DRAFT

SANDIA REPORT

SAND2011-xxxx
Unlimited Release
Printed November 2011

Hazards Assessment of the Proposed Hadera Liquefied Natural Gas Deepwater Port Project

Anay Luketa and Michael Hightower

Prepared by
Sandia National Laboratories
Albuquerque, New Mexico 87185 and Livermore, California 94550

Sandia is a multiprogram laboratory operated by Sandia Corporation,
a Lockheed Martin Company, for the United States Department of Energy's
National Nuclear Security Administration under Contract DE-AC04-94AL85000.

Sandia National Laboratories

Issued by Sandia National Laboratories, operated for the United States Department of Energy by Sandia Corporation.

Available to DOE and DOE contractors from
U.S. Department of Energy
Office of Scientific and Technical Information
P.O. Box 62
Oak Ridge, TN 37831

Telephone: (865)576-8401
Facsimile: (865)576-5728
E-Mail: reports@adonis.osti.gov
Online ordering: http://www.osti.gov/bridge

Available to the public from
U.S. Department of Commerce
National Technical Information Service
5285 Port Royal Rd
Springfield, VA 22161

Telephone: (800)553-6847
Facsimile: (703)605-6900
E-Mail: orders@ntis.fedworld.gov
Online order: http://www.ntis.gov/help/ordermethods.asp?loc=7-4-0#online

HAZARD ASSESSMENT OF THE PROPOSED HADERA LIQUIFIED NATURAL GAS DEEPWATER PORT PROJECT

Mike Hightower
Energy Surety Engineering and Analysis Department

Anay Luketa
Fire Sciences and Technology Department

Sandia National Laboratories
P.O. Box 5800
Albuquerque, New Mexico

October 2011

ABSTRACT

In August 2011, with approval and encouragement by the United States Department of Energy, Sandia National Laboratories was funded by the Israeli Ministry of Infrastructures Israel Natural Gas Lines to provide hazards and risk evaluations of the proposed Hadera LNG Deepwater Port. The goal of Sandia's technical evaluation was to assist the Israel Natural Gas Lines in ensuring that the hazards to the public and property from a potential liquefied natural gas (LNG) spill during marine import, transfer, storage, and regasification operations were appropriately evaluated and estimated.

Sandia was asked to evaluate the safety issues of the Hadera LNG Deepwater Port operations relative to the risk and safety analysis framework identified in a 2008 Sandia report on deepwater ports, "Breach and Safety Analysis of Spills Over Water for Large Liquefied Natural Gas Carriers". That report provides a framework for assessing hazards and identifying approaches to minimize the consequences to people and property from a spill from newer and larger LNG ships operating at deepwater LNG ports. There was also interest in having Sandia apply the additional insight on hazards analysis and safety issues being developed from the recent Sandia and the United States Department of Energy's experimental and modeling studies of cascading damage issues to large LNG ships from large LNG spills conducted from June 2008 through May 201.

This report summarizes the results of the Sandia safety and hazards evaluations of the Hadera LNG Deepwater Port. For this effort we conducted a site-specific hazards and safety assessment for the proposed Hadera LNG Deepwater Port location and operations. This included evaluation of site-specific credible accidental and intentional threats; wind, weather, and environmental conditions; and consideration of LNG ship size and port operations options. Overall, the maximum potential fire hazards are expected to be less than 5 km from the deepwater port location, and the maximum potential dispersion thermal hazard distances are expected to be less than 4 km from the deepwater port location. Since the proposed Hadera LNG Deepwater Port would be approximately 10 km offshore, the thermal hazards from a fire or dispersion event at the port are not expected to impact either people or property on shore.

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.

To support the technical analysis required for this project, the authors worked with many organizations, including several Israeli agencies to collect background information on proposed system design and operations, and appropriate local and regional considerations on threat considerations in order to assess potential LNG spill safety and risk implications.

The following individuals were especially helpful in supporting our efforts and providing technical and programmatic information.

Danielle Monosson – United States Embassy, Tel Aviv
Robert Corbin – United States Department of Energy
Samuel Tordjman – CEO, Israel Natural Gas Lines
Ishai Ashlagi – Israel Natural Gas Lines
Adi van Velsen – Israel Natural Gas Lines
Efraim Bibi – Contractor, Israel Natural Gas Lines
Aharon Weissman – Manager, Port of Hadera

CONTENTS

LIST OF FIGURES

LIST OF TABLES

LIST OF ACRONYMS

DOE	United States Department of Energy
DOS	United States Department of State
FSRU	Floating Storage and Regasification Unit
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	meter
m^2	square meter (area)
m^3	cubic meter (volume)
m/s	meter per second
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 both industry's and the public's attention to marine LNG import and export activities.

In August 2011, the United States Department of State and Department of Energy requested and authorized Sandia National Laboratories (Sandia) to support the Israel Natural Gas Pipeline Company in evaluating the potential hazards to the public and property from a large LNG spill at a proposed LNG deepwater port (DWP) import terminal approximately 10 km off the coast of Hadera, Israel. Sandia was asked to evaluate the potential hazards based on the risk and safety analysis framework provided in two Sandia reports, "Guidance on Risk Analysis and Safety Implications of a Large Liquefied Natural Gas (LNG) Spill over Water" [Hightower et al 2004] and "Hazard Analysis of Spills from Larger LNG Ships", [Luketa et al 2008] published in 2004 and 2008 respectively. Those reports provide a technical framework for use by industry and regulatory agencies to assess the hazards from a potential LNG spill on 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 proposed Hadera LNG Deepwater Port was to assist the Israel Natural Gas Lines and the Israeli Ministry of Infrastructure in ensuring that the hazards to the public and property from a potential LNG spill during transfer, storage, and regasification operations at the proposed DWP were appropriately evaluated and estimated.

Initial Site Evaluation and Hazard Analysis Discussions

Sandia was provided with an initial hazards and safety analysis scope of work in August 2011 for review. Based on our review, several technical issues were identified that were discussed with a number of Israeli agencies in a series of technical and programmatic meetings held in Tel Aviv, Jerusalem, and a site visit to the Hadera Port from August 8-12, 2011. These meetings included representatives from the Israel Ministries of Defense, Infrastructure, and Transportation, the Port of Hadera, the Israel Natural Gas Pipeline Company (INGP), the U.S. Department of State (DOS) Embassy in Tel Aviv, the U.S. Department of Energy (DOE), and Sandia. Based on these meetings, a final scope of work was agreed to that included the following major points for consideration in the site-specific hazards and safety analyses of the proposed Hadera LNG DWP:

- Agreement to consider both Floating Storage and Regasification Unit (FSRU) and buoyed LNG regasification options for the DWP, including consideration of the use of the maximum size LNG ships currently projected, up to 260,000 m^3 capacity.
- Identification and agreement on the general intentional and accidental credible threats to be considered.
- Identification and agreement on the fire and dispersion hazard analysis values to be considered in evaluating hazard distances.
- Agreement to provide information on process safety considerations associated with LNG storage and regasification operations of the two marine LNG delivery options.
- Agreement on site-specific weather and nearby ship traffic data to be provided.

Following these meetings, the Hadera Port site visit, and receiving some of the site-specific weather and ship data, Sandia was able to identify the types of credible accidental and intentional events that should be considered at the proposed Hadera LNG DWP. Using this information along with information on the marine LNG ships and processing to be used, and the site weather conditions, the expected fire and dispersion hazard distances were evaluated from August through October 2011.

[redacted] *Hazard and Safety Assessment Results*

Our analyses focus on the possible thermal hazard distances from a fire or vapor dispersion from a large LNG spill during operations at the deepwater port. A large spill could occur due to the breaching of one or more LNG cargo tanks from any of the LNG ships or special LNG Floating Storage and Regassification Units (FSRUs) that might be associated with the operation or marine import of LNG to the Hadera Deepwater Port. To conduct the spill and hazard analyses, a range of credible, site-specific, accidental and intentional breach events have been identified and evaluated. For our hazard analysis we used Hadera location-specific operational, accidental and intentional threat, and environmental factors determined in cooperation and consultation with Israeli national security and port operations authorities.

The approach we used was based on guidance presented by Sandia in two technical reports in 2004 and 2008 for conducting risk and safety assessments for large LNG spills on water. The 2004 report presents a recommended step-by-step approach for assessing hazards to the public and property for accidental and intentional LNG cargo tank breach events consistent with inner harbor transit of LNG ships of 125,000 m^3 to 145,000 m^3 capacity. The 2008 report extended this analysis approach to offshore, deepwater LNG ports, where there is less surveillance and the potential for larger intentional and accidental threats to LNG ships is more likely. Also, LNG ships often considered for use at LNG deepwater ports are larger, commonly in the 215,000 m^3 to 265,000 m^3 capacity range. We have used the approach presented in the 2004 and 2008 reports to support the U.S. Coast Guard in evaluating hazards to the public for several different U.S. LNG deepwater ports on the Pacific, Atlantic, and Gulf coasts.

Threat and Breach Analysis Results

The threat evaluations identified the maximum governing intentional event for spill and hazard analyses. These events include consideration of LNG handling, storage, and processing accidents, ship collisions, and intentional attacks including the breach of multiple LNG cargo tanks from a coordinated intentional attack. The hole sizes noted represent the largest hole sizes calculated for a range of accidental and intentional events considered including collisions, shoulder fired weapons, under water weapons, explosive attacks, and air and water based attacks and weapons. Most of the intentional events that create large breach sizes require some type of explosive charge that provides an ignition source to start a pool fire. Based on breach analyses conducted by Sandia for the credible threats identified, it was estimated that a 12-15 m^2 breach in up to three LNG cargo tanks would provide the maximum spill at one time for a fire event. This was based on potential credible intentional events. Process accident damage estimates suggest that slightly smaller breach sizes would occur, bur probably only to a single cargo tank.

In considering vapor dispersion for a deepwater port, a ship collision provides the largest potential breach size. Using approaches summarized in the 2004 Sandia report for evaluating ship collisions and calculating breach sizes, we evaluated the general ship size and traffic patterns near the proposed Hadera Deepwater Port. Based on the ship traffic, sizes and speeds near the port, we have calculated that an equivalent hole size in an LNG ship from a collision with a large ship could be approximately 25 m^2.

The hazard analyses were based on breaches of the maximum ship proposed for use at the site, a 265,000 m^3 capacity LNG carrier or FSRU. These events could all lead to a release of about 75% of the LNG from each cargo tank breached.

Fire Hazard Analysis Results

The fire hazard analysis used a solid-flame model with the most current large-scale LNG fire data for surface emissive power, burn rate, and flame height to diameter ratio collected by Sandia in a set of large LNG fire tests on water, conducted from February through December 2009 [Blanchat et al 2010]. Based on the breach sizes discussed above, a three cargo tank spill was calculated to create a pool diameter of approximately 1019 m. The atmospheric temperature and relative humidity used in the model was based on historical weather records and reflects probable conditions during colder periods. Lower temperatures and humidity levels provide the highest transmissivity values, thereby providing the greatest hazard distances.

Using the above spill pool diameter and atmospheric data from the Hadera site and the most recent fire data and conditions, distances to various heat flux levels are provided below. The high and low parametric variations were assessed by performing a variation of one parameter around the nominal case. The nominal case is based upon the parameter combination of pool fire of 1019 m, a surface emissive power of 286 kW/m^2, a burn rate of 3.5×10^{-4} m/s, an estimated flame height of 660 m, and a transmissivity of 0.7.

Heat Flux Level (kW/m^2)	Distance (m)*
37.5	1091 ± 56
5	2681 ± 262
1.5	4702 ± 337

* plus/minus value is one standard deviation based upon parametric variations

Exposure to a heat flux level of 37.5 kW/m^2 for 10 minutes results in damage to process equipment, structural steel, and storage tanks. A heat flux level of 5 kW/m^2 of approximately 40 seconds duration results in second degree burnsfor exposed skin, but is considered a permissible level for emergency personnel with appropriate clothing based on an average 10 minute exposure duration. A heat flux level of 1.5 kW/m^2 will potentially result in sunburn in some individuals but will not cause any permanent injury. For many countries, a heat flux level of 5 kW/m^2 is considered a safe level for accidental human exposure, while in other countries the value can vary from 3 kW/m^2 or lower.

These results suggest that even for a very large three tank release of the largest LNG ship currentlyin service, the thermal hazards from a fire would not be expected to reach the shore 10 km away. The three tank release considered might lead to damage of the other two cargo tanks on the vessel, but the expected timing of the damage of ten to fifteen minutes will lead to subsequent rather than simultaneous releases of LNG. This could increase the duration of the pool fire, but not the hazard distances.

Dispersion Hazard Analysis Results

Based on the breach size of 25 m^2 for a collision event, we estimated that the spill would result in a pool diameter of approximately 850 m. Detailed computational fluid dynamics (CFD) simulations of the associated dispersion event for this pool diameter were conducted at Sandia. Part of the requirements of the analysis is to perform a validation of the modeling results, specifically comparison to the Burro LNG dispersion datasets. Results suggest that for stable atmospheric conditions with a wind speed of 2 m/s, the maximum distance to the lower flammability limit (LFL) for a pool diameter of about 850 m is expected to be about 4,000 m, and takes approximately 20 minutes to achieve this distance. The peak cloud height will be roughly 150 m. These results suggest that the potential maximum hazard distances from a breach and dispersion event will not reach the public or property onshore.

Summary Results

As presented above, both the fire and dispersion hazard distances calculated for the proposed Hadera LNG Deepwater Port, located 10 km offshore, are not expected to cause any impact to the public or property onshore. The fire and dispersion hazard distances, based on the site-specific credible threats, environmental conditions, and proposed marine LNG import operations considered, will not extend more than 5000 m from the LNG deepwater port buoy. Based on our evaluation, the results of a large breach event will likely be a fire, not a vapor dispersion, since there will be many ignition sources for the LNG from the events that cause a large breach.

For events that cause small spills and potential fires, current LNG operational and safety approaches will minimize any hazards and impacts to the onshore public or property. For events that could create a large spill of cryogenic LNG and a large pool fire, the LNG vessel will most likely be severely damaged anddisabled. This should be considered in port contingency, operational, and safety planning. A large pool fire from a large spill could also damage other cargo tanks, but based on our analysis, the timing of the damage to the cargo tanks could take ten to fifteen minutes. This would lead to subsequent releases of LNG, but not simultaneous releases of LNG from all LNG cargo tanks. Therefore, the duration of the pool fire could be longer, but the expected pool fire dimensions and the associated fire hazard distances would not increase.

In comparing these results to the nominal hazard distances provided in the 2008 Sandia report for offshore LNG operations, both the fire hazard distances to 5 kW/m^2 and the dispersion hazard distances calculated are similar. This provides some assurance that the hazards from operations and conditions at this site are not significantly different from many other LNG deepwater port locations, especially those we have evaluated for the US Coast Guard. As such, we are confident that these hazard analysis results accurately represent the maximum hazards distances from large LNG spills at the Hadera LNG Deepwater Port.

2. PROJECT BACKGROUND AND SITE INFORMATION

The following information provides a description of the project location and the general conditions and operations associated with the facility and terminal. These characteristics impact the analyses associated with estimating potential spills, calculating the size of a spill, and the evaluating the extent of the hazards from a fire or dispersion from a spill. Since the proposed design is conceptual, it could change somewhat in the future. Therefore, the current terminal and facility hazard and safety analyses should be updated if significant design or operational changes occur in the future.

Identifying Information

Facility:	Hadera LNG Deepwater Port
Location:	Approximately 10 km offshore of Hadera, Israel in the Mediterranean
Terminal Design:	Floating storage and regasification unit (FSRU), or buoyed regasification ship
Capacity:	Up to 265,000 m^3 FSRU capacity, 215,000 m^3 delivery capacity
Technology:	Moored bouy system with flexible riser connected to subsea natural gas pipline
Period of operation:	Multiple years starting in 2014

Project Background

The proposed Hadera LNG DWP is a marine LNG import facility about 10 km off the coast of Israel near the port city of Hadera. The project would have several elements:

- 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 either a floating storage and regasification unit (FSRU), that would be permanently buoyed and be used to transfer, store, and regasify LNG,
- Or the terminal would be a bouy system that would enable LNG regasification ships to connect and discharge LNG over the course of a day or two and then leave,
- In both cases, the natural gas would be pumped via a flexible riser and transition to an existing subsea pipeline.

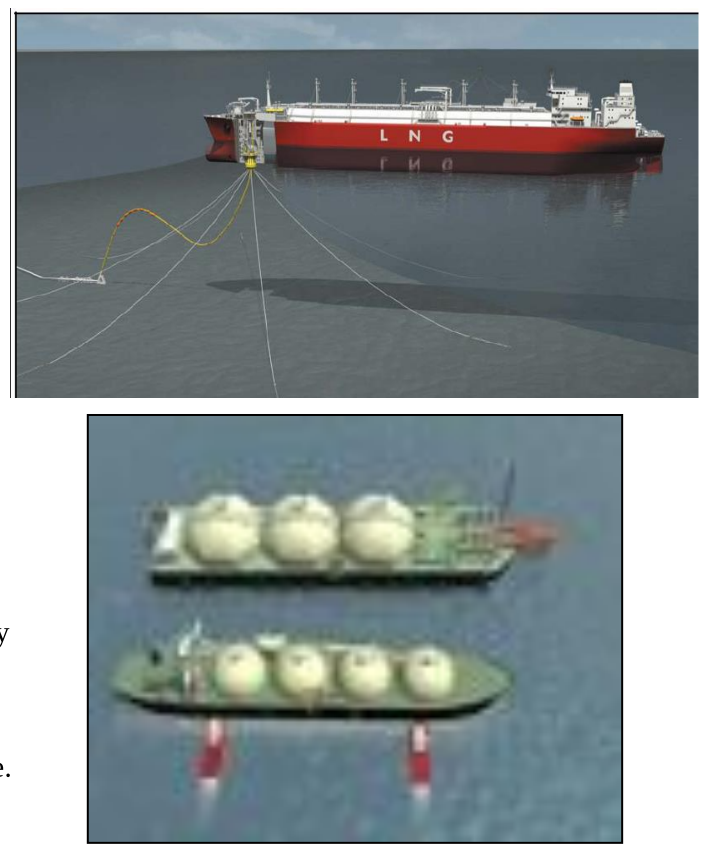

Figure 1. Conceptual designs of the Hadera LNG Deepwater Port.

[redacted] *Hadera LNG Deepwater Port Site Information*

The proposed Hadera LNG Deepwater Port is shown in Figure 2 and is located in the Mediterranean approximately 10 km off the coast of Hadera, Israel in water approximately 80 meters deep. The site is about 4 km east of the North-South sailing fairway parallel to the Israeli coast and located in the southern portion of the East-West sailing fairway from the Port of Hadera. Figure 2 includes the notional location of the buoy and tether system and a proposed 2.2 km radius exclusion zone.

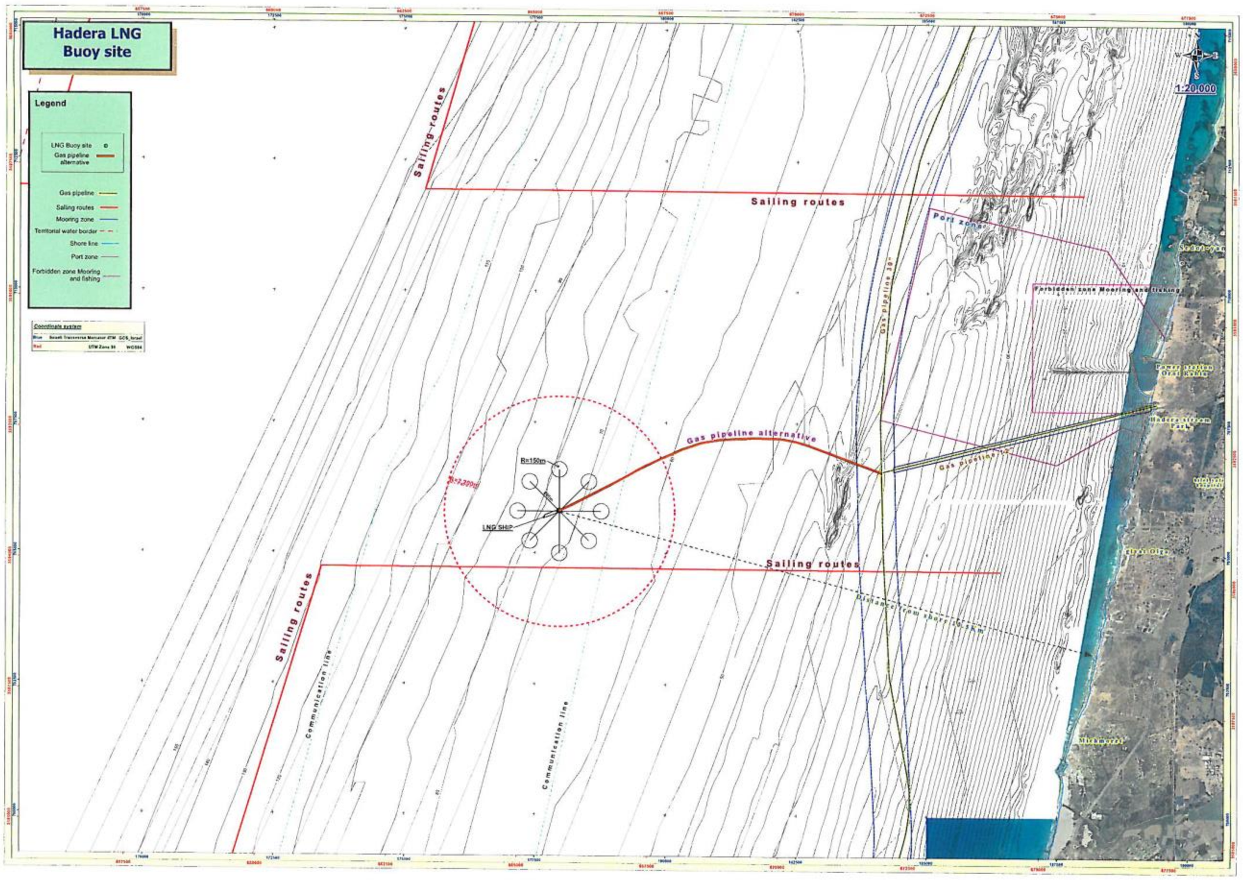

Figure 2: Proposed Hadera LNG Deepwater Port location.

[redacted] *Hadera LNG DWP Characteristics and Conceptual Operations*

An FSRU-based DWP design would include the following nominal operational capabilities:

- Use of an LNG ship with regasification capabilities permanently tied to a mooring buoy with a turret system for regasifying LNG and pumping it into an underwater flexible riser connected to a subsea natural gas pipeline network,
- Utilization of a 265,000 m^3 FSRU, that would be approximately 320 m long by 55 m wide, with a standard double-hull design,
- The FSRU is designed to receive LNG shipments from other LNG ships carrying up to 215,000 m^3 of LNG using ship-to-ship LNG transfer technology.

A Moored buoy-based DWP design would include the following nominal operational capabilities:

- LNG ships with regasification capabilities would arrive based on natural gas demand and attach to an undersea mooring buoy using a turret system and pump the regasified LNG into a flexible riser and then into a subsea pipeline network. Regasification and send out of the LNG cargo could be accomplished in 1-2 days, depending on natural gas demand,
- After completing the regasification and transfer of the LNG, a ship would detach from the buoy and head back to sea,
- Utilization of 215,000 m^3 LNG regassification ships
- Regasification ship sizes vary, but could be up to approximately 320 m long by 55 m wide, with standard double-hull designs,
- The buoy system would remain 10-30 m underwater waiting for use by another regasification ship.

[redacted] *Hadera Site Environmental Conditions*

Site temperature and wind conditions directly influence potential hazards from large LNG spills, fires, or dispersion events because they directly impact pool formation, atmospheric conditions, and dispersion directions. The site air and water temperatures impact the vaporization rate and therefore the size of the potential pool fire from an LNG spill, the thermal transmissivity of the atmosphere and therefore the hazard distances from a fire, and properties of a potential dispersion. The site wind conditions impact predominately the direction of a potential dispersion. The local temperature data collected suggest a nominal air temperature of 10-30 degrees centigrade.

The wind speed and direction data over the past five years were obtained for the Hadera Port area and are presented in Figure 3. The data show the distribution of wind directions and wind speeds that could be expected at the DWP site. The data indicate a mean wind speed in the area of about 4.2 m/s, with the most common wind speeds ranging between approximately 2-9 m/s. The most common wind direction is from the west blowing along the east-west fairway toward shore about 35% of the time. The other common wind directions are either from the north, parallel to the shore about 15 % of the time, or blowing offshore about 30% of the time. Relatively calm winds blowing onshore occur about 12 % of the time. Calm and stable wind and environmental conditions provide for the largest vapor dispersion distances from a spill and should be considered for dispersion evaluations. For reference, 1 knot = 0.514 m/s.

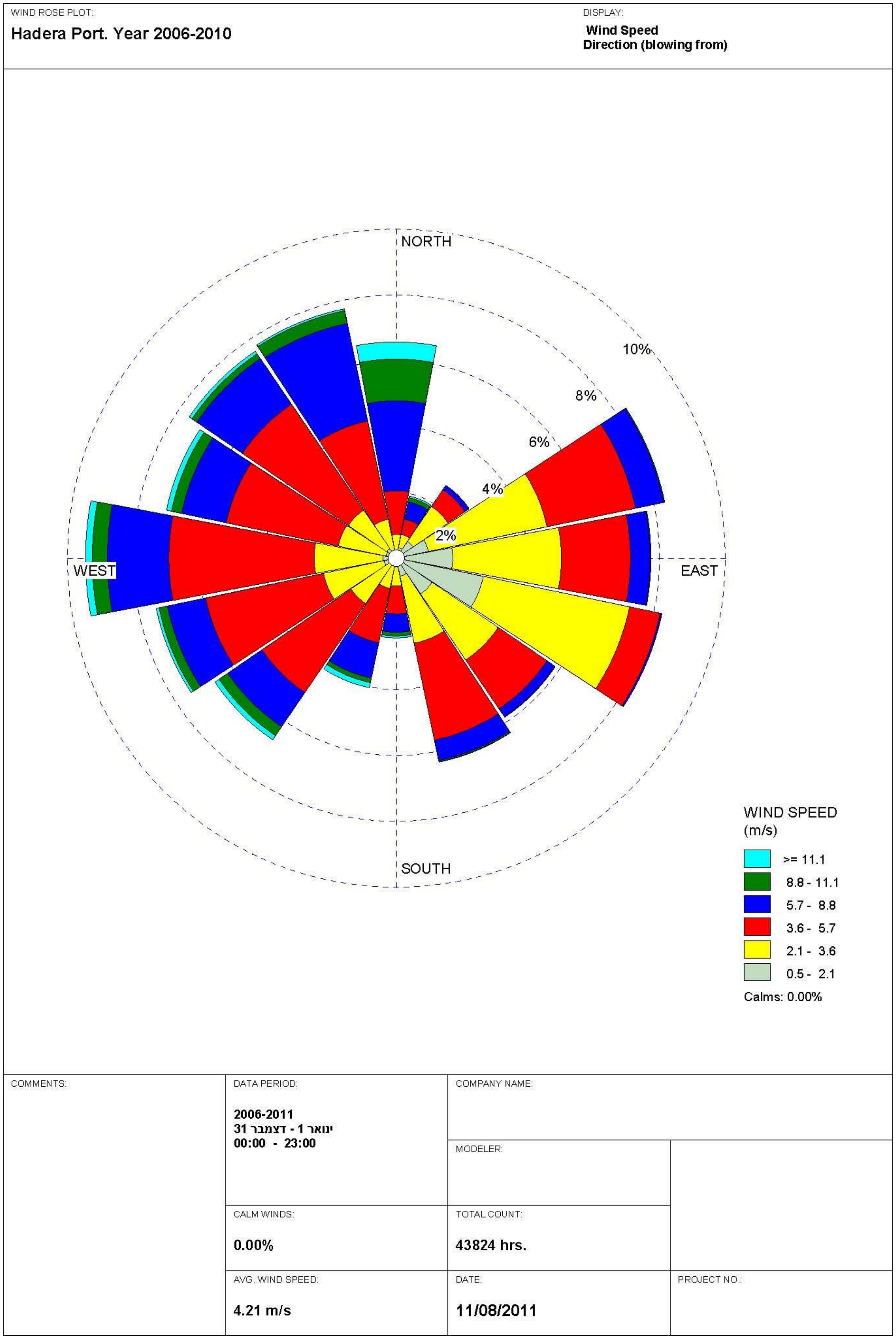

Figure 3: Wind speed and direction data for the Hadera Port area.

3. HAZARD AND SAFETY ANALYSIS CONSIDERATIONS

Every potential LNG site or facility is unique and site-specific factors such as terminal location, operating conditions, environmental conditions, site-specific threats, and available safety and security measures and emergency response capabilities are different. While the nominal hazard issues and general hazard distances for a typical LNG Deepwater Port are presented in a 2008 Sandia report, that report also recommends that a systems-level, site-specific hazard analysis should always be conducted to make sure that the impact of a proposed marine LNG import terminal on the safety to people and property are as accurately evaluated as possible.

Therefore, a site-specific, systems-level, evaluation of the proposed Hadera LNG Deepwater Port was conducted by Sandia for the INGL. 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 and property and infrastructure.

In our evaluation for the Hadera LNG DWP, we followed the risk analysis guidance framework developed and presented in the 2004 Sandia report to systematically assess the Hadera LNG DWP. The framework was used to 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 evaluated is presented below.

Hazards, Safety, and Risk Assessment of Marine LNG Imports

When conducting a hazards, safety, or risk assessment of an LNG import facility, the assessment should include consideration of 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 hazards and risks and include:

- The context of the import facility – location, site-specific environmental conditions, LNG import operations, importance of the LNG imports to the regions energy reliability and security,
- Potential threats – potential accidental events and credible intentional events for the region and the specific LNG import operations,
- Safety goals and risk management goals– identification of levels of hazards and consequences to be avoided, such as injuries and property damage, as well as consideration of LNG supply reliability requirements, and
- Protection and risk management systems and approaches – 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 LNG import operations and safety and security systems in place can effectively meet the safety and risk management goals identified for a proposed terminal location and operations. If so, then the safety and security measures and operations developed for the LNG import facility are considered adequate. If the initial safety assessment determines that the identified safety or risk management goals are not met, then modifications to the import terminal in terms of changes in site location, import operational design, improved safety and security measures, and/or improvements in emergency response, protection, or early warning measures should be considered to improve the overall safety and security measures at the terminal to meet required safety, security, and terminal protection goals.

Hazardous marine import operations, such as LNG imports, also should be reviewed on a regular basis to reassess the adequacy of safety and security measures relative to changes in safety or security concerns that occur over the life of a terminal. Changes in any number of factors, including the regional or national role or importance of the terminal for natural gas and energy supply security, changes in threats or threat-levels, changes in risk management goals, or changes in safety systems or the allowable hazard level could impact the conclusions and basis for the original hazards and safety evaluation.

[redacted] *Hazard and Safety Assessment Framework*

For the proposed Hadera LNG Deepwater Port, Sandia was asked to conduct a hazard and safety study. This would be considered as the first phase of an overall safety and risk assessment. Of prime importance in a safety study is to assess the nominal hazards from an accidental or intentional cargo tank or processing system release of LNG and assess impacts to the LNG vessel, crew, LNG import and gas pipeline operations, other nearby shipping or boating operations, and hazards to the public and infrastructure onshore. Below we provide a summary of the items evaluated in conducting the hazards and safety analysis for the Hadera LNG Deepwater Port.

Site Characterization

The context of the LNG facility such as location, site-specific conditions, and nominal expected operations were identified. Information collected included:

- **Type and Proximity to Neighbors**
  - Distance to residential, commercial, and industrial facilities or other critical infrastructures such as bridges, tunnels, power plants, shipping piers, and
  - Distance to any marine shipping and transit operations or channels – Assess proximity or remoteness from a major ship channel and shipping types and speed.
- **Environmental Conditions**
  - Prevailing wind direction, speed, and variability, for evaluation of wind-driven spill and dispersion movement,
  - Severe weather considerations – evaluate need to consider storm surges,
  - Tidal heights and currents and influence on spill movement or 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,
  - Transit considerations– additional marine traffic (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.

Threat Identification

The potential or credible threats possible for the facility, based on site location and relative attractiveness of either an LNG tanker or other nearby targets, were identified. These include:

- **Accidental Event Considerations –** shipping patterns, frequency of other large ships, major objects or abutments to be avoided, processing or storage operations issues, warning systems, potential weather impacts on waterways or shipping operations,
- **Intentional Event Considerations –** credible intentional threats possible for this region and at this site based on a history of past threats and shipping attacks, consideration of shipping threats often considered internationally, difficulty of attack scenarios for a given site due to surveillance and protection schemes, and locally available resources such as weapons and explosives, and
- **Attractiveness of Targets –** impact of an LNG ship attack on energy surety, impact on facilities near navigational routes, impact on other facilities near site not associated with LNG operations.

From these evaluations, a range of possible LNG breach and spills and their associated fire and dispersion thermal hazards to the onshore public and facilities, and marine operations can be calculated. These initial hazards and safety analyses provide an idea of the level of consequences that can be expected to the LNG ship, the LNG deepwater port and equipment, other marine operations near the port, and the public and infrastructure onshore.

[redacted] *Risk Assessment Consideration Framework*

If the calculated consequences are judged to have major impacts on either the LNG port, shipping, or the onshore public or infrastructure, then a detailed risk analysis can be performed to identify safety measures and operational changes to help reduce the likelihood or consequences of either a potential accidental or intentional event that could occur at the facility.

Risk analyses were not the purpose of this study and were not conducted. But the initial hazards and safety assessment can support a follow on risk assessment if so desired. A risk analysis should include the elements identified in the 2004 Sandia report, which would include the following general steps:

Identify Risk Management Goals and Consequence Levels

Setting of risk goals and consequence levels would be conducted in cooperation with stakeholders, public officials, and public safety officials. Considerations 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. 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.

Identify 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 deepwater port, or in transit. They include not only safety features but also safety and security-related operations and emergency response and recovery capabilities. These would include:

- **Operational Prevention and Mitigation Considerations**
  - System operations, 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.
- **Improved Protective Design**
  - Design for storm surges, blasts, thermal loading,
  - Security measures – surveillance, exclusion areas, and
  - Redundant offloading capabilities.

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.

Like the hazards and safety analysis, any risk management evaluation should be reviewed and updated regularly to assess if changes in threats or threat levels, operations, LNG tanker designs, or protective measures have occurred that would negatively impact the ability of the system safeguards to meet the identified public health and safety and facility energy surety goals. While a range of 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.

4. THREAT AND BREACH ANALYSES

Several types of accidental or intentional events are possible for this offshore LNG terminal that could cause a large spill. They include collisions with another ship, spills during LNG transfers, accidents associated with the storage and regasification of the LNG, or an intentional attack. The results from these events could include the breach of an LNG cargo tank or cargo tanks and a subsequent fire or dispersion. The type of threat will govern the size of the spill and the likelihood of a fire or a dispersion event. Therefore, a range of potential accidental and intentional events were considered for the Hadera LNG Deepwater Port and were used to calculate the largest breach sizes and spill volumes expected.

[redacted] *Accidental Collision and Breach Evaluations*

The range of accidental collision events were assessed to identify those of major concern or having the greatest risk to people and property. The severity of an accidental breach of an LNG vessel during a collision depends on the location, vessel designs, relative vessel collision speeds and collision alignment, and operational mitigation or prevention systems in place to limit potential damage.

Published work is not available that relates damage to LNG vessels (in the form of breach size) due to collisions for different striking vessel type, speed and energy. But a report by Sandia, SAND2004-6258 includes finite element modeling of collisions of a series of ships with a double-hulled design similar in overall size, mass, and design to some LNG carriers. The results of that analysis is a set of curves that can be used to estimate the hole size on the outer and inner hull of a LNG carrier as a function of the impact kinetic energy of the collision as shown in Figure 4, which is replicated from the Sandia report.

While double hull ship designs are similar, the curves in Figure 4 should only be used as guidance on possible breach sizes for different collision events. However, Figure 4 does provide some understanding of what types of collisions should be considered. For example, the figure shows that small ships with low kinetic energy (low mass and low impact velocity) will likely not cause penetration of the inner hull, and that the most import ships to consider are those with high kinetic energy (high mass and high impact velocity). For this analysis, we focused on those vessels with the appropriate combination of displacement and speed to estimate the resultant potential collision breach sizes. Therefore small tugs and workboats with an absorbed energy of less than 1.0E+08 N-m will not be a significant issue for breach and spill considerations.

Information for the estimated annual ship traffic near the proposed Hadera LNG DWP provided to Sandia is shown in Table 1.

Table 1. Estimated Ship Traffic Near the Hadera LNG DWP

Category	Estimated Ship Transits per year	Displacement Metric tonnes	Speed Knots
Small tugs, work boats, trolleys	1000	10,000-30,000	10-12
Coal ships to Hadera power plant	50	60,000 – 170,000	8-10
Large ships – Cruise ships and container ships	2140	120,00-140,00	15-20
LNG Ships	100	130,00-160,00	10-15

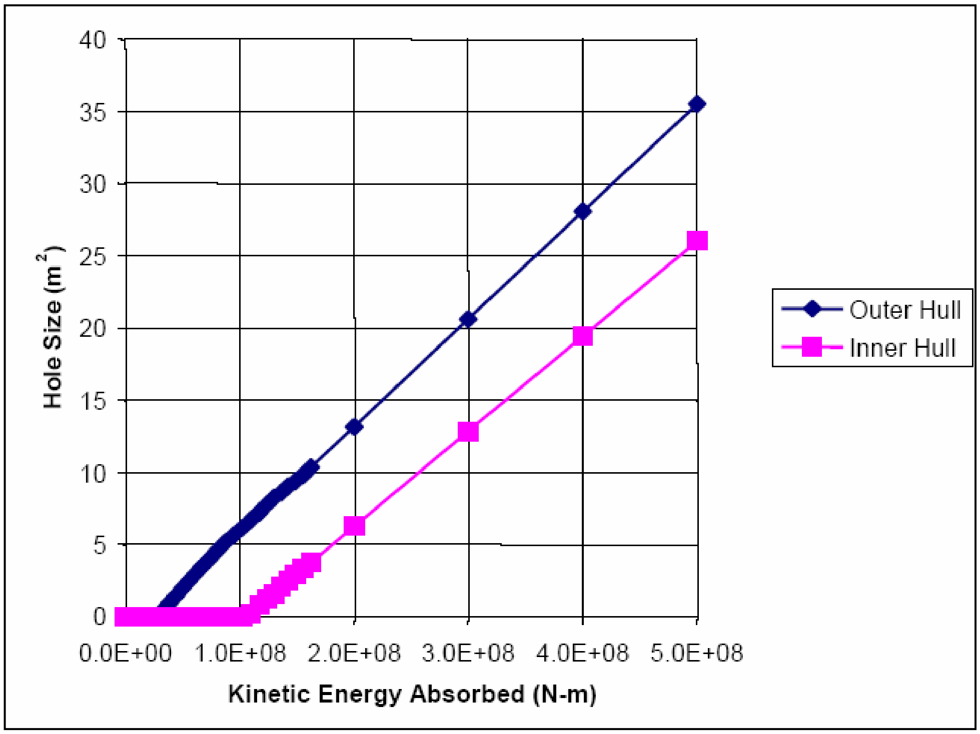

Figure 4. Double hull tanker hole size vs. kinetic energy. (SAND2004-6258)

Using an approach identified in (Ammerman 2002) and typically used for ship collision analysis, the estimated breach sizes can be calculated based on the large ships noted in Table 1 including the coal, cargo, cruise, and LNG ships. This approach is an energy and momentum balance approach that includes the effect of the mass and momentum of the ship and water to calculate the absorbed kinetic energy by the impacted ship. The collision analysis assumes that the bow of the impacting ship is rigid and is therefore considered a conservative assumption, providing larger hole sizes than expected. In comparison with the few double hull ship collisions recorded, the estimates of breach size are about 25 percent higher than have been reported.

The methodology for calculating the size of an inner hull breach in a LNG ship (from a vessel to vessel collision) includes the following steps:

- Calculate the kinetic energy of the striking vessel. This is based on local ship data, specifically the range of displacement and speed of vessels in the area surrounding the deepwater port area of operation,
- Calculate the absorbed energy of the LNG ship based on the kinetic energy of the striking vessel,
- Estimate the inner hull breach size, based on a linear relationship between hole size and kinetic energy from Figure 4 and Figure 5,
- Calculate the final breach spill size that will be applied in the accidental collision consequence modeling assuming 90% of the extrapolated inner hull hole area will be plugged following the collision (e.g., ships will not separate following collision).

Because of the proximity of the Hadera LNG DWP to the North-South sailing channel, it was assumed that it would be possible for one of the large container or passenger ships operating near the Hadera LNG DWP to lose control and collide with either an FSRU or a moored LNG ship. These ships would have to be more than 4-5 km off course to collide with an LNG ship at the Hadera LNG DWP. A more likely collision scenario is with the large coal ships that routinely enter the East-West sailing channel and could pass nominally within 2-3 km o the Hadera LNG DWP buoy. The estimated adsorbed kinetic energy by an LNG ship would range from about 1.0 to 4.9 E+09 N-m, assuming a 90 degree collision impact angle. The range in breach sizes noted is predominately influenced by the ship speeds that could occur for the larger ships operating near the Hadera LNG DWP.

The data from Figure 4 was extrapolated and presented in Figure 5 for larger kinetic energies to estimate the inner hull hole size for the absorbed kinetic energy values. This suggests breach sizes from 50 to 250 m^2. The work of Ammerman has been used to support reducing the predicted breach size resulting from an accidental collision event with LNG ships. Ammerman's work was originally commissioned to provide a comparative analysis of oil outflow from breeched cargo tanks among double hull crude oil carriers. The hypothesis that the striking ship would remain lodged in the structure of the damaged vessel was informally derived from a survey of worldwide tanker collision events. A value of 90% plugging was assumed to derive the "Maximum Spill Area" detailed in Table 2. This would be the area from which LNG would spill out onto the water and create a LNG pool. Using the 90% plugging concept, the spill areas for collisions would vary from 5 to 25 m^2, depending on the likelihood of the collisions by different ships.

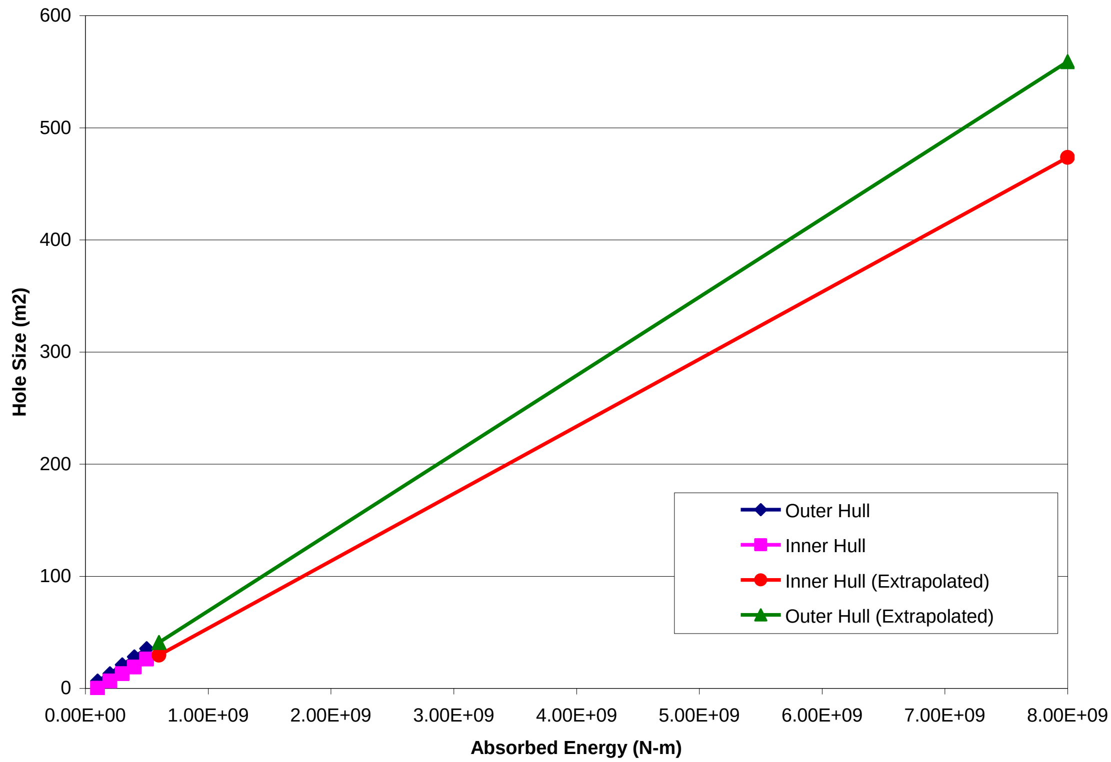

Figure 5. Extrapolated hole size vs. absorbed energy curve

[redacted] *Process and LNG Handling Accident and Breach Evaluations*

Process accidents included spilling of LNG onto the water, a spill of LNG during marine ship-to ship transfers, or a spill during operations with the buoy transfer system. An evaluation of the possible hazards from a direct LNG spill from a jettison of the LNG cargo indicates this is a relatively slow process compared to large breach events, and poses no major risk to the ship or the public onshore. Process accidents during transfer of LNG from an LNG delivery vessel to the FSRU suggests that some confinement of the spilled and vaporized LNG may be possible. The current ship to ship transfer technology includes emergency shutoff systems that would prevent significant loss of LNG. The general level of peak overpressure that could occur with this type of event is comparable with overpressure data from natural gas vapor cloud explosions. Based on our analysis of this type of spill and the size and location of a potential high pressure explosion, the damage would likely be confined to one LNG cargo tank and would be less than 5-10 m^2. The breach size is significantly controlled by the LNG structural framing and double hull design.

The regasification and buoy transfer system for LNG ships is located in the bow of the ship in a turret design that is reinforced against potential fires and explosions. Overall, the processing system layout and safety considerations in the design suggest that the potential cargo tank breach from off-normal events in the processing area would impact only one LNG cargo tank. A similar estimate of a 5-10 m^2 breach in the cargo tank was estimated because of the similar overpressure values expected and the internal transfer structural framing and design.

[redacted] *Intentional Breach Analysis Considerations and Evaluation*

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.

Sandia evaluated the potential size of breaches of the FSRU based on a range of possible credible threats. The exact type and scale of events evaluated 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 has conducted a series of two and three dimensional computational shock physics explosive analyses to estimate the breach sizes to use for spill and fire analyses for LNG ships up to 265,000 m^3.

Based on these evaluations, Sandia recommends the following intentional breach sizes be used in calculating potential LNG spill rates, spill volumes, and hazard distances at the Hadera LNG DWP:

- A maximum breach size of 16 m^2 in up to three LNG cargo tanks,
- A maximum volume of LNG initially spilled from a breached cargo tank that would contribute to the immediate spill onto water would be approximately 70% of the cargo tank capacity.

Since only one LNG vessel would be full at a given time at the Hadera LNG DWP, the total maximum spill would not exceed a cumulative 70% spill volume from three cargo tanks.

Recommended LNG Cargo Tank Breach Sizes and Spills to Consider

[redacted]

Based on our threat and breach analyses discussed, the range of potential breach sizes deemed credible are shown in Table 3. 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 or LNG regassification ship that could cause a fire or explosion and lead to the breach an LNG storage tank. The intentional events include a range of threats against an LNG ship at an offshore DWP, 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 every cargo tank simultaneously. Current threat information and assessments, as well as LNG vessel design characteristics, suggest that this event is neither realistic or credible. 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 three-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 Maximum LNG Cargo Tank Breach and Spill Scenarios

Storage Tanks Breached	Event	Total LNG spilled (m^3)	Area of breach per tank (m^2)
Accidental Collision Event (Dispersion)			
1	Collision with large ship at speeds approaching 20 knts, puncture of single LNG cargo tank, assuming plugging of puncture with vessel	37,000	5-25
Off-normal Processing Event (Fire)			
1	Off-normal processing event that causes breach of LNG storage tank near deck level	30,000	10
Intentional Event (Fire)			
3	Multiple LNG cargo tank large intentional event	111,000	16

5. FIRE, DISPERSION, AND HAZARD ANALYSIS

The following discussions provide a description of the assumptions and modeling used for LNG pool spreading, fire modeling, and the vapor cloud dispersion and associated hazard distance calculations. These analyses were conducted using the maximum spill events identified for fire and dispersion from Table 2 for the possible breach sizes of a 265,000 m^3 capacity LNG carrier.

Fire Hazard Modeling

The following discussion provides the results for the thermal hazards analysis. The predicted hazard distances were calculated using a solid-flame model to represent an LNG pool fire. This model as well as the approach used to calculate the pool diameter is described in the 2004 Sandia LNG report. Table 3 provides the assumptions used for the parameters required for the calculation of the maximum pool diameter and hazard distances. The atmospheric temperature and relative humidity is based upon historical weather records and reflects probable conditions during colder periods. Lower temperatures and humidity levels provide the highest transmissivity values, thereby providing greater hazard distances.

Table 3. Assumptions for Thermal Hazards Analysis for an LNG pool fire

Hole size (m^2)	16
Number of tanks breached	3
Pool diameter (m)	1019
Atmospheric temperature (K)	280
Relative Humidity (%)	20
Density of LNG (kg/m^3)	420
Burn rate (m/s)	3.5×10^{-4} ($2.6 – 4.5 \times 10^{-4}$)*
flame height (m)	SNL correlation, Eq. (1) (eqns. 1a, 1b)*
SEP (kW/m^2)	286 (248 – 326)*
Transmissivity	Wayne formula, Eq. (2-3) (±10%)*

*range of variation

The flame height, H, is based on a correlation recently developed at Sandia and is the following

$$H/D = 4.196Q^{*0.539} – 0.930. \qquad (1)$$

Variation in the predicted flame height is incorporated by utilizing the following equations.

$$H/D = 4.828Q^{*0.539} – 1.023. \qquad \text{(high range of uncertainty)} \qquad (1a)$$

$$H/D = 3.623Q^{*0.539} – 0.837. \qquad \text{(low range of uncertainty)} \qquad (1b)$$

D is the diameter of the pool and $Q^* = \frac{\dot{m}\Delta H}{\rho_a T_a C_{p_a} \sqrt{g} D^{5/2}}$

where $\dot{m}$ is the fuel mass loss rate in units of kg/s, ΔH is the heat of combustion (50 MJ/kg for methane), and the thermal properties, ρ_a, C_{pa}, and T_a are evaluated at surrounding conditions. Using equation (1) an H/D value of 0.65 is obtained based on the nominal burn rate of 3.5 x 10^{-4} m/s and pool diameter of 1019 m.

The transmissivity is calculated using the following formula.

$$\tau = 1.006 - 0.01171\log_{10} X(H_2O) - 0.02368(\log_{10} X(H_2O))^2 - 0.03188\log_{10} X(CO_2) + 0.001164(\log_{10} X(CO_2))^2 \quad (2)$$

where, $X(H_2O) = (R_H\, P\, 2.8865 \times 10^2)/T$ and $X(CO_2) = 273\, L/T$.

$X(H_2O)$ and $X(CO_2)$ are the amount of H_2O and CO_2 along a path length, L (m). R_H is the relative humidity (0 – 1.0) and S is the saturated water vapor pressure in mm of mercury at the atmospheric temperature T (K). The saturated water vapor pressure can be determined from the Antoine formula where the coefficients are from Stull applicable over the temperature range 255.8 – 373 K.

$$\log_{10} P = 4.65430 - \frac{1435.264}{T - 64.848} \quad (3)$$

The pressure, P, must be converted from bar to mm mercury by multiplying eq. (3) by 750.061. Figure 6 provides the transmissivity as a function of distance for a temperature of 280 K and relative humidity of 20%.

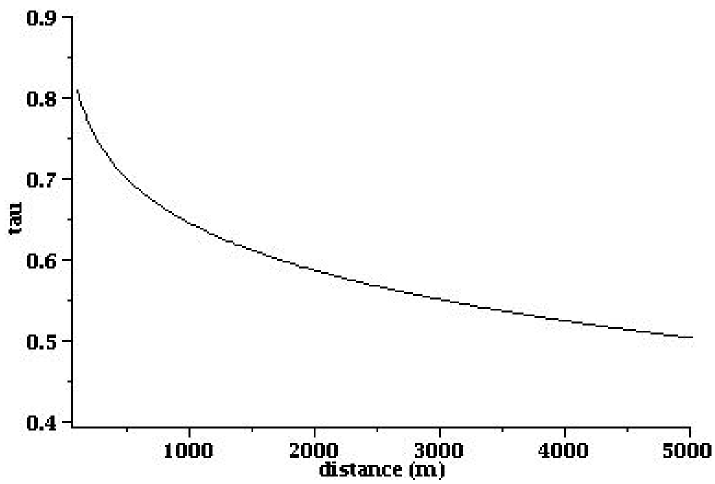

Figure 6: Transmissivity as a function of distance (T = 280 K, rel. hum = 20%).

Using the above assumptions, distances to various heat flux levels are provided in Table 4.
The high and low parametric variation is assessed by performing a variation of one parameter around the nominal case. The nominal case is based upon the parameter combination of SEP of 286 kW/m^2, burn rate of 3.5 x 10^{-4} m/s, flame height using equation (1), and transmissivity using equations (2) and (3).

Table 4: Calculated Thermal Hazard Distances for a 1019 m Pool Fire

Heat Flux Level (kW/m^2)	Distance (m)*
37.5	1091 ± 56
5	2681 ± 262
1.5	4702 ± 337

* plus/minus value is one standard deviation based upon parametric variations

Exposure to a heat flux level of 37.5 kW/m² for 10 minutes results in damage to process equipment and storage tanks. A heat flux level of 5 kW/m^2 of approximately 40 second duration results in second degree burnsto exposed skin, but is considered a permissible level for emergency personnel with appropriate clothing based on an average 10 minute exposure duration. A heat flux level of 1.5 kW/m^2 will potentially result in sunburn in some individuals, but will not cause permanent injury.

These results suggest that even for a very large three tank release of the largest LNG vessel currentlyin service, the thermal hazards from a fire would not be expected to reach the shore 10 km away. The three tank release considered might lead to damage of the other two cargo tanks, but the expected timing of the damage of ten to fifteen minutes will lead to subsequent rather than simultaneous releases of LNG. This could increase the duration of the pool fire, but not the hazard distances.

[redacted] ***Dispersion Modeling Evaluation***

This section provides a description and assessment of the LNG dispersion calculations performed by Sandia. A dispersion event is extremely unlikely as discussed in the 2004 Sandia LNG report. If such an event were to occur, the likelihood is it would be for a collision event. Therefore, the largest potential breach size estimated for an accidental collision from Table 3 would be 25 m^2 . This would result in a pool diameter of 853 m. A computational fluid dynamics (CFD) simulation of a dispersion event by Sandia was conducted as well as a comparison with previous dispersion analyses for similar breach and spill events. Sandia conducted dispersion analyses for the 2008 Sandia report and has provided review and guidance to the United States Coast Guard for numerous proposed deepwater ports. All of these have involved review of CFD simulations of dispersion by independent consultants.

Part of the requirements of the analysis is to perform validation, specifically comparison to the Burro LNG dispersion datasets. Thus, these previous calculations can be utilized to help bracket the estimate for the upper bound distance to a lower flammability limit (LFL) of 5% methane by mass for this location. The LFL is the lowest value at which LNG can be ignited if the vapor cloud comes into contact with an ignition source. Based on current and previous simulations for stable atmospheric conditions with a wind speed of 2 m/s, the maximum distance to the LFL for a pool diameter of 853 m is expected to be about 4,000 m, taking approximately 20 minutes to achieve this distance. The peak cloud height will be roughly 150 m.

These results suggest that even for a very large dispersion, the thermal hazards from an ignition and flash fire of a dispersed vapor cloud would not reach the shoreline 10 km away.

6. SUMMARY RESULTS

As discussed above and presented in Figure 7 below, both the fire and dispersion hazard distances calculated for the proposed Hadera LNG Deepwater Port, located 10 km offshore, are not expected to cause any impact to the public or property onshore. The fire and dispersion hazard distances, based on the site-specific credible threats, environmental conditions, and proposed marine LNG import operations considered, will not extend more than 5000 m from the LNG deepwater port buoy (the thick dark red circle in Figure 7). The major hazards to shipping will be less than 1100 m from the buoy (the thick dashed red circle in Figure 7).

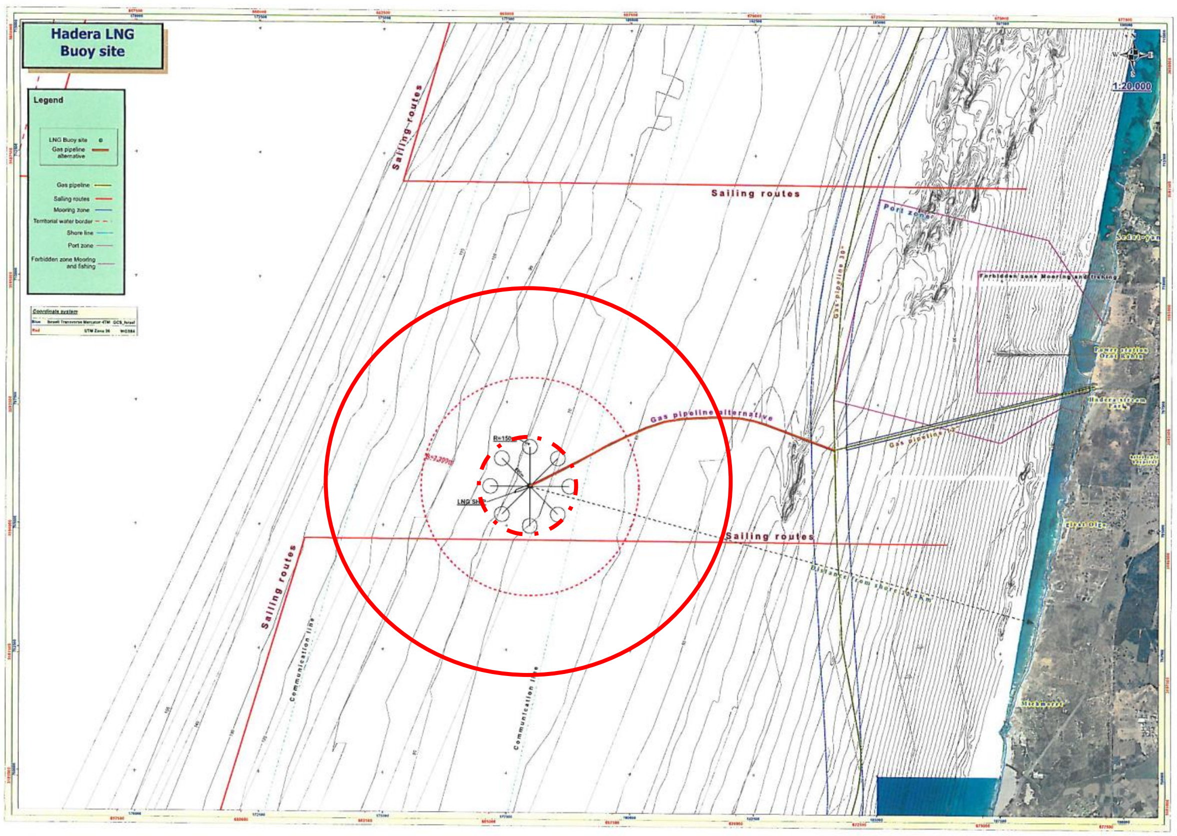

Figure 7. Relative hazard distances for large LNG spills.

For dispersion events, the largest hazard distance of about 4000 m is similar to the maximum fire hazard distance shown in Figure 7. None of the events will impact shipping in the North –South sailing fairway and there should be only minimal impact on ships outside the East-West sailing fairway as shown by the dashed red heavy line.

For events that cause small spills and potential fires, current LNG operational and safety approaches will minimize any hazards and impacts to the onshore public or property. For events that could create a large spill of cryogenic LNG and a large pool fire, the LNG vessel will be severely damaged anddisabled. This should be considered in port contingency, operational, and safety planning. A large pool fire from a large LNG spill could also damage other cargo tanks on the LNG vessel, but based on our analysis, the timing of the damage to the cargo tanks could take ten to fifteen minutes. This would lead to subsequent releases of LNG, but not simultaneous releases of LNG, from all LNG cargo tanks. Therefore, the duration of the pool fire could be longer, but the expected pool fire dimensions and the associated fire hazard distances would not increase.

In comparing these results to the nominal hazard distances provided in the 2008 Sandia report for offshore LNG operations, both the fire hazard distances to 5 kW/m^2 and the dispersion hazard distances calculated are similar. This provides some assurance that the hazards from operations and conditions at this site are not significantly different from many other LNG deepwater port locations, especially those we have evaluated for the U. S. Coast Guard. As such, we are confident that these hazard analysis results accurately represent the maximum hazards distances from large LNG spills at the Hadera LNG Deepwater Port.

7. REFERENCES

Ammerman, D., "Marine Safety Systems, Control Ballast Tanker Interactive CD," SAND2002-3188P, Sandia National Laboratories, Albuquerque, NM, 2002.

Blanchat, T., Helmick, P., Jensen, R., Luketa, A., Deola, R., Suo-Anttila, S., Mercier, J., Miller, T., Ricks, A., Simpson, R., Demosthenous, B., Tieszen, S., and Hightower, M. "The Phoenix Series Large Scale LNG Pool Fire Experiments", SAND2010-8676, Sandia National Laboratories, Albuquerque, NM, 2010.

Hightower, M., Gritzo, L., Luketa, A., Covan. J., et. al., "Guidance on Risk Analysis and Safety Implications of a Large Liquefied Natural Gas (LNG) Spill Over Water", SAND2004-6258, Sandia National Laboratories, Albuquerque, NM, December 2004.

Koopman, R. et. al., "Burro Series Data Report – LLNL/NWC 1980 LNG Spill Tests", UCID-19075, Lawrence Livermore National Laboratory, Livermore, CA, 1982.

Luketa, A, Hightower, M., Attaway, S., "Breach and Safety Analysis of Spills Over Water from Large Liquefied Natural Gas Carriers", SAND2008-3153, Sandia National Laboratories, Albuquerque, NM, May 2008.

Stull, D.R. "Vapor Pressure of Pure Substances Organic Compounds." *Ind. Eng. Chem.*, 1947: 517-540.

DISTRIBUTION LIST

5	MS0755	Mike Hightower, 6111
5	MS1135	Anay Luketa, 1532
2	MS0918	Central Technical Files, 8945-1
2	MS0899	Technical Library, 9616

Xx TBD

Sandia National Laboratories