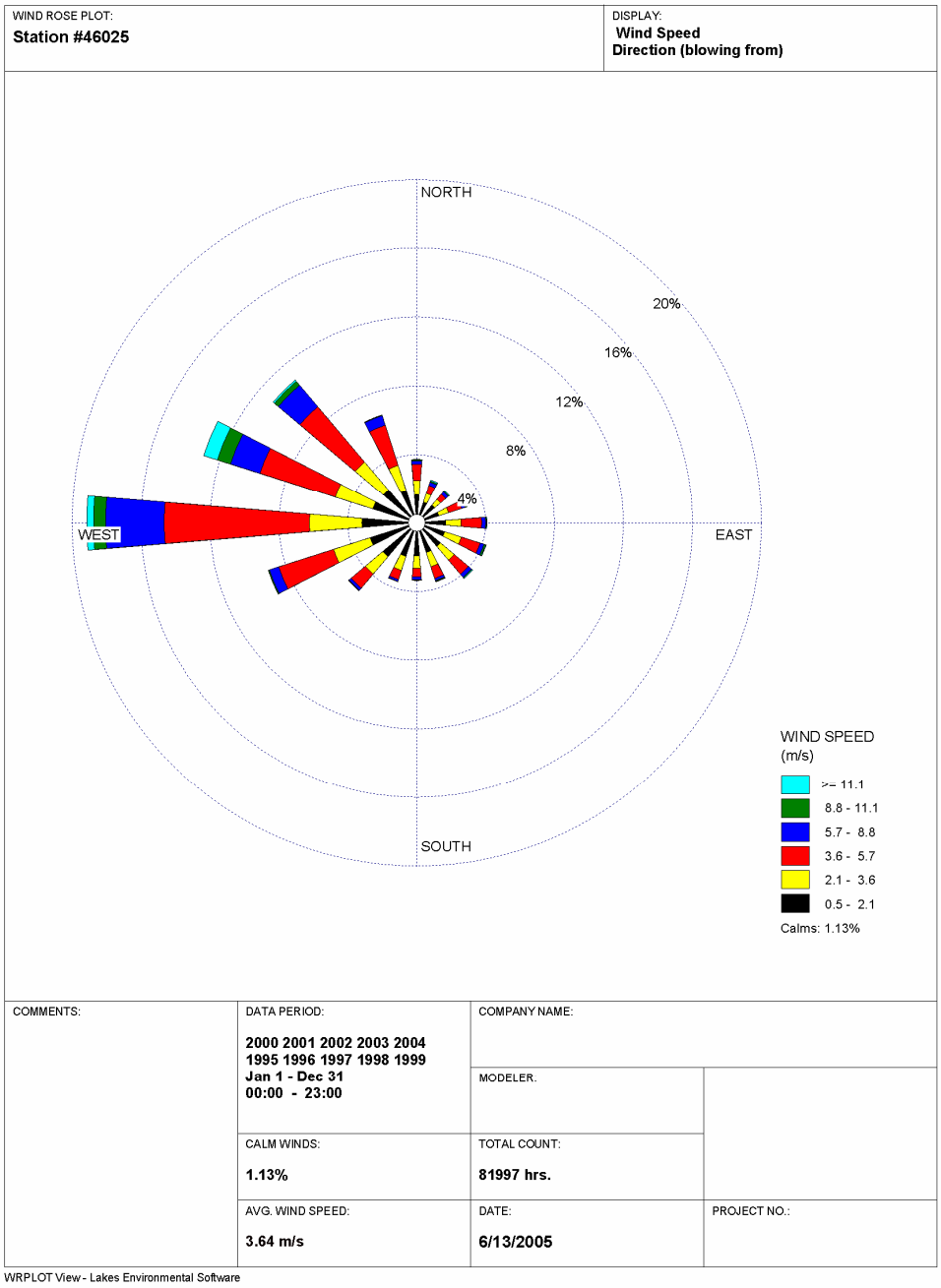

Figure 3: Wind direction data collected from a buoy 14.1 km from the FSRU site.

(Location of FSRU: 33°51'52" N 119°02'02" W. Location of Buoy: 33°44'42" N 119°05'02" W.) The weather data from this buoy can be found at http://www.ndbc.noaa.gov/station_history.php?station=46025

3. HAZARD AND RISK ANALYSIS ISSUES IDENTIFIED

Each potential LNG site or facility is unique and site-specific factors such as terminal or facility location, operating conditions, environmental conditions, site-specific threats, and available safety and security measures and emergency response capabilities, must be considered in evaluating the impact a proposed marine LNG terminal concept could have on the safety to people and property. Therefore, a site-specific, systems-level, evaluation of the possible events that could cause an LNG spill at a proposed marine import terminal or facility is necessary.

A systems-level risk analysis of the proposed Cabrillo Port Deepwater Port Project was conducted for the CSLC by Risknology and is documented in multiple reports including "Independent Risk Assessment of the Proposed Cabrillo Port Liquefied Natural Gas Deepwater Port Project – Revision 1"[1], "Environmental Impact Statement/Environmental Impact Report for the Cabrillo Port Liquefied Natural Gas Deepwater Port – Draft"[2], and "Cabrillo Port LNG Deepwater Port – Security and Risk Workshop"[3]. A systems-level hazard and risk evaluation should include consideration of the LNG import tanker, unloading facility design and operations, storage system design and operations, regasification and natural gas distribution system design and operations, the body of water and environmental conditions associated with an LNG unloading and regasification facility or system, and evaluation of the consequences of a possible spill on nearby people or property.

In our review and evaluation of the Cabrillo Port IRA, we followed the risk analysis guidance framework developed and presented in the recent Sandia report "Guidance on Risk Analysis and Safety Implications of a Large Liquefied Natural Gas (LNG) Spill Over Water"[4] to systematically review and assess the approach and findings presented in the Cabrillo Port IRA. The framework was used to help identify the major issues that should be addressed to provide an accurate analysis of the potential hazards associated with marine LNG operations at the proposed facility. An overview of the framework, review approach, and issues and concerns identified is presented below.

Risk Assessment of Marine LNG Imports

When conducting a risk assessment of an LNG import facility, the assessment should include the LNG tanker, the import terminal facilities and location, the navigational path, and the nearest neighbors along the navigational path and at the import terminal. Four classes of attributes affect overall risks and include:

- The context of the import facility – location, site specific conditions, LNG import, importance 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 to be avoided, such as injuries and property damage, LNG supply reliability required; and
- Protection system capabilities – LNG tanker safety and security measures, LNG import operations safety and security measures, and early warning and emergency response/recovery measures.

These attributes must then be evaluated to determine if the protection system in place can effectively meet the risk 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 import facility are adequate. If the initial risk assessment determines that the identified risk management goals are not met, then potential modifications in location and site conditions, import operations, safety and security measures, or

emergency response and early warning measures should be considered to determine how to improve overall safety and security to meet identified protection goals.

Hazardous marine import operations, such as LNG imports, need to be reviewed on a regular basis to reassess the adequacy of safety and security measures. Changes in any number of factors including the context of the facility, changes in threats or threat-levels, changes in risk management goals, or changes in risk management and safety systems could impact the basis for the original evaluation, making a reassessment of the risks to people and property necessary. We summarize below our approach in assessing the risks to the public and property from an LNG import facility and our initial issues and concerns identified for the Cabrillo Deepwater Port facility.

Risk Assessment Framework and Identified Issues

Step One - Characterize Assets

The context of the LNG facility such as location, site-specific conditions, and nominal operations must be identified. Information that should be considered 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 channel or remote from channel.
- **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 size and design,
  - Expected frequency of shipments,
  - Processing operations associated with facility – 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.

After reviewing the Cabrillo Port IRA[1], the following issues were identified:

1. Proximity and frequency of recreational and commercial vessels such as fishing vessels or sailing vessels and their impact on hazard concerns or protection goals.
2. Proximity and frequency of commercial or military cargo vessels or hazardous material cargo vessels and their impact on hazard concerns or protection goals.

3. The need for additional information on LNG storage, regasification, and transmission operations, pressures, safety features, etc.

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 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 facility attack, impact on facilities near navigational route, impact on other facilities near site not associated with LNG operations.

After reviewing the Cabrillo Port IRA[1], the following issues were identified:

1. Impacts on the FSRU from regasification and natural gas transmission operation accidents, and impacts on regasification and transmission from possible FSRU accidents should be considered in more detail.
2. Actual sequencing of spill events from accidental or intentional breaching events should be considered. While a "worst-case" scenario can be instructive, using it alone can be counter productive to general risk analyses and does not provide a technically consistent or sound risk assessment approach.
3. Hazards should be calculated for spills that include both potential fires as well as possible vapor cloud dispersion. Both may be possible, though under different conditions or events, one or the other might be more likely.
4. Multiple intentional events should be considered based on the distance and availability of emergency or Coast Guard support and FSRU safety and security features and operations.
5. The results of the accidental breach evaluations appear to be consistent with many existing studies for the size and type of FSRU cargo tanks, and the double-hull FSRU design.

Step Three - Determine Risk Management Goals and Consequence Levels

Identify risk management goals or consequence levels for LNG 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.

After reviewing the Cabrillo Port IRA[1], the following issue was identified:

1. While assessing hazards to the public on the beach is an appropriate criteria, hazards to other infrastructures – such as shipping, hazards to closer public- such as boaters, hazards to crews, and hazards and impacts on energy supply should be considered. Risk management and protection goals should be considered and established for these elements.

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, at the 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.

After reviewing the Cabrillo Port IRA[1], the following issues were identified:

1. General FSRU operations and safety features were not initially available but were identified as available in other documents[2,3]. A short overview of these operations and safety measures should be discussed in the Cabrillo Port IRA to facilitate some understanding of the conceptual safety and security goals and systems. The information should include information on expected LNG transfer operations, storage operations, regasification operations, and natural gas transmission operations. The FSRU is more than an LNG vessel and safety and security measures will be different. The 40-year history and safety record of marine LNG import vessels, while important and having some bearing on LNG safety, should not be used as a default for this new facility concept.
2. Discussion of deep water port surveillance and protection from the Coast Guard should be discussed along with the expected approach to security.

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.

The risk management process should then be updated regularly to assess whether changes in threats or threat levels, operations, LNG tanker design, or protective measures have occurred that would impact the ability of the system safeguards to meet identified or improved public health and safety goals.

If the potential hazard distances and hazard levels calculated exceed the consequence levels and risk management goals for the LNG terminal and import operations, then enhanced risk mitigation and

prevention strategies, changes in operations or location of the facility, 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.

Summary of Discussions to Resolve Issues and Concerns

Based on this initial evaluation of the Cabrillo Port IRA, the issues identified above were presented at the USCG Technical Review Panel meeting in San Antonio on April 11th and 12th, 2005, at the offices of ACE Consultants. The meeting included technical representatives from Sandia, the USCG, and the CSLC. Technical representatives from ACE, Risknology, and Ecology and Environment, the engineering and risk management consultants who developed and conducted the Cabrillo Port IRA, were also involved in the two-day meeting.

During this meeting, extensive discussions on Sandia's initial review and evaluation of the Cabrillo Port IRA were conducted. During these discussions, clarification of many of the initial issues was accomplished. Based on these discussions, the following major action items were identified to resolve all issues.

1. Expanding and moving some of the information into the summary and body of the report to provide better clarification of some of the analyses already conducted.
2. Reassessment of the proposed breach and spill conditions. More credible threats exist and may be more likely than the catastrophic total release scenario originally considered in the Cabrillo Port IRA. Sandia agreed to discuss their findings to date on cascading issues including foam insulation degradation. Sandia also agreed to provide open access information on ship impact analysis and intentional event threat analysis.
3. Establishing a fire and dispersion technical group to address the technical issues associated with the fire and dispersion modeling concerns identified. These efforts included interchange of Burro Series[5] LNG spill test data for model validation, evaluation of modeling assumptions including parameter values, addition of fire modeling and hazard analyses, evaluation of model grid size issues and sensitivities, and evaluation of initial and boundary conditions for dispersion analyses.
4. Establishing a processing and safety technical group to address the technical issues associated with LNG storage, regasification, and transmission operations on the FSRU, which is somewhat unique relative to past marine LNG import into the U.S. This included interchange of process safety concepts, operations, security provisions, and providing information on the results of the Security and Safety Workshop conducted for the Cabrillo Port IRA.

To resolve the issues identified, the Technical Review Panel conducted weekly conference calls as needed to discuss analysis and evaluation results. A second Technical Review Panel meeting was held in Albuquerque on June 14th, 2005 to assess the progress on the resolution of the issues. By this time, most of the processing safety issues and issues with credible accidental and intentional threat concerns had been resolved.

The remaining concerns were with the fire and dispersion hazard analysis results and approaches. Because of the potential large spill size postulated in the threat analyses, the computational fluid dynamics techniques employed in the calculations required extensive evaluation, calibration, and validation. These issues required constant interaction between the members of the Technical Review Panel. The computational fluid dynamic analyses required a thorough examination of all input variables, as well as boundary and initial conditions and grid and domain sizes.

Vapor dispersion issues were resolved by the end of August 2005 and all of the fire analysis issues were resolved by late September 2005. All of the technical issues initially identified by Sandia in the review process were resolved by early October 2005.

The following sections discuss each of the major elements of the Sandia review and assessment. The sections provide detail on the issues and the resolutions developed for the major system impacts on public health and safety from a potential spill. The sections include discussions of the credible threat scenarios, evaluation and selections for detailed consideration for spill evaluation, processing safety and security concerns, and fire and dispersion hazard analyses results.

4. THREAT AND BREACH ANALYSIS EVALUATION

Based on the initial review of the Cabrillo Port IRA as discussed in Section 3, the original breach, spill, and hazard analyses were limited. While a breach analysis was conducted for ship collisions, there originally was limited analysis of the size of possible breach events that might occur from either an intentional event or from an off-normal processing event. Therefore, additional threat analyses and associated breach analyses were recommended for both the intentional and processing events.

Threat Evaluation

Several types of accidental threats exist for this type of offshore terminal. They include collisions with 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. The type of threat impacts the size of the spill and the associated hazards. The range of potential accidental events should be assessed to identify those of major concern or having the greatest risk to people and property.

A range of intentional threats are also possible for this type of offshore terminal. These threats can range from insider threats to intentional external 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 attacks. These threats provide a range of breach conditions and potential spill events. Each threat should be considered to assess the potential and likelihood for specific terminal locations and designs.

The intentional breach analysis originally in the IRA considered only a catastrophic, simultaneous, three-tank release, which may be unrealistic based on the current understanding of credible events, as identified by intelligence agencies and the Department of Homeland Security (DHS). Therefore, Sandia recommended that the intentional threats be reexamined based on emerging guidance from DHS and from the intelligence community and noted in the recent Sandia report and the associated classified report on possible intentional threats.[4,6]

Breach Analysis Evaluation

The analysis of the results for the collision breaching events identified in the Cabrillo Port IRA included the use of modern finite element modeling techniques to analyze the deformation and interaction of a ship colliding with the FSRU. The FSRU, which is a double-hull vessel design, makes it particularly robust for normal collisions or ship accidents. Based on the FSRU double-hull design, which provides even greater standoff between the storage tanks and the outer hull than a typical LNG vessel, the identified collision events and the suggested breaching results appear reasonable relative to other double hull tanker collision studies using similar analysis methods and threats.[4,7] Based on this evaluation, the breach sizes suggested in the Cabrillo Port IRA for a ship collision appear logical and adequate based on the current state-of-the-art for modeling and analysis of these potential large-scale accidents.

An evaluation of the possible hazards from an LNG spill during transfer from an LNG cargo ship to the FSRU suggests that some confinement of the spilled and vaporized LNG may be possible. The general level of peak overpressure and FSRU damage identified in the Cabrillo Port IRA with this type of event seem to be comparable with overpressure data from natural gas explosions. Therefore, the spill and breach conditions suggested for LNG transfer and handling appear reasonable and appropriate.

An 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 suggest that the potential threats from off-normal events in the processing area would probably impact initially only one FSRU storage tank.

The intentional breach analysis originally in the IRA considered only a catastrophic, simultaneous, three-tank release, which may be unrealistic based on the current understanding of credible threats and events. Sandia evaluated the potential size of breaches of the FSRU based on a range of possible credible threats. The exact type and scale of these threats is discussed in a recent classified report by Sandia[6], but included a range of insider and external attacks from sea and air with a range of weapons. Based on considering this range of threats and the physical characteristics of the FSRU, including hull and storage tank design and standoff, Sandia suggested a range of potential hole-sizes to use for spill and dispersion analyses.

The evaluations identified two governing intentional events that should be considered for spill and hazard analyses. 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 could be assumed.

Threat, Breach, and Spill Analysis Resolution

Based on the reviews presented in the two recent Sandia LNG reports[4,6], as well as recent draft DHS guidance on intentional threats, estimates of possible breaching events were recommended. These are listed in Table 2 and were suggested for inclusion in the final Cabrillo Port IRA analysis. These events bracket the range of potential breach sizes deemed credible. The accidental breaching events include the possibility of collisions of the FSRU from another vessel. The processing breaches identified include consideration of a potential accidental processing equipment failure, based on the current FSRU configuration, that might cause a fire or explosion and that might lead to the breach an LNG storage tank. The intentional events recommended include a range of threats against an FSRU in the open ocean, where an intentional attack might be possible.

As shown in Table 2, these recommendations include some rather large potential spills, but not a single catastrophic release of all three storage tanks simultaneously. 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 should be conservative.

From the results shown in Table 2, the intentional two-tank release is expected to be the governing spill for hazard distances because of the total volume assumed spilled over a relatively short time span.

Table 2. 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

5. SPILL, DISPERSION, AND FIRE ANALYSIS EVALUATION

This section discusses the assumptions and models used for LNG pool spreading, vapor cloud dispersion, pool and vapor cloud fires. Based upon our initial review, pool spreading calculations were reasonable and appropriate. The major issues identified were associated with vapor dispersion and fire modeling and were the focus of this evaluation. Additional analyses were conducted by the Technical Review Panel to address these issues. An assessment of the adequacy of the assumptions and models used are discussed below as well as validation conducted to compare modeling results to test data.

Dispersion Modeling Evaluation

This section provides a description and assessment of the LNG dispersion calculations performed by ACE consultants using the Fire Dynamics Simulator (FDS)[8]. The dispersion calculation results can be grouped into an initial and final set. ACE provided an initial set of results in the IRA which were reviewed by Sandia. Issues were found and suggestions were provided to ACE resulting in a revised or final set of dispersion calculations. The initial and final set of results and a description of the Sandia suggestions are presented in this section, as well as an assessment of the final results.

Initial Calculations

The breach scenarios shown in Table 3 for the LNG storage tanks, each assumed to contain approximately 100,000 m^3 of LNG, were considered by ACE. The initial set of dispersion results shown in Table 4 for these breach scenarios were performed using a wind power law profile of 6 m/s at an elevation of 10m with an exponent of 0.15. Two mass flux values were considered, one calculated by FDS and the other specified. Both values are within the range of experimentally measured values and uncertainty.

Table 3: Breach Scenarios

Scenarios	Number of tanks	Assumed LNG volume spilled (m^3)	Area of breach (m^2) per tank
3-A	1	100,000	20
3-B	1	50,000	1013
5.1A	3	300,000	Instantaneous (all tanks)
B	2	200,000	7

Table 4: Initial Dispersion Results

Scenarios	Mass spilled (kg)	Pool dimensions (m)	Pool area (m^2)	Equivalent pool diameter (m)	Time to evaporate (s)	Max distance to LFL (m)
3-A	4.25×10^7	800 x 860	540,354	829	562	1790* (1937)**
3-B	2.13×10^7	950 x 1080	805,819	1013	189	1880* (2022)**
5.1A	12.75×10^7	1360 x 1260	1,345,858	1309	676	2590* (2150)**
B	8.50×10^7	611 x 615	295,125	613	1477	1915* (1855)**

*using a mass flux calculated by FDS of 0.14 kg/m^2s
**using a specified mass flux of 0.195kg/m^2s

Initial Assessment

The following describe Sandia's evaluation of the initial LNG dispersion calculations. These conclusions are based on code to code comparison and the input file provided by ACE pertaining to the 2-tank, 7 m^2 breach scenario. As part of a diagnostic process and in the absence of test data of the LNG spill sizes under consideration, Sandia performed similar dispersion calculations using VULCAN[9,10, 11] and FUEGO[12], which are computational fluid dynamics models. Sandia obtained lower flammability limit (LFL) distances of between 7000-8000m, versus the approximately 2000m distance obtained by ACE. LFL is commonly considered as the basis to identify vapor hazard distances based on possible ignition of the vapor and subsequent fire. Thus, due to this large difference, Sandia performed several FDS simulations of LNG dispersion to investigate why the results differed. There were three main issues that were identified in the evaluation of the original ACE FDS analyses, which resulted in an under prediction of dispersion distances. The issues were:

1. An incorrect value to identify the LFL was used in the input file.

   The lower flammability limit (LFL) for methane is 0.05 on a volume fraction basis, and 0.0276 on a mass fraction basis in air. By default FDS provides specie fraction on a mass basis as stated in the user's manual. This feature can also be verified using the post processor Smokeview provided with FDS. The input file developed by ACE measured an iso-contour of .05 on a mass fraction basis, instead of the correct value of 0.0276. This difference in specification of LFL criteria can result in a lower distance to LFL. The input file should be corrected to a value of .0276 for the iso-contour of methane on a mass fraction basis.

2. The methane is released into a flow field which is in a transitional state and has excess mixing.

   The input file developed by ACE initialized the flow field with a uniform value of 6 m/s shortly (1 second) before the methane was injected, and specified a wind boundary condition at the upstream boundary throughout the duration of the simulation with a power-law profile having a value of 6 m/s at an elevation of 10 m and exponent of 0.15. All other boundaries were specified as 'open' boundaries. There were two difficulties identified with this set of initial and boundary conditions. First, the flow field should be allowed to come to a quasi-steady profile before the methane is injected due to the difference between the initial and boundary velocity profiles, and secondly, open boundary conditions adjacent to parallel flow creates excessive mixing.

   For the case modeled, the flow field develops a boundary layer which will grow in the downwind direction as the methane is dispersed. By injecting methane into the domain before the flow field is allowed to come to a quasi-steady profile, excess mixing will be present that will significantly reduce the distance to LFL.

   After several investigative simulations it was also realized that parallel flow adjacent to 'open' boundaries introduces excess mixing. Initially, Sandia tested a case in which a delay time was introduced before the methane was released to allow for the domain to develop a quasi-steady profile. Introducing a delay time was found not to be sufficient; rather a 'mirror' boundary condition at the side boundaries parallel to the wind and a free-slip wall condition at the top domain provided a power-law wind profile uniformly across the domain before the methane was released.

   The 'mirror' boundary condition is a no-flux, free-slip condition. If this boundary is placed sufficiently far from the pool, any effect from the suppression of entrainment is negligible. It should be noted that this is not a buoyant plume problem as in a pool fire where there is high entrainment. Entrainment is

very low as the methane is released since it is at a low temperature. Since mass is being injected into the domain, air should be displaced initially to conserve mass. The displaced air can exit out of the 'open' domain at the downwind end.

In order to minimize excessive mixing from a highly unsteady flow field, given the available boundary conditions in FDS, the side boundary conditions should be modified from 'open' to 'mirror' and a delay time from the initialization of the flow to when the methane is released should be introduced. The top boundary should be specified with either a free-slip wall condition or a 'mirror' condition placed sufficiently far from the pool since open boundary conditions adjacent to parallel flow create excessive mixing. The flow field should be initialized with a value of zero.

3. The reduced temperature of the LNG pool was not correctly reflected.

   The correct low density of the injected methane was specified by ACE, but the gas was released at ambient temperature. The evaporating vapor from an LNG pool is a dense gas (1.5 times that of air) at a very cold temperature of -162°C. If the temperature is not specified correctly, the vapor becomes excessively buoyant since methane at atmospheric temperatures (21°C) is about half the density of air. This effect will reduce the distance to the LFL. To assess this effect, the input file developed by ACE was run by Sandia (with a coarser mesh, 25 x 25 x 5 m instead of the mesh used by ACE of 15 x 15 x 2 m). The results show that for FDS, the temperature rather than the density should be specified for the pool in order for the methane to be injected with the proper temperature and density.

   The results also showed that the temperature actually increased above atmospheric temperature around the pool as the methane was injected. It is believed that this occurred since a 'reaction' flag was invoked. This flag signifies a combustion process and hence an ignition source will be present and will provide some heating. ACE set the burning rate to 10^{-7} kg/m^2 s presumably to prevent burning. This 'reaction' flag should be removed for dispersion calculations.

Final Calculations

A final set of calculations was performed by ACE that incorporated the corrections for the three issues identified. The 2-tank, 7-m^2 hole scenario (case B), was identified as the case resulting in the longest distance to maximum LFL. Thus, dispersion calculations were performed for this case as shown in Table 5. The wind condition was also varied to reflect the lower and average occurring wind conditions around Cabrillo Port as presented in Section 2. Thus, cases were considered with wind power law profiles of 2 m/s and 4 m/s and an exponent of 0.11 at a 10 m elevation.

Table 5: Final Dispersion Results

Scenario	Wind speed (m/s)	Max distance to LFL (m)
2-tank, 7 m^2 hole	2	11,175
	4	9,420
	6	8,280

Final Assessment

The 2-tank, 7-m^2 hole case was performed by ACE with a relatively coarse, stretched mesh with a minimum of 20 m width cells in each direction. Sandia performed a simulation of this case using FDS but with a finer uniform mesh, 10 m cell widths in each direction for a total of 22.4 million computational

cells, and found results for vapor dispersion to be somewhat less than the ACE results as shown in Table 6. Thus, the final result from ACE for 2-tank, 7-m^2 hole case appears to be reasonable and should provide a conservative estimate of dispersion distances.

Table 6: Final Dispersion Result Comparison for 2-tank, 7-m^2 Hole Scenario

Simulation performed by	Maximum distance to LFL (m)
ACE (FDS)	~11,000
Sandia (FDS)	~7,000

An additional component to this assessment is validation of FDS against experimental data from LNG dispersion tests. The Burro series is the most appropriate data set for model result comparison[5]. An FDS simulation of the Burro 8 test was performed by ACE using a 5x5x1 m cell resolution. A maximum distance to LFL of 490 m was obtained as compared to 420 m from experimental data. Sandia also performed an FDS calculation of Burro 8 on a finer uniform grid (1 m cell widths in each direction with almost a total of 7 million cells) and found a maximum distance to LFL of about 500 m using a wind speed of 1.63 m/s at a 1 m elevation and an exponent of 0.186.

A 20% difference with over prediction is within reasonable agreement given the resolution of the simulation, the use of a symmetry plane, and the exclusion of modeling the surrounding terrain. A symmetry plane will suppress any mixing down the centerline resulting in a greater distance to LFL. From the tests, the dispersion cloud impacted the surrounding terrain which had up to a 7 m rise. Thus, it is expected that by including the terrain that a shorter distance to LFL would result.

FDS simulations performed by Sandia to date, as well as evaluation of the mathematical models of the code indicate that FDS is capable of simulating LNG dispersion, but a large number (10 million to 100 million) computational cells are required. It would be optimum to perform these dispersion simulations with finer resolution, however lower resolution simulations result in longer distances to LFL due to the turbulent mixing being under resolved. Therefore, the current FDS analyses provide a conservative assessment of safety hazard distances.

Fire Modeling Evaluation

In the initial Cabrillo Port IRA, fire modeling was not conducted. Sandia recommended that fire modeling for both pool and flash scenarios be conducted for several reasons. For many of the large intentional and accidental spills, the threat scenarios suggest that an LNG fire could be a likely outcome and therefore thermal hazards from fires should be analyzed. Based on suggestions from Sandia, a series of fire modeling analyses were developed by ACE. ACE considered two scenarios for fire, a pool fire and vapor cloud fire (or flash fire). The following will provide the assumptions used and results by ACE and then Sandia's assessment of their results.

Pool Fire

Final Results

For the pool fire calculation ACE used a right cylinder, solid flame model. The Moorhouse correlation was used to calculate flame height for a pool fire diameter of 640 m, resulting from the largest spill (2-tank, 7-m^2 hole case). Table 7 shows their results for distance to various heat flux levels. The heat flux levels shown in Table 7 are commonly used by industry and the National Fire Protection Association to

identify hazard levels. The high levels of heat flux can severely impact process equipment and piping if sustained for over 10 minutes. The 5 kW/m^2 value is commonly considered the heat flux level appropriate for protection of human health and safety.

Table 7: ACE Pool Fire Results

Heat flux (kW/m^2)	Distance (m)
37.5	810
12.5	1620
5	2640

Final Assessment

Sandia reviewed and assessed the ACE pool fire calculations by calculating heat flux as a function of distance as shown in Figure 4. 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 x 10^{-4} m/s, and a transmissivity of 0.8 were used. The Moorhouse correlation and view factors can be found in the SFPE Handbook of Fire Protection Engineering, 2nd edition[13]. Sandia pointed out that the 3rd edition has this equation misprinted where the leading factor should be 6.2 instead of 62. Both the Sandia and ACE results included this correction. The Sandia results are in close agreement with the results by ACE. The model used is appropriate given the absence of obstacles. The assumptions made are reasonable given the current knowledge of the required input parameters and should provide a conservative estimate of thermal hazard distances.

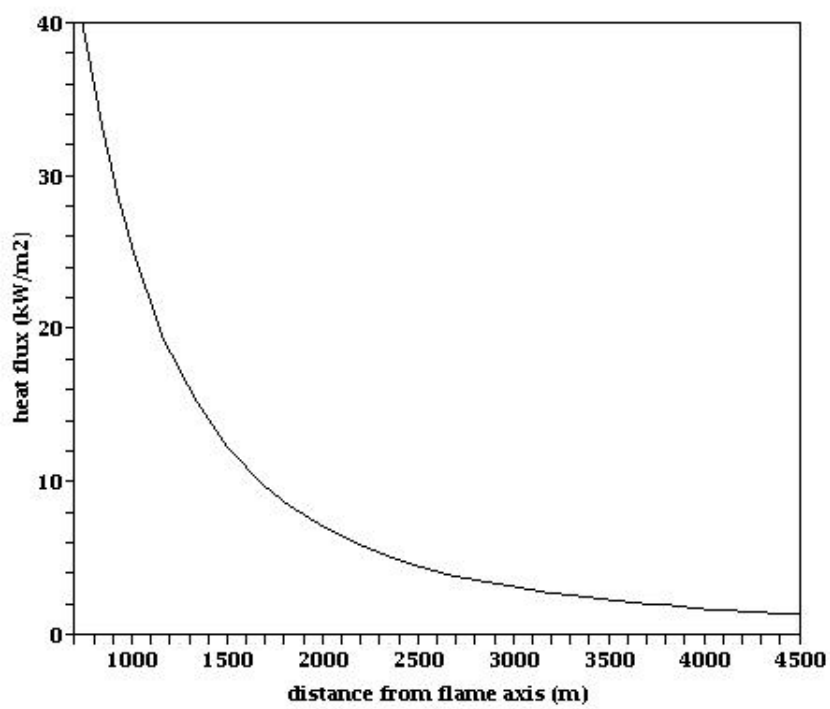

Figure 4: Sandia calculation of pool fire hazards.

Flash fire

Final Results

ACE used a solid flame model to calculate the thermal hazard distances resulting from a flash fire and used the approach described in the SFPE Handbook of Fire Protection Engineering (3rd ed.) on page 3-11[13]. The equations for the view factor for a rectangular flame in the 3rd edition are incorrect, and the correct equations can be found in Reference 14 and were used by ACE. ACE assumed a surface emissive power of 200 kW/m^2, transmissivity of 0.8, maximum cloud height of 30 m, upward flame velocity of 0.16 m /s, flame propagation speed of 5 m /s, and a flame height to width ratio of 0.4. They performed three calculations at 60, 72, and 90 minutes after dispersion. Table 8 shows their results for distance to various heat flux levels at these times.

Table 8: ACE Flash Fire Results

Heat flux (kW/m^2)	**Time after dispersion (min)**		
	60	**72**	**90**
	Distance (m)*	**Distance (m)***	**Distance (m)***
37.5	400	280	175
12.5	880	560	310
5	1440	920	500

* Distance measured from edge of vapor cloud

Final Assessment

Sandia reviewed and assessed the flash fire results by calculating heat flux as a function of distance shown in Figure 5. The same input parameters were used as ACE except a surface emissive power of 220 kW/m^2 and an upward velocity of 0.2 m/s were used. This upward velocity will give a flame height to cloud height ratio of 10 which is what was found from the Coyote experiments on vapor cloud fires[15]. This approach results in a maximum flame width of 750 m. The results are in close agreement with the results by ACE. The model used and the assumptions made should provide a conservative estimate of the thermal hazard distances. The results are also conservative because of the transient nature and spatial variability of vapor cloud fires. Heat flux levels will not be maintained for durations required to cause injury at certain locations relative to the cloud. Thus, a global hazard zone as provided by ACE should be conservative.

Overall, the final results for both fire and dispersion hazard distances after incorporating the recommended Sandia changes appear to provide reasonable estimates of hazard levels and distances for what was considered credible events. The analyses developed should provide conservative estimates of expected hazard distances.

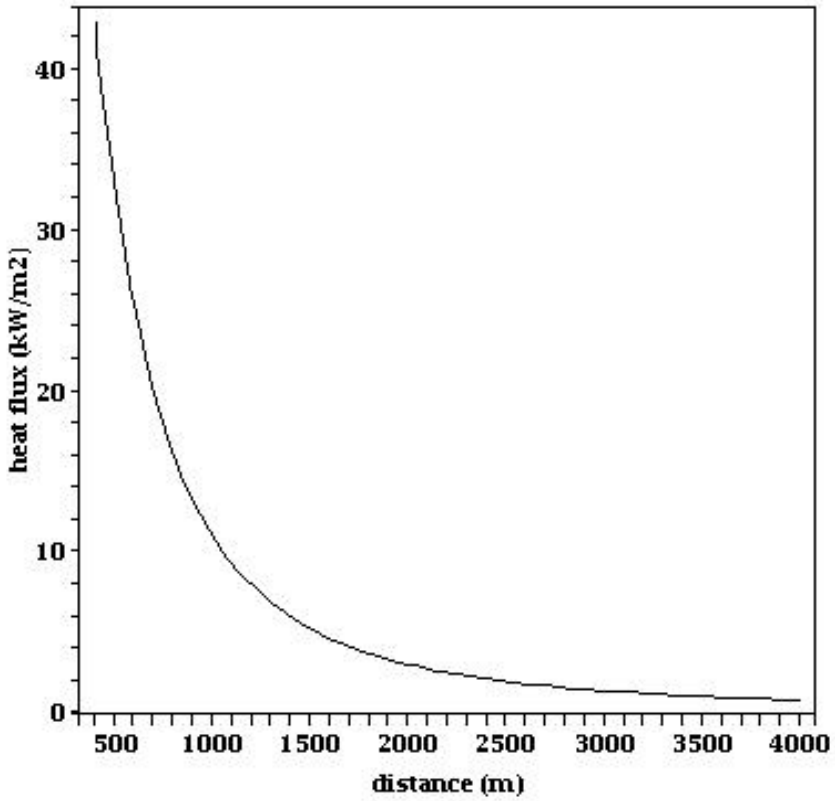

Figure 5: Sandia calculation of flash fire at 60 minutes after dispersion.

6. PROCESS SAFETY AND SECURITY RISK EVALUATION

An effective risk management plan for a program such as the Cabrillo Port Liquefied Natural Gas Deepwater Port Project will assure that risks leading to unacceptably high consequences are either eliminated or reduced to acceptably low residual levels. Safety and security stresses that can trigger accident/incident sequences leading to catastrophic consequences are best understood and managed according to escalating threat levels. Thus the design and response of the system can break the chain of events or otherwise cap the consequence to an acceptable level. In considering safety stress, the escalating levels can be called *normal*, *off-normal* and *emergency* environments. In considering security stress, the analogous levels are labeled *MARSEC 1*, *MARSEC 2* and *MARSEC 3* (MARSEC stands for MARitime SECurity as defined in 33 CFR 101).

The relationship of these tiered levels and risk management is two-fold. First, as environmental stress escalates, the system may limit operations in some way to help cap consequences. Second, the stress thresholds separating neighboring levels (e.g., normal and off-normal) can be adjusted to take optimal advantage of preventive or mitigative measures. Of course the likelihood of occurrence of safety—and especially security—threats is not known with certainty, so some measure of personal judgment is called for in the design and evaluation of a system subject to high consequences. Safety stresses include weather and natural stresses, and operational error.

Sandia sought to provide in its review of the Cabrillo Port IRA a qualitative evaluation of whether credible risks leading to high consequences have been identified and addressed. This does not necessarily mean that all such risks have been driven to zero, or nearly so, by implementing some positive measure(s). It means, rather, that such risks have been either considered or have been judged to be acceptably small.

In its guidance document for assessing risk of inadvertent or intentional releases of LNG, Sandia considered mainly open-water transportation operations. By contrast, the Cabrillo project covers a much broader spectrum than LNG off-loading by including LNG storage (within the FSRU) regasification and pumping gas to shore. Some aspects of the proposed design—especially active and passive methods for station keeping—have an extensive track record in other deep water systems (e.g., drag anchors). But other operations on a floating facility (e.g., processing) have fewer applications in the LNG industry and as such may involve more uncertain risks.

Process and System Safety and Risk Assessment

In the review of the Cabrillo Port IRA, a major element that must be noted is that the facility is currently only in the conceptual design stages. Significantly more detail in the overall system safety and security design elements and operations will be available in the future. Additionally, safety and security measures can be incorporated where needed. Based on our review of the Cabrillo Port IRA, the following concerns were identified in the review of the current system process safety and security. For each item discussed, risk management considerations are presented that should be considered in the final system and terminal design and final facility operations.

- Details of pressurization of the natural gas must be considered. LNG will be regasified at high pressure where the gas then vaporizes directly. 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 the tanks may ensue.

The initial conceptual design includes a safety tunnel for crew safe haven in the event of a processing accident. While appropriate, in the final design additional protection elements might be considered to ensure that the crew will be able to activate safety systems and that multiple cargo tanks will not be damaged in the case of this type of event.

- The location of the FSRU is sufficiently remote from shore as to pose limited risk to shore-side persons or facilities under any scenario of LNG release. But if the mooring were to fail, whether caused accidentally or intentionally, there should be a contingency plan to prevent the FSRU from drifting near shore.

- If normal LNG processing operations are interrupted for an extended period, use of diesel fuel (1,000 m^3 capacity) for backup power could become depleted. But planned replacement of used fuel is by small finite quantities (350 gallon drums); prolonged continuous use is assumed to never occur. Consideration of the maximum duration of backup power required and for what purposes should be considered relative to safety and security issues.

- The FSRU will not have the capability to avoid storms like a regular LNG tanker. If, for example, a large storm is headed for the site, it is not clear what contingency plans exist to prevent or mitigate negative consequences. Such contingency plans should be considered to minimize consequences.

- The use of odorant in the LNG and natural gas exported from the FSRU should be considered to ensure safety and security of Cabrillo Port operations.

- If normal exporting operations are interrupted for an extended period, boil-off and venting would seem to be a potential safety problem if the rates are high. Contingency plans for boil off should be considered.

- Firefighting during an event when an offloading tanker is alongside may prove more difficult than for FSRU involvement alone. Contingency plans and safety procedures during these types of events should be well developed.

- If emergency abandonment were to occur, contingency plans should be developed that minimize risks to the FSRU, crew, and hazards to the public and property.

- The FSRU terminal includes risers and pipelines. Riser and pipeline maintenance and operations need to be fully integrated into the overall FSRU system safety and security and risk management plans. The impact of a malfunction, damage, or leak of a riser or pipeline may have on the FSRU system should be considered for operational and safety issues.

System Safety and Security Design Recommendations

The FSRU is still in the preliminary design phases. A final evaluation of the proposed process safety and security measures therefore are not appropriate or possible at this time. The following recommendations are provided to assist in the final FSRU design to insure that operations of the various components of the FSRU, including regasification and transmission, will not increase hazards and risks to the public and property that exceed the hazards from accidental or intentional threats. Major elements that should be considered include:

1. Implement LNG processing and regasification operations that include appropriate safety and security measures such that an off-normal processing event or events can not cascade to an LNG spill larger than the identified credible case of a 2 tank – 7 m^2 breach.

2. Implement pipeline operations safety and security measures such that off-normal events can not cascade to an LNG spill larger than the identified design event.
3. Implement FSRU LNG storage tank protection technologies, such as improved materials, insulation, and structural capabilities, such that possible cascading damage to storage tanks from spills, fires, or off-normal processing events can be reduced.
4. Implement safety and security measures for the crew such that FSRU operations can be safely shut down and security measures initiated in the case of an accident or off-normal operational event.
5. Include appropriate security measures to reduce the ability to inappropriately board or take control of the FSRU and/or associated operations in this more remote location.

7. SUMMARY OF ISSUES AND FINAL RESOLUTIONS

The Cabrillo Port IRA was developed to provide an assessment of the risks associated with a floating, offshore, LNG receiving and processing terminal. The safety and risk analyses conducted and presented in the Cabrillo Port IRA were coordinated through the California State Lands Commission and the US Coast Guard. The FSRU is in the conceptual design stage, and the Cabrillo Port IRA attempted to assess the risks associated with the proposed conceptual design. As such, some assumptions on possible safety and security concerns, expected operating conditions and procedures, and risk prevention and risk management opportunities were necessary.

Likewise, in our review of the Cabrillo Port IRA, Sandia was required to make some assumptions about potential safety and security issues, operating conditions, and risk prevention and mitigation needs. The purpose of the Sandia effort was to help provide the US Coast Guard and the California State Lands Commission with the best understanding possible about the potential hazards and risks to the public and property of the conceptual FSRU and the proposed Cabrillo LNG Deepwater Port. The Sandia review focused on providing a system-level review of the assumptions, analyses, and modeling approaches identified and used in the Cabrillo Port IRA.

Based on the Sandia review, many of the initial Cabrillo Port IRA assumptions, evaluations, modeling, and risk analyses appeared appropriate. Sandia did identify issues and concerns with some assumptions and analyses in the Cabrillo Port IRA. Many of the concerns dealt with the difficult area of the identification and evaluation of credible intentional threats and the analysis of the potential fire and dispersion hazards associated with possible large LNG spills. Both the threat and hazard analyses can be very difficult and complicated. After several months of technical interactions/discussions and additional modeling, the Technical Review Panel, which included representatives from the US Coast Guard, California Lands Commission, Sandia, and the developers of the Cabrillo Port IRA, is in general agreement with the assumptions, analytical methods, and the final results for dispersion and fire modeling.

The efforts of the Technical Review Panel have resulted in refined analyses that provide hazard results that are representative of the consequences to public safety and property from a potential FSRU breach and spill. Based on these efforts, the hazards identification and distances estimated in the final results are reasonable and acceptable relative to the current understanding of large LNG spills over water.

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