RISK ASSESSMENT

Grassy Point LNG

Prepared for

Newfoundland LNG, Ltd.

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1. Executive Summary

Newfoundland LNG undertook a study of the LNG related risks associated with the operation of the proposed Grassy Point LNG terminal. The structure of this study was siting criteria enumerated in CSA Z-276-2007 "Liquefied Natural Gas (LNG) - Production, Storage and Handling" and the associated LNG shipping. The risk assessment methodology of CSA Z-276 - 2007 incorporates the maximum credible LNG release scenarios and the hazard models to determine the severity and distances of the resulting hazards. This methodology combines the likelihood and consequences in the traditional manner. It also provides a standard of acceptable risk level as represented by the hazard levels that are acceptable for siting. Factors affecting risk and safety addressed included:

- Likelihood of the event occurring
- Behavior of LNG should a release occur during the event
- The potential zone of influence and severity of hazard
- Potential hazards to the public outside the facility
- Potential damage on adjacent property
- Physical effects on the environment
- Ship to Ship Transfer
- Effects on the Community and Future Development

This risk assessment, based on the risk-based "*Siting Study for the Grassy Point LNG Transshipment and Storage Terminal*" performed by Quest Consultants, Inc. in November 2007 confirms that the proposed facility design at the selected Grassy Point site meets all of the safety requirements for LNG siting specified by CSA Z-276-2007. The following discussion provides a more detailed insight into the potential causes and consequences of the various hazard scenarios.

2. Introduction to LNG Risk Assessment

Liquefied natural gas, or "LNG", is natural gas which has been adequately cooled to condense into a liquid. This reduces the volume of ambient temperature, atmospheric pressure natural gas by a factor of 620:1. This permits shipment and storage of large amounts of natural gas as a relatively benign but very cold liquid at essentially atmospheric pressure. The density of the LNG is less than half of the weight of water.

The safety and risk aspects specific to LNG are a result of two factors. The first is the large quantities which can be and are transported and stored. The second factor is that if released, the LNG will evaporate and mix with air. Natural gas, when mixed with air will burn if the mixture concentration is between 5% and 15% fuel. Thus the risk arises from a release and the ignition of vapours. Safety focuses on preventing releases, mitigating consequences and siting facilities such that the public is not exposed to the consequences.

The terms “safety” and “risk” are generally used in a very generic sense. Safety is a lack of significant risk when perceived as being less than or at least consistent with acceptable risk levels. Risk is defined as the consequences of a potential hazard multiplied by the probability of its occurrence. In the assessment of safety and risk, the likelihood of occurrence is considered. Risk assessments are more structured to allow a numeric representation and a quantitative comparison with acceptable risk levels.

Safety standards for the regulation of LNG facilities act as design guidelines. In Canada, the LNG safety standard is the Canadian Standards Association (CSA) publication CSA Z-276-2007 “*Liquefied Natural Gas (LNG) - Production, Storage and Handling*.” The safety and potential risks are evaluated by establishing compliances with the CSA Z-276-2007 requirements.

The distance from the Grassy Point facility to the town of Arnold’s Cove is approximately 1600 meters. The thermal radiation that would be observed from the site controlling fire of the storage tank impoundment would produce a flux of less than 0.8 kW/m^2 at that distance. This is equivalent to the amount of solar radiation that would be observed on a hot sunny day. The flammable vapour cloud from the code-required credible spill scenarios remains on the facility property and does not affect the adjacent Newfoundland Transshipment Limited (NTL) crude oil transshipment terminal or the town of Arnold’s Cove. The waterfront area in the immediate vicinity of the facility could see thermal radiation of a flammable cloud, but either of these conditions would not be instantaneous and would allow time for anyone affected to move out of the area.

3. Code Compliance Methodology

The risk fundamentals of the siting study are to establish the level of safety. These fundamentals are:

- Establishing the resulting LNG release from credible events.
- Calculation of the areal extent of the hazards (pool fire and vapour cloud).
- Determining the potential exposures, primarily exposure of the public.
- Determining the surrounding distances to which these significant hazards extend, the zone of influence or "exclusion zone." The purpose of the exclusion zone code requirements is the protection of the public (population and property) surrounding the facility. Protection and safety of the facility itself is also covered, but the public safety requirements are so strict that the facility protection is a secondary benefit.
- Confirming that these zones of influence to not exceed the CSA Z-276-2007 requirements.

This type of code compliance analysis provides a more comprehensive perspective of risk in the following aspects.

PUBLIC	OWNER
Public safety risk	Investment risk
Environmental risk	Employee safety
Loss of service	Loss of revenue

4. Hazards - LNG Spills

The hazards discussed for LNG involve having an LNG spill. The primary hazard of the flammable LNG is the possibility of a fire (vapours mixed with air will burn). The two limiting conditions are an LNG release with and without immediate ignition. If the ignition is immediate or relatively soon after the start of the release, the fire size is determined by the LNG release rate which fuels the fire. If the ignition is delayed, an LNG vapour cloud will develop and disperse as it expands and/or moves downwind. For ignition to occur, the concentration of vapour in the atmosphere must be at less than 15% which is the Upper Flammable Limit (UFL). At concentrations above the UFL there is not enough air to sustain combustion. As the cloud expands, eventually the concentration drops below 5% vapour in the atmosphere. This concentration of 5% is the Lower Flammable Limit (LFL). At concentrations below 5% vapour in the atmosphere there is not enough fuel to sustain combustion. If ignition occurs, the area with concentrations at or above the lower flammable limit (5%) will be at risk. The vapour cloud will burn back to the source of vapour. This source can be either the release itself or a pool of LNG accumulated prior to ignition. From these scenarios emerge two explicit CSA Z-276-2007 requirements for the protection of the public beyond the boundaries of the facility. These are the two “exclusion zones” which are required for facility siting. Specifically, there are the “vapour dispersion exclusion zone” and the “thermal radiation exclusion zone”.

Other hazards from lack of oxygen (asphyxiation) and low temperatures (frostbite) occur only in the immediate area of the release and would be confined to the site. The hazard of asphyxiation becomes acute at oxygen levels of 9% and below, which would occur only at vapour concentrations above 50%. The heat transfer from LNG vapours is low such that exposures to cold vapours are not a hypothermia or frostbite hazard. Direct spills of liquid can cause injury but these are only a hazard to plant employees. Employees of the facility will be trained and instructed as to a safe course of action to follow in the event of an emergency as required by the codes covering the facility.

Two related factors are relevant. Vapour/air mixtures produce a visible fog because any significant concentration, even below the LFL, is below the atmospheric dew point temperature. Except in unusually hot, dry climates, the LFL will be well within the visible fog. This is very useful because it easily identifies a release, indicates the direction and extent of its travel, and identifies the limits of flammability. All vapour and liquid systems are closed such that in normal operations there are no liquid or vapours escaping. These hazards extend to distances much less than the code required exclusion zones.

The siting study performed by Quest Consultants, Inc. examined both the code required LNG spills which would occur accidentally at the facility and spills which could occur in the vicinity of a carrier. The code required calculations are defined to calculate the worst possible credible spills. The code required case for a single containment tank in the thermal radiation analysis is where the storage tank impoundment is full and on fire. This case is accomplished by having the storage tank lose integrity and fill the dike before catching on fire. The code requires siting the facility such that resultant thermal radiation isopleths from a full dike fire contain the higher levels on the site. This means that the impact from this would remain on site. For this to happen, the tank would have to collapse instantaneously without an ignition source. The LNG tanks are constructed in a manner that this is extremely unlikely. The vapour dispersion calculation design spill for the storage tank is a spill from the transfer line, which is less. Again, to have an incident of greater magnitude, there would be need to be an instantaneous spill and this is extremely unlikely. Because the worst case scenarios are considered, the facility is sited in such a manner that any accident, malfunction or upset condition at the facility will not impact the public. It is possible to imagine an instance where the spill could be greater, but the circumstances required to produce this are almost impossible to achieve. The Quest Consultants, Inc. "*Siting Study for the Grassy Point LNG Transshipment and Storage Terminal*" found that there would be no harmful impact from any of the modeled scenarios on either the NTL facility or the town of Arnold's Cove. If the LNG carrier were to have an incident on the water, the most hazardous thermal zone of the most hazardous event would extend 265 meters from the center of the vessel. This would not be an instantaneous event and any traffic on the waterway would have time to move out of the vicinity.

The distance from the Grassy Point facility to the town of Arnold's Cove is approximately 1600 meters. The thermal radiation that would be observed from the site controlling fire of the storage tank impoundment would produce a flux of less than 0.8 kW/m^2 at that distance. This is equivalent to the amount of solar radiation that would be observed on a hot sunny day. The flammable vapour cloud from the code-required credible spill scenarios remains on the facility property and does not affect the adjacent Newfoundland Transshipment Limited (NTL) crude oil transshipment terminal or the town of Arnold's Cove. The waterfront area in the immediate vicinity of the facility could see thermal radiation or a flammable cloud, but either of these conditions would not be instantaneous and allow time for anyone affected to move out of the area.

5. Vapour Dispersion Hazards

In each scenario evaluated, the possibility of a fire from vapour dispersion or thermal radiation can be a major contributor to risks; therefore, a brief explanation of these phenomena is appropriate. When a release occurs, the LNG will vapourize as it comes into contact with the relatively warm surfaces and atmosphere. The initial hazard following a release comes from the LNG spreading over the surface and vapourizing as it absorbs heat. The vapour generated will mix with air which begins the vapour dispersion process. The code establishes a set of design criteria and environmental conditions that represent the maximum credible release scenario for design and code compliance. The criteria are based on atmospheric conditions specific to the facility and the facility's containment configuration. Using the code criteria, the analyst is able to calculate the theoretical distance the flammable concentration of a vapour cloud will travel. This distance is the Lower Flammable Limit (LFL) vapour dispersion isopleth. This distance is represented on a site plan as a ring of equal concentration, called an "isopleth". CSA Z-276-2007 requires that the isopleth for a LFL vapour cloud must not go beyond the LNG facility boundaries or property that cannot or will not have occupancies and thus result in a distinct hazard to the public. The hazard is not the vapour itself, but the possibility that it could be ignited. If ignited, the vapour cloud will not expand any further, but instead, will burn back to the vapour source. The LNG fire will continue to burn until the fuel is consumed or the fire extinguished. An LNG vapour cloud, mixed with air will not explode unless confined in an enclosure.

The code required vapour dispersion calculations for the Grassy Point LNG facility are the vapour excursion from a design spill at each impoundment area. The Quest Consultants study shows that the exclusion zones from these events are contained on the property and do not pose a hazard to the general public.

6. Thermal Radiation Hazards

If a fire occurs, there will be radiant heat from the flame which could cause personal injury, property damage and potentially secondary fires. The potential personal injury of the public is the primary concern. The severity of the injury depends on the intensity of the radiant heat, the exposure time and any protective factors such as clothing. The intensity or thermal flux level is measured in kilowatts per square meter (kW/m^2). This unit is generally unfamiliar but if related to sunlight with a clear sky, direct sunlight radiant heat is about 1 to 1.5 kW/m^2. The limiting radiant heat for the CSA Z-276-2007 restriction on general public exposure is 5 kW/m^2 or, say, 5 times strong sunlight. This is not instantly injurious but becomes quite uncomfortable fairly quickly. Ultimately these flux levels can cause injury. Recent "real live person" experiments have shown that 60 seconds at 5kW/m^2 is not injurious and does not cause continued discomfort after the radiant heat exposure is discontinued. The duration of exposure factor allows time for an exposed person to find protective shelter from the direct exposure and/or move away from the fire. In summary, the 5 kW/m^2 exposure limit provides a high level of safety.

The code required thermal radiation calculations for the Grassy Point LNG facility are a full dike fire for the storage tanks or a fire over the full extent of each impoundment area. The Quest Consultants study shows that the exclusion zones from these events are contained on the property and do not pose a hazard to the general public.

7. Hazards from Refrigerants

7.1 Mixed Refrigerants

The refrigerant cycle includes the vaporization and condensation of the refrigerant, usually under pressure. A leak from this system has the potential to produce a flammable cloud. The primary concern for hydrocarbon processing facilities is the potential for fire. The fire prevention fundamentals are: the elimination of vapours producing releases of products, the elimination of vapours mixing with air to form flammable mixtures and the elimination of ignition sources. These measures are undertaken in design and operational procedures. Mitigation measures are also undertaken to reduce hazards if a release incident does occur. These center on minimizing the release rate and volume. Control and confinement of the release are very constructive.

The characteristics of LNG and the appropriate safety measures are reflected in CSA Z-276-2007, which prescribe certain analytical safety assessments to confirm safe siting and design to protect the public.

The commonly used "mixed refrigerants" are methane and the heavier hydrocarbons ethane, propane and butane. Iso-pentane can also be used. Ethylene and nitrogen may be refrigerant components as well. These components are often referred to as Liquefied Petroleum Gas (LPG) or Natural Gas Liquids (NGL). The heavier hydrocarbons also have different safety characteristics as well as different combustion characteristics. Propane is a common fuel with a very large accumulation of experience resulting in separate CSA codes and safety practices for propane facilities. CSA Z-276-2007 makes many of the code provisions applicable to "LNG, refrigerants and flammable gases" as well as referencing CSA B-149.2, *"Propane Storage and Handling" and* NFPA 30, *"Flammable and Combustible Liquids"* code. Ethane and ethylene are not used domestically, but have wide use in the petrochemical industries.

Common with natural gas, the primary hazard of these heavier hydrocarbons is fire, either immediate upon vapour release or a delayed ignition of vapours which creates a potential hazard to the extent that the vapours are not dispersed below the lower flammable limit (LFL) concentration. The safety assessment for the NGL vapour dispersion is similar in kind to LNG vapour dispersion analysis, but different in detail. Upon release, both LNG and NGL vapours are heavier than air (negative buoyancy) because they are cold (LNG, -160°C; ethane, -100°C; propane, -45°C). As they warm to ambient temperature, there is a decrease in density and the vapours become lighter. LNG vapours will become about ½ the density of ambient air and becomes buoyant. Ethane reaches a density equivalent to that of ambient air. Propane remains heavier than air and thus is a "dense gas" at ambient temperature. The density influences the vapour dispersion and must be considered.

The flammable limits are also different for these three gases. The lower flammable limit is the concentration below which there is not enough fuel to support combustion. The comparative LFLs are 5% for methane, 2.9% for ethane and 2.1% for propane. The upper flammable limit is the concentration above which there is not enough air (oxygen) to support combustion. The combination of buoyancy and LFL properties make the NGLs, and propane in particular, of greater concern. An equivalent release creates further distances for the LFL hazard.

Methane has a relatively lazy flame due to the smaller molecule (less energy) and higher ignition temperature. This low flame front speed does not create an overpressure ahead of the flame front, hence, no flame front acceleration or explosion. An ethane flame front can accelerate and cause an overpressure. The propane flame front does accelerate rapidly. If the flame front travels far enough, the flame front speed exceeds the sonic velocity and a violent vapour cloud explosion can occur.

This can create a different type of hazard which may occur with gases stored under pressure, a phenomenon referred to as a BLEVE, or Boiling Liquid Expanding Vapor Explosion. Large methane and ethane storage can be refrigerated (cold) at pressures slightly above atmospheric pressure. For the refrigerant quantities required for liquefaction, it is more practical that they be stored in high pressure cylinders at ambient temperature but remain as gases. It is very common to store propane in relatively modest pressures (10 bar) in pressure vessels up to 250,000 litres. At these pressures the propane will liquefy at ambient temperature. The container will have liquid on the tank bottom and a vapour space above the vapour. If such a propane pressure vessel is subjected to extended fire exposure, the temperature of the contents increases as will the pressure. Although these vessels are equipped with safety pressure relief set at about twice the normal operating pressure. When these relief valves open, the pressure is maintained at the relief valve setting and the tank will vent. In these circumstances, the liquid evaporation keeps the bottom of the tank at the boiling temperature. However, the vapour above the liquid may be unable to keep the steel at the top of the tank from getting very hot. This will weaken the steel which may rupture and release the contents. The superheated liquid immediately vaporizes and causes a vapour cloud explosion.

Notwithstanding the different behavior of the heavier vapours, the risks are offset by much smaller inventories as well as by the specific equipment designs and appropriate fire protection provisions. These materials are handled in everyday operations that are not different in any significant way in the context of being part of an LNG facility. The LNG codes cover an LNG facility and have anticipated refrigerants with the CSA Z-276-2007 code provisions. Because the NGL volumes are smaller, the LNG based siting is generally not a problem from a public safety perspective. However, as part of the safety assessment, NGL hazards and possible consequences are considered. For specific NGL equipment, the appropriate design practices and safety precautions are incorporated. Such precautions include additional hazard detectors, disposal of discharges from safety relief valves, and thermal protection (fire proofing). In particular, additional firewater is provided for exposure protection by means of firewater monitors and deluge systems. In summary, the liquefaction process and refrigerant storage do not contribute to offsite risk.

7.2 Nitrogen

Nitrogen is often used in LNG facilities for inerting or reducing the heating value of the sendout. It can also be used as a refrigerant. The two hazards of concern are displacement of air and low temperature if used as a liquid. Oxygen concentrations below 10% can cause unconsciousness and possibly cause death. However, this requires a nitrogen content of greater than 50% which would be unlikely unless a leak were to occur inside a closed room. Nitrogen storage is typically placed in an outside location to reduce the hazard of asphyxiation. Under properly controlled conditions proper protective clothing for low temperatures must be used when handling any cryogenic liquids. This will limit the hazard of exposure to low temperature.

8. Analytical Methodology

The CSA Z-276-2007 code requires that the maximum credible LNG release rate be established. An LNG release will land on some configuration of a surface such as the area within the impoundment, a catch basin or trench. The evaporation (vapour generation rate) and the accumulation rate of unevaporated LNG are then determined. The vapour generation rate is then used as input to the vapour dispersion calculation to determine the downwind vapour concentrations and, specifically the distance to the LFL concentration. The LFL represents the limit of the hazard.

The vapour travel distance calculations include the influence of wind, atmospheric stability, humidity and temperature. In no-wind conditions, the vapour cloud will tend to be symmetrical around the vapour source. Light winds will move the vapour cloud downwind but with a minimum of mixing due to turbulence. Increasing wind speed increases turbulence and mixing with a reduction in the LFL excursion distance. The CSA Z-276-2007 requires the use of wind and atmospheric conditions which result in the furthest distances.

The thermal radiation is based on the assumption that the surface of the liquid pool which holds the accumulated LNG is burning. From this, a flame size and height are determined and the radiant heat as a function of distance is calculated. The wind also has an effect on the radiant heat levels downwind in that it will tilt the flame. This influence is also required to be considered by CSA Z-276-2007.

The design criteria for impounding configurations and the related thermal radiation limits generated by a fire are specified in the codes. Thermal radiation isopleths (lines of equal heat flux) are calculated for 30,000W/m^2 (10,000 BTU/ft^2-hr), 9,000W/m^2 (3,000 BTU/ft^2-hr) and 5,000W/m^2 (1,600 BTU/ft^2-hr). These levels depend upon the nature of the occupancy outside the plant boundaries which would be subject to the radiant heat from a fire. Like vapour dispersion isopleths, the thermal radiation isopleths must either remain on site or within controlled property.

9. Design Considerations

CSA Z276 outlines the criteria for designing an LNG facility that will protect the public from a credible, major release or incident. The following brief explanation provides a broad overview of the design concepts and elements, but does not cover every code requirement and design detail.

Each storage tank is surrounded by an impounding dike which is designed to contain at least 110% of the storage tank capacity. The design basis is for a total release of the tank contents. The code also addresses the siting and spacing of multiple tank configurations.

The process area is required to be provided with a spill containment area, which flows to an impounding area. The CSA Z-276-07 design basis is a full-flow release from the largest piece of equipment for a period of 10 minutes; or for a shorter time where demonstrable surveillance and shutdown provisions exist. For the Grassy Point facility, Quest has concluded that a 3 minute release period is sufficient time for the surveillance and shutdown procedures to be effective in containing the incident. For an LNG import terminal, the design release rate is from the LNG unloading line from the ship during unloading. The transfer piping will have spill containment or trough under the pipe rack, which also is directed to a sump. The design basis is for a 10-minute, full-flow release from the largest transfer pipe. Depending on the facility configuration, the process area and transfer piping can use the same sump or independent sumps. In summary, the facility must be designed such that the exclusion zone requirements are met.

10. Design Approach

The details of the layout and equipment are provided in other documents but the highlights are:

- The LNG tanks have no penetrations above the maximum liquid levels such that the only way LNG can leave the tank is to be pumped out or to have a collapse of the tank integrity.
- The tanks are surrounded by an impoundment which will contain more than 110% of the full tank contents.

- Areas outside the tank impoundment are provided with drainage and catch basins which will contain any LNG release from the process area.
- There will be an extensive hazard detection system and continuous monitoring from the control room.
- There will be an emergency shut down system which will secure the facility in case a hazardous event occurs.

11. Independent Safety and Siting Assessment

A safety and siting study, "*Siting Study for the Grassy Point LNG Transshipment and Storage Terminal*", was prepared by Quest Consultants, Inc. in November 2007 and is included in this report in Appendix C. This study was executed in the format of a code compliance audit for the siting requirements. The result of this study is the conclusion that Newfoundland LNG's proposed Grassy Point LNG project meets the requirements of CSA Z-276-2007.

12. Environmental Impacts

Negative long-term environmental impact from an LNG release is virtually non-existent. LNG is colorless, odorless, non-toxic and leaves no residue after evaporation. LNG (liquid) has a specific gravity in the range of 0.45; therefore it will float on water. LNG and LNG vapour are not soluble in water which precludes water contamination. The specific gravity of LNG vapour is 0.55. LNG vapours become buoyant at temperatures above -107ºC. The buoyancy of the vapour enhances the dispersion in the atmosphere with no long-term hazardous effects. One of the attractive features of natural gas is that, unlike an oil spill, an LNG release does not require any environmental clean-up effort. Methane is considered to be a greenhouse gas but there are no vapours released in normal operations as all systems are vapour tight.

Potential damage to environmental and socio-economic components is limited to short-term hazards to flora, fauna and humans in the immediate vicinity of the release. There are no LNG or vapour releases as a result of normal operations. Any short term releases would be the result of an accidental spill or component failure. The affected area would probably be in the cleared area around the tanks and process, but certainly within the facility boundaries. For example, any fish in the immediate vicinity (a few hundred meters) of an LNG ship release would unlikely be frozen or otherwise harmed as any freezing of the water would be at the surface of the water. The surface of the water will be at the melting temperature of the ice. The ice will soon melt and the environment will return to normal with no residual trace of the incident. Likewise, any animals or birds within the vapour dispersion or thermal radiation isopleths caused by a release could be immediately harmed or killed. An animal may not recognize a visible fog (vapour cloud) as a fire hazard and thus suffer if they are in the flammable cloud if it is ignited. If they were not within the vapour cloud if ignited, they could escape. If an LNG pool on water is ignited ("pool fire"), marine mammals will likely stay away. It should be noted that persons can and have run faster than a flame front. Immediately after an LNG release, the area would be suitable for animals and humans to use again. Local population (animals or people) and property should sustain no long-term effects from an LNG release. The LNG facility is designed to contain any incident on site or within the controlled property.

The environmental protection regulations require that this LNG facility file periodic notices with Environment Canada on the facility relative to the LNG inventory and changes of inventory. An environmental emergency plan is also required and is permitted to be integrated into more general emergency plans. Comprehensive safety and environmental procedures will be prepared using the safety studies for code regulation compliance, analysis of emergency scenarios and the final facility design.

13. Ship Safety and Impacts

The safety, risk and environmental impacts of the LNG shipping are considerably different in kind compared to the receiving facility. In principle, the hazards are similar, i.e., a large fire from the immediate or delayed ignition following an LNG release. The difference is that the potential causes of a release are different and the area potentially affected by the consequences moves along the route of a ship in cargo. This precludes the onshore approach of the impoundment and exclusion zones. The maritime approach is an evaluation of the suitability of the waterway. This includes potential navigational issues and population densities along the route. In the case of Grassy Point, the waterway is ideal.

Regulations are set regarding clearance areas between ships and smaller boats. There is a small recognition that the cargo is flammable and would vaporize quickly if spilled on water. Regardless of the very low probability of a collision, it is the general practice to establish a safety or security moving zone for the LNG carriers. This also serves to keep small boats clear of the hazards associated with getting too close to any large ship. In most ports, the determination of appropriate clearances are at the discretion of the local authority on a site specific basis.

In evaluating the safety of the ship's passage, it is instructive to examine the potential causes of a cargo release and the safety record of the 40+ years of LNG shipping experience. The ship characteristics are that they are very large. In physical size the largest of these are 350 meters in length overall (LOA) with a 54 meter beam and 12.5 meter draft. However, the cargo hazard is related to the mass of the cargo rather than physical dimensions. Currently a typical 145,000m^3 ship has a cargo mass of about 65,000 tonnes. Some of the large LNG ships now under construction will have as much as 117,000 tonnes. In comparison, large oil tankers have cargos of 275,000 tonnes or more. Thus, although LNG ships are physically large, they are by no means exceptionally large from an energy content standpoint.

The relatively large physical size (compared to cargo tonnage) of LNG ships is due to the low density of the cargo and the hull space occupied by the double hull, ballast tanks, secondary containment and insulation of the cargo tanks. These factors also increase the robustness of the hull, resistance to hull penetration and the depth of penetration required to release any cargo. The LNG carriers are double hulled such that such a penetration would have to go through the outer hull, ballast tanks, insulation and finally, the cargo tank.

Each of the primary causes of the release of cargo from the cargo tanks has been considered. These are:

- Grounding

- Ship collision
- Terrorism or sabotage

14. Ship Grounding and LNG Release

When evaluating the possibility of a ship grounding at or near the terminal, two factors must be considered: the physical features of the navigable area adjacent to the waterfront and berth, and the speed and control of the LNG ship. The navigable waters surrounding the Grassy Point facility are sufficiently deep that grounding would require a loss of ship's propulsion or steerage that would cause the ship to leave the channel or berth area. While grounding is always possible, as the ship approaches the facility it will be under control of a licensed pilot. The maneuvering for berthing and turning of the ship will be assisted by tugs. The tugs will be able to control the movement of the ship and prevent grounding. The potential for damage in the event of grounding would be further mitigated by the ship's reduced speed as it approached the berth and its double hull.

Although tug escorts are not required for LNG ships by the CSA regulations, they are a prudent addition to the safety of navigation. When a ship is berthed, it has to go at a very slow speed and therefore has no steering capability. The berthing approach is to get parallel to the dock, but off the dock (by a space of about 50 meters). 50 meters is essentially between 1 ½ and 2 ships width. At this time, the ship is essentially motionless, parallel to the dock, but off the dock. The tugs assist by pushing the ship sideways against the dock. Furthermore, the ship is generally heading outward (back out to sea) and therefore has to be turned around prior to berthing. The tugs turn the LNG ship and push it to berth. It is up to the pilot. The LNG ships will only come within a few kilometers of the terminal before picking up the tugs as they slow down.

The hazards from grounding depend on the nature of the bottom and the speed of the ship. Two LNG ship groundings have occurred in the last 30 years. The *El Paso Paul Keyser* ran aground off the Straits of Gibraltar, at a speed of 14 kts, when it struck a rock pinnacle. The *LNG Taurus* grounded outside Tobata Harbor, Japan. Foul weather prevented the local pilots from boarding the *LNG Taurus* and the vessel grounded while maneuvering (unassisted) to turn and depart the harbor area. In both cases, extensive hull damage was sustained but the double hull construction common to all LNG ships prevented a breach of the cargo tanks. The cargo tanks on the *Paul Keyser* (membrane type) were deformed, but did not leak cargo. Therefore, it may be assumed that any grounding that might occur at low maneuvering speed, near the LNG terminal, would not be of sufficient force to cause a cargo release. The possibility of cargo release is extremely remote. The greater hazard is the release of fuel oil from tanks in the vicinity of the engine room. This fuel is a persistent oil and will cause damage to the environment if released. The likelihood of a release is small, as the vessel is more likely to ground out on the forward end of the vessel.

Without actual data on a grounding that resulted in a cargo release, one can only theorize on the results along the following line of logic. In the event of a grounding that caused a breach of the outer hull, seawater would enter the double bottom. Damage sufficient to also breach the cargo tank, while extremely remote, would result in LNG being directly exposed to seawater. Tests involving large spills onto water indicate that the incident would cause the exposed water to freeze and liquid cargo would not be immediately released. Furthermore, since LNG has a density about half of water, the LNG would "float" on top of the water and a significant amount would not escape through a breach in the hull bottom. Hydraulic pressure could displace the cargo and push liquid out of the safety valves until equilibrium was reached; however, depending on the size of the hole, the ice that formed when seawater was exposed to LNG would probably form a "scab" over the failure point and mitigate any hydraulic effects. (A common temporary repair for LNG leaks is to wrap a wet rag around the leak. The rag will freeze and seal the leak until the system is secured and permanent repairs can be made.)

Direct exposure to the relatively warm seawater would cause LNG to evaporate, create large amounts of vapour, and build pressure in the damaged cargo tank. Excess pressure would lift the safety valves and vapour would escape to the atmosphere. A significant vapour cloud would be generated. Without an ignition source, the vapour cloud would continue to form until the contents of the exposed tank had been vaporized. If the vapour cloud found an ignition source, it would burn back to the source and continue to burn at the safety valve stack until the cargo tank was empty or the fire extinguished. If unconfined, LNG does not explode; it simply burns. Danger to the surroundings would be a function of the LNG ship's location at the time of the grounding. However, the potential hazards from vapour dispersion and thermal radiation of the ship's cargo tank would most likely be from the relief valve stacks. Additionally, as part of the ship's design, venting is provided for the cargo tank annular spaces, (which are nitrogen purged) and double hull ballast tanks. It should be reemphasized that no LNG ship grounding has ever resulted in a cargo release, and the maneuvering and control factors involved in berthing an LNG ship make the possibility of grounding extremely remote. For the approaches to the Grassy Point terminal, the water depth essentially precludes a grounding for an LNG ship.

15. Cargo Release During Transfer

The potential for the release of cargo during the transfer process from the ship to the dock is a credible incident. For such an incident, the two most probable causes would be the ship moving outside the operational reach of the unloading arms or the failure of a cargo transfer piping during the transfer process. The position of the loading arms is monitored for movement fore and aft vertical motion and movement off the dock. Three excursion levels within the movement envelope are significant. At the first, warning is given to both to the ships cargo officer and to the facility. The second level is an automatic shutdown of the unloading process. The third level is an automatic, dry-break disconnect of the arms. If the ship movement causes the unloading arms to disconnect, the release would be minimal; primarily vapour. All new unloading arms are equipped with a Powered Emergency Release Coupling (PERC) system, which automatically closes the valves and interrupts the transfer of cargo in an emergency. The amount of cargo released from this "dry break" is limited to the small amount in the connection between the two PERC ball valves located at the ships cargo manifold. This small amount would dissipate rapidly. In the rare incident that the vapour found an ignition source, the fire would be small and burn out quickly.

The failure of a component, either on the LNG ship or in the shore facility, could allow a continued flow of cargo until the failure was detected. Detection would, however, be rapid due to the extensive array of gas detection equipment both on the ship and ashore. Furthermore, while cargo is being transferred, additional personnel are assigned to physically observe the transfer equipment on the LNG ship and in the terminal. In addition to surveillance by personnel, the flow and pressure conditions of the transfer are monitored in both the ship's cargo control room and the facility's control room. Any significant release would cause an increased flow, a decrease in transfer pressure and an increased pump current; all of which will be quickly noted by the cargo officer and monitoring/alarm system. In the terminal, the operator will note a decrease in flow rate accompanied by a change in pressure. Any release that occurred in the terminal would be confined by the impoundment areas located throughout the facility and would be directed to the respective sump. Per CSA Z-276-2007 requirements, the sumps are designed to accommodate the full volume of flow, for a period of ten minutes or shorter if sufficient proof can be furnished that the incident duration will be shorter, from pipe or component release. Should the release occur on the LNG ship, the ship is equipped with catch basins, water sprinkler systems, and hull protection systems that will protect the hull and components from damage. Such a release would be directed over the ship's side to the waterway. It should be emphasized that ship's personnel are assigned watch positions to physically observe and respond to any malfunction in the ship's cargo transfer system. Any significant malfunction or failure would be reported immediately and an Emergency Shutdown (ESD) would be initiated to stop cargo transfer.

The potential for release of cargo is also present during a ship to ship transfer. For such an incident, the two most probable causes would be either ship moving outside the operational reach of the unloading arms or the failure of a cargo transfer hose during the transfer process. The position of the loading arms is monitored for movement fore and aft vertical motion and movement off of both ships. Both ships will be moored with a maximum tolerance of 2 meters fore and aft. Three excursion levels within the movement envelope are significant. At the first, warning is given to both ship's cargo officers. The second level is an automatic shutdown of the unloading process. The third level is an automatic, dry-break disconnect of the arms. If the ship movement causes the unloading arms to disconnect, the release would be minimal; primarily vapour. All new unloading arms are equipped with a Powered Emergency Release Coupling (PERC) system, which automatically closes the valves and interrupts the transfer of cargo in an emergency. The amount of cargo released from this "dry break" is limited to the small amount in the connection between the two PERC ball valves located at the ships cargo manifold. This small amount would dissipate rapidly. In the rare incident that the vapour found an ignition source, the fire would be small and burn out quickly. There is a deluge system/water spray provided for use at both cargo manifolds to contain any event. The transfer hoses will have annual testing and constant visual verification during the transfer process. The water curtain system will be available to contain the vapour produced from a break in the hose before the ESD system is able to shut down the transfer.

16. Terrorism and Sabotage

Terrorism in general receives intensive publicity and is a high profile concern in several countries involved in controversy. LNG shipping safety has been a particularly popular target for opposition to LNG import terminals often for other reasons falling into the NIMBY (Not-In-My-Back-Yard) category. Acts of sabotage are always possible, but the chances of this type of threat are remote for several reasons, including:

- Terminal and shipping personnel will be screened by the terminal before hiring.
- LNG ships and personnel will be monitored under the new International Ship and Port Facility Security Code (ISPS Code), which has been established by the International Maritime Organization (IMO), effective July 1, 2004.
- Ship crews tend to be very stable as the jobs are considered to be very attractive. There is very little turnover in terminal staffing.
- The new ISPS Code will require a written Port Facility Security Plan.
- LNG facilities are required by CSA Z-276-2007 to have significant security features built into the facility.
- Terrorists are more interested in “high profile” targets with strong symbolic value, or targets that can cause mass casualties or severe economic damage. In general, LNG terminals are not attractive targets due to their “low political profile”, difficulty of attack, and high level of security.
- The Grassy Point ship traffic provides essentially no preferential attractiveness as target selection.

A successful act of terrorism will require a high level of training and must be capable of being planned and initiated without detection. This limits the size of the weapon that can be used in the attack and, therefore, limits the credible threats to those using relatively small, easily accessible, and easily transported weapons. Weapons that could be moved undetected are limited primarily to hand-held rocket launchers, such as an RPG (rocket-propelled grenades) or a truck loaded with explosives, such as the one used in Oklahoma City. Other types of weapons systems would likely be too large, complex, and easily detected. Additionally, the LNG ship is subject to threat from a small boat loaded with explosives, such as the one used against the *USS Cole,* in Yemen, or the French tanker *Limburg*. Had either of these attacks been inflicted on an LNG carrier, there would have been no cargo release because the double hull plus separate cargo tanks would not have been damaged to the extent of causing a release with these explosions.

The most accessible targets are the facility's storage tanks or the cargo tanks on a LNG ship at the dock. However, in each case, the access difficulties essentially limit weapons to those that could be carried by hand. The access by vehicles limits approach to the point that the explosive would not be close enough to the structures to cause significant damage. Other smaller targets within the facility would produce minimum results.

The scenario involving a truck carrying explosives is not credible because even if the truck is able to pass the facility entrance security gates, the impoundment dike around the storage tanks will prevent the truck from getting close enough to cause any significant damage to the tank. Likewise, the truck will not be able to get closer to the LNG ship than the parking lot at the base of the dock and would not be able to inflict significant damage. A major factor in the security design is preventing unauthorized access to any area which could be considered as a possible target.

The RPG-type weapon would most likely be launched from some distance. The shore-based storage tanks have a double wall construction. The size of the hole made by an RPG (less than 3") in the inner tank will be relatively small since the outer tank and insulation should absorb most of the blast. The amount of liquid discharged from the tank will be a function of the penetration diameter and the height where the hole was made. If, for example, the penetration is near the top, the subsequent release would be less than if the penetration was at the middle of the tank. The result of a penetration and subsequent leak from the shore-based storage tanks would be a release into the impoundment dike. If the LNG was not exposed to an ignition source, the released LNG would vaporize. The vapour dispersion for LNG into the impoundment dike will have been calculated and the vapour cloud would remain within the property lines until the vapour is below the LFL, as required by code. If the LNG release was exposed to an ignition source, the vapour would burn back to the source (the impoundment dike) and the LNG vapour from the impounded liquid would continue to burn. The thermal radiation from the LNG fire has been calculated for the site and the hazardous levels of thermal radiation are confined to the site, as required by code.

The LNG ship's cargo tanks are surrounded by insulation within the double hull construction of the ship. The tops of the tanks have an outer cover above the main deck, called the weather dome. The cargo tanks are protected below the main deck by double hull construction. As in the case with LNG storage tanks, the weather dome should absorb most of the blast from an RPG type weapon or a truck bomb and any damage to the cargo tank will be reduced. The damage would most likely be above the main deck and would not cause a significant release. Additionally, the angle for an RPG type weapon would be less than 90º such that penetration would be degraded. Missile attacks on an LPG ship in the Persian Gulf during the Iran-Iraq War (1980-1988), resulted in deck fires which were subsequently extinguished. The penetration and subsequent leakage from an LNG ship cargo tank would flow overboard and into the waterway. Tests have indicated that LNG when spilled into a large body of water will freeze the water and may capture part of the LNG as hydrates. The vapours will be released as the hydrate ice melts. Like the storage tank scenario, vapours will disperse until they either reach a concentration below the LFL or find an ignition source. Any credible incident which would cause a significant release from a ships cargo tank will also be an ignition source. In addition, the ship itself will be an ignition source. Ignited vapours would burn back to the source and continue to burn until the fuel was consumed or the fire extinguished. The size of the fire will be determined by the release rate and the fire location will be in the immediate area vicinity of the release. Such an incident would be adequately distant from any habitations. As the thermal radiation isopleths that extend over any water is below 9 kW/m^2, any persons in the area of a fire will have adequate notice to remove themselves from the area.

If a release is the result of an intentional or unintentional grounding, the LNG will be vaporized by the seawater which will form a buoyant vapour cloud. If this vapour cloud were ignited, there would be a small diameter relatively tall vertical fire. In these two instances, a release above the water line or a release below the water line both result in a local fire rather than a large pool fire which would be characteristic of spill on land. The energy required to cause a release of cargo in a grounding is very large and would require both high ship speed and a hard, penetrating bottom. As ships near enough to Grassy Point to cause a hazard will not be traveling at such speeds and will be assisted by tugs, a grounding which would create a release is not credible. The two significant LNG ship groundings did not cause any cargo to be released. Vapour dispersion and thermal radiation values can be calculated for the cargo tank release of an LNG ship; however, due to the prior explanation of an LNG ship cargo release in the waterway there would be limited, if any, damage onshore.

The most credible sabotage threat is from a small boat loaded with explosives. The credibility of this threat is greatly reduced by the fact that the LNG ship will be located in restricted waters with security provisions in the berth area. The security provisions are normally for protection of the LNG vessel, other ships or a secondary benefit of the security craft as a deterrent of sabotage in the waterway. The double hull construction of all LNG ships will mitigate any damage to the cargo tanks caused by an explosion at the waterline. Should a boat carrying explosives manage to attack the ship and a release occur, the result would be similar to that of a grounding except that there would be a high probability of ignition with a fire alongside the hull. The LNG would come in contact with seawater. The seawater may freeze, as the heat from the seawater is absorbed to vaporize the LNG. Vapour dispersion would occur until either the vapour cloud reached a concentration below the LFL or the vapour cloud found an ignition source. If ignited, the vapour would burn back to the vapour source and continue to burn until the fuel was consumed or the fire extinguished.

The possibility of a large plane being hijacked and flown into any target has been greatly reduced following the security measures implemented after September 11th. The probability of an accidental crash of an aircraft of adequate size is remote. Terrorists are more interested in "high profile" targets with strong symbolic value, or targets that can cause mass casualties or severe economic damage. LNG terminals are not an attractive target due to their "low profile", robustness and high level of security. The other possibility is mechanical failure and loss of control of an aircraft; however, most aviation accidents involving large commercial aircraft occur during takeoff or landing. The proposed location is remote from an airport handling large aircraft. A small personal aircraft could lose control and crash into the facility, but this would not impact the facility with the severity of a large commercial aircraft. The one incident of a small aircraft flying into an LNG tank (Newark, NJ) resulted in no damage to the tank. For these reasons, the scenario of a plane flying into either an LNG terminal or an LNG ship docked at the terminal is remote.

Should a large commercial aircraft crash in the terminal, the most significant type of incident would be a direct hit on a storage tank. The impact of the aircraft would be sufficient to breach the tank and cause an LNG release. Investigations of the World Trade Center and the Pentagon attacks show that the aviation fuel ignited immediately and burned on impact. Any LNG vapour cloud generated by an aircraft crash and release scenario would have an ignition source immediately and vapour dispersion would not be an issue. Any release from a storage tank would be contained within the impoundment and the thermal radiation would be similar to that of the code designated tank failure. The facility will be designed with a storage tank impoundment that will contain a total release from a storage tank. This is the code requirement for single containment tanks. Only one tank failure at a time needs to be considered by code. The thermal radiation isopleths are calculated for each impoundment and the resultant isopleths are mapped such that the outer limit is determined. As the code required $5kW/m^2$ thermal radiation isopleths for the storage tank impoundments is contained on the facility property, this type of incident will not create a hazard to the surrounding area outside the facility. Likewise an aircraft striking an LNG ship could breach a cargo tank, but the facility is designed to mitigate damage to the surrounding area from an LNG ship cargo tank release. Furthermore, emergency procedures require that while in the berth the LNG ship hang "fire wires" over the side, fore and aft, which make it possible for tugs to pull the LNG ship away from the dock and further protect the facility and surrounding area. As with the storage tank, vapour dispersion would not occur, as the cargo would be ignited by the aviation fuel fire.

17. Acts of Nature

The possibility of a significant LNG release resulting from an act of nature, such as a severe storm, ice storm, or earthquake is remote because CSA Z-276-2007 contains design requirements that take seismic, wind, and weather factors into account. The tanks will be designed for the seismic rating of the region, and the tank profile will take into account the wind loads (both typical and maximum) for the region. Equipment and structures will be designed to withstand the harshest recorded environment for the region. A lightening strike will not affect the system, unless it strikes a vent mast or other component that has a natural gas leak, creating a methane-rich environment. Significant leaks should be detected by mandated safety systems before they become a source of ignition. Such vent fires would be small and are easily extinguished.

Should an act of nature cause a release, the result will be the same or less than other causes previously cited. An LNG release would be impounded and the resulting vapour dispersion or thermal radiation would be limited to the terminal site and not cause injury or damage to adjacent property.

Acts of nature involving an LNG ship should be divided into two categories, predicted conditions, and unpredicted events. A predicted condition would be high winds, hurricane, ice storm, etc. Unpredicted acts would be those events that occur suddenly, such as earthquakes. The LNG ship will not dock and, if docked, will undock and depart should the weather exceed the design criteria. If extreme weather were predicted, the LNG ship's officers would monitor the weather to avoid being caught in restricted waters during the storm.

Unpredicted events of nature, such as earthquakes, present a different scenario. The worst case would be the LNG ship breaking its moorings during a cargo discharge. Breaking moorings occurred once in the past when a sudden 100-mph wind, called a "sumatra," blew the *LNG Aries* off the dock while loading cargo in Bontang, Indonesia. In such a case, the unloading arms would exceed their operational range and the automatic disconnection (PERC) system would activate. A small amount of LNG would be released; probably not enough to even reach the water. If the LNG ship broke all its moorings and propulsion was not available, the ship could drift and either allide with the dock or ground. Allision at low speed would possibly be sufficient to penetrate the outer hull but not sufficient to breach the cargo tanks. (Allision is a relatively new term adopted by the marine regulators to indicate the impact of a moving ship with a fixed "obstacle" that is not moving.) Other damage to the ship caused by events of nature is not plausible due to the ship being designed to be seaworthy in all types of weather.

18. External Fire

The possibility of an LNG release caused by external events, such as a forest fire or adjacent oil storage fire, is extremely remote because the facility is built from non-combustible materials, mostly steel and concrete. Further, CSA Z-276-2007 requires that the facility be designed to contain vapour dispersion and thermal radiation within the boundaries of the facility, as explained in detail above. The critical components of the import terminal for both operation and safety are not susceptible to even large fires at the distances provided by the exclusion zones and plant boundaries. These components are predominantly fire resistant. All components containing LNG are alloy steel externally insulated. The safety zones also work to isolate the facility and prevent an external fire from threatening the facility. Storage tanks would be protected by the impoundment dike, which would serve as a firebreak around the tank and process area. Furthermore, the facility will be equipped with an extensive firefighting system, which can be used to protect the facility from an external fire.

An escalating LNG release as the result of a fire within the plant is unlikely for the same reason. Due to the flammable nature of LNG, terminal personnel are extremely safety conscious. While accidents have occurred, they do not typically result in fires large enough to initiate a subsequent release or emergency escalation. However, in the event of a fire initiating a release, vapour dispersion would not be an issue because an ignition source would be immediately present. A major release would be contained within the dike or sump and thermal radiation is predictable and part of the risk assessment process. A vapour release that ignited would burn until the fuel was consumed or the fire extinguished. In either case, the fire and thermal radiation would be contained within the facility boundaries, minimizing the danger to the surrounding area. The code mandated firefighting systems should prevent the fire from spreading to storage tanks and process equipment not directly involved in the initial incident. All storage tanks and systems are sealed such that no fugitive vapours are present to be ignited.

Because the LNG ship's cargo tanks contain only an oxygen-free environment, the cargo cannot burn unless a release occurs and ignites. Furthermore, since maintenance is not performed on the cargo system while the LNG ship is in port, the concept of a fire initiating a cargo release is not credible. In the event of a cargo tank fire, the credible scenario is a single tank fire. The LNG ship is equipped with an extensive array of firefighting equipment, including large, dry chemical systems and sprinkler systems designed to contain a cargo system fire. In the worst-case scenario, firefighting efforts would fail and the shipboard fire would burn uncontrolled. The thermal radiation isopleths can be calculated for a cargo tank fire and the range of damage will be known. The radiant heat would be less than the code required full impoundment fire and more remote from the public. The facility's unloading platform and cargo manifold will likely be exposed to thermal radiation and may sustain some damage; however, as the footprint for a fire on the ship is smaller than the full impoundment footprint and the calculated thermal radiation distance that would damage the ship calculated for the storage tank impoundment does not impact the ship, conversely the main terminal facility should be outside the ship's most dangerous thermal radiation isopleths. Emergency procedures require that, during cargo transfer, the LNG ship hang "fire wires" over the side, fore and aft, which make it possible for tugs to pull the LNG ship away from the dock and further protect the facility.

Relative to the potential for explosions, two situations must be considered. It must be remembered that for the LNG, only LNG vapour or natural gas can undergo combustion, and only then if oxygen is available. If the oxygen comes from mixing with air, the flammable limit requires more than 5 parts air to 1 part LNG vapour. In any container, such as a cargo tank or LNG storage tank, there is no air (or oxygen) available; therefore, there can be no reaction; neither burning nor explosion. In the case where there is a release of LNG vapour into the open air, there can be combustion, but the flame front is slow and does not accelerate such that there is no overpressure, i.e., explosion.

19. LNG Release Due to Equipment or System Failure

The most credible type of release is the result of equipment or system leakage, such as a leaking valve seal or flange gasket. This type of release is typically small and non-threatening. The probability of such a failure is greatest at flanges or joints where components, pipes, and valves are connected and undergo temperature changes. These small leaks are visible and easily repaired by facility personnel. The next level of failure would be a leak associated with a piece of equipment. In this case, the equipment is typically replaced in service by a "spare" component and secured for repairs.

The LNG facility will be equipped with an extensive array of gas detection and flame detection equipment. Small leaks will be detected either visually, by trained personnel working in the facility, or by the detection equipment. Small leaks and/or fires should be easily handled by facility personnel, with assistance from the local fire department if necessary.

A system failure that generates a major release will have the same net effect as the other major incidents evaluated above. A release will be contained and directed to a sump, thus mitigating the extent of vapour dispersion. Should the vapour ignite, the thermal radiation will be mitigated by the release's containment in the sump. The fire will continue until the fuel is consumed or the fire is extinguished. Damage will be confined to the terminal boundaries, including any controlled areas outside the property lines.

20. Conclusions

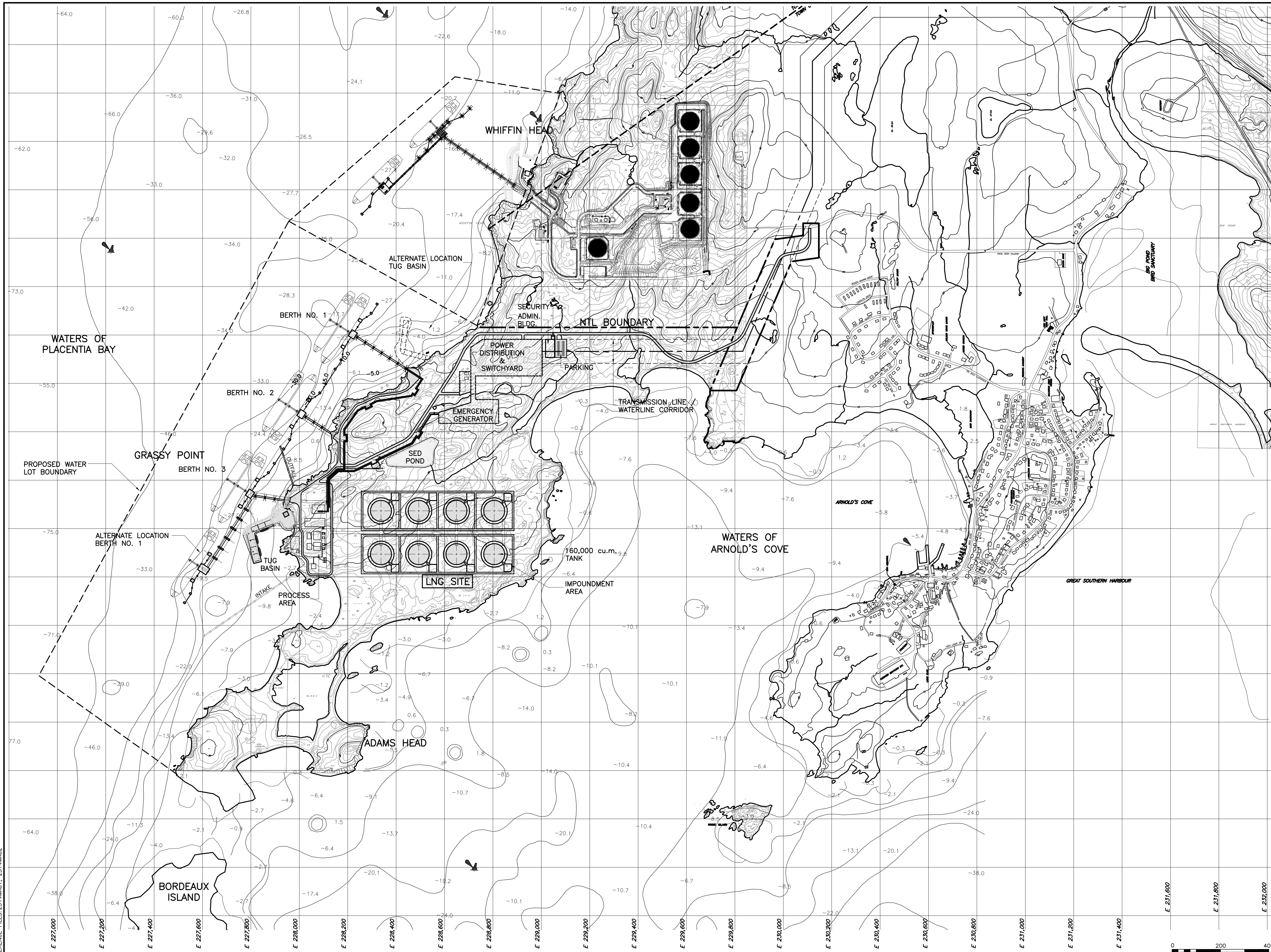
The design and construction of LNG terminals and LNG ships are regulated by various national and international codes. The risk associate credible accidents and failure scenarios have been established and facilities are designed to minimize the effects of a credible LNG release. The design criteria make safety of the surrounding population and property a priority.

The Grassy Point LNG facility will be designed so that any credible scenarios as cited above will not result in significant risks of injury or damage beyond the LNG terminal's property lines, including the berth area and any controlled adjacent property. Any danger to the surrounding animal population, habitat or property will be minimal and LNG accidents do not create long-term environmental issues.

APPENDIX A

Grassy Point LNG Site Plan

REFERENCE FILES: 2314MA01, 2314MA02



CONTRACTOR MUST VERIFY ALL DIMENSIONS AND CONDITIONS ON SITE BEFORE PROCEEDING WITH ANY PORTION OF THIS WORK. REPRODUCTIONS OF THIS DRAWING MAY HAVE BEEN REDUCED OR ENLARGED. REFER TO GRAPHIC SCALE. DO NOT SCALE DRAWINGS FOR CONSTRUCTION.

NOTES:

TANK FARM: TANK SIZE = 160,000 cu.m.
IMPOUND AREA = 155mx155m

DESIGN VESSELS:

1. THE BERTH ARRANGEMENT IS DESIGNED TO ACCOMMODATE THE FOLLOWING VESSELS.

CAPACITY (cu.m.)	DWT (t)	LOA (m)	BEAM (m)	DRAFT (m)
140,000	72,000	285	44	11.5
265,000	125,000	335	52	13.5

REV.	REVISIONS	REVISED BY	APP. BY	DATE
A	ISSUED FOR REVIEW			07/10/26

NORTH

PROFESSIONAL STAMP: REGISTERED PROFESSIONAL ENGINEER R. T. BAILEY SIGNATURE DATE PROVINCE OF NEWFOUNDLAND

PERMIT HOLDER STAMP

PROVINCE OF NEWFOUNDLAND
PERMIT HOLDER
CLASS "A"
This Permit Allows
BAE • NEWPLAN GROUP LIMITED
To practice Professional Engineering in Newfoundland and Labrador.
Permit No. as issued by APEGN C0003 which is valid for the year 2005.

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CLIENT
NEWFOUNDLAND LNG LIMITED

PROJECT
GRASSY POINT LNG TRANSSHIPMENT & STORAGE TERMINAL

TITLE
8 TANK GENERAL LAYOUT

DESIGNED BY	R.T.B.	CHECKED BY		DATE	
DRAWN BY	G.L.	APPROVED BY		DATE	
SCALE	AS SHOWN	BNG PROJ. No.	722314		
		CLIENT PROJ. No.			

DRAWING No. DW1 – 01 – GM – XX – 301 REV. A

APPENDIX B

ICF International Qualifications

ICF INTERNATIONAL LNG
QUALIFICATIONS AND EXPERIENCE

ICF International is a large, international firm that performs technical analyses of environmental and project development issues from an interdisciplinary perspective.

In October 2005, ICF acquired Project Technical Liaison Associates, Inc. (PTL). PTL is well known in the Liquefied Natural Gas (LNG) industry for their 28 years of technical advice, primarily to Owners of LNG facilities.

Our depth of experience and staff expertise encompasses all relevant aspects of LNG projects, including siting, environmental, technical, safety, and market analyses. Special emphasis is placed on the Client's perspective and interests.

In permitting assistance, ICF has worked with applicant staff and their in-house and outside counsel, as well as with senior staff and attorneys from FERC and a number of other Federal agencies.

Our LNG team specializes in the coordination efforts between regulatory agencies and the client. Our experts are continuously reviewing the most current regulations and code compliance under National Fire Protection Association (NFPA), U.S. Department of Transportation (DOT), Federal Energy Regulatory Commission (FERC), U.S. Environmental Protection Agency (EPA), U.S. Department of Homeland Security, and the U.S. Coast Guard, along with state and local regulations. PTL's specialized capabilities include facility siting, consequence analysis (thermal radiation/vapor dispersion), threat analysis, waterway suitability, seismic analysis, risk management plans, and site selection documentations.

- Regulatory experts with both US and International Regulations
- Excellent relationships with Government and Regulatory Agencies.
- 28 year history as industry leaders as LNG technical advisors.
- Critical Knowledge of LNG, LPG and other cryogenics.
- Industry leader in environmental, NEPA analysis and natural resource sectors.
- Proven track record of results working on time-sensitive projects.
- Critical knowledge and experience on the ground with community relations
- Experts in LNG safety, security and thermal dispersion modeling

We assist clients with feasibility studies, conceptual designs, code compliance, HAZOP requirements, preparation of FERC permit applications, interfacing with jurisdictions, community relations, and Quality Assurance for construction. For operations, ICF provides training, code compliance and problem solving.

ICF has worked on all five existing LNG import facilities, over ¾ of the North American Peakshaving facilities and over ½ of the proposed LNG import facilities.

Existing LNG Import Facilities Projects

- *Distrigas Everett LNG Receiving Terminal.* Jim Lewis, a Senior Executive in ICF, designed and operated the facility and was responsible for the first LNG cargo into the US.

- *Elba Island LNG Receiving Terminal.* Provided Code Compliance Support and assisted with terminal expansion.

- *Trunkline LNG Receiving Terminal.* Assisted the sequence of owners of Trunkline LNG since 1978 as technical advisor. Most recently provided a code compliance audit of the facility.

- *Dominion Cove Point LNG Receiving Terminal.* Provided technical support to every owner associated with the Cove Point LNG facility. Assisted with the reinstatement of the facility from its mothballed state, including community relations, to the expansion of the facility. Conducted feasibility and marine studies for the redistribution from the facility.

- *Penuelas LNG Receiving Terminal.* Performed due diligence for Enron and "fit for service" review prior to startup of the Penuelas, Puerto Rico LNG facility.

Proposed LNG Import Facilities Projects (Northeast)

- *Broadwater LNG Receiving Terminal.* Provided support to Saipem on the Long Island LNG facility, including regulatory code compliance and assistance in the preparation of Resource Report 13 of the facility FERC Application.

- *Crown Landing LNG Receiving Terminal.* Provides community relations support to BP on their proposed Delaware Bay facility.

- *Northeast Gateway LNG Receiving Terminal.* Provided assistance to Excelerate Energy with Hazard Assessment and community relations for the Northeast Gateway offshore project.

- *Quoddy LNG.* Provides community relations support for the Quoddy Bay LNG facility. Conducted several live LNG demonstrations for the public in Bangor, Maine.

Proposed LNG Import Facilities (Gulf Coast)

- *Bay Crossing LNG Receiving Terminal.* Provides community relations support to BP on their proposed LNG facility in Galveston, Texas.

- *Calhoun LNG Receiving Terminal.* Provides technical consulting to Gulf Coast LNG Partners, LP, for their Calhoun LNG facility. Conducted Community Relations support, including public open houses and live LNG demonstrations in Port Lavaca and Point Comfort, Texas. Assisted with preparation of Resource Reports 1, 11 and 13 for Calhoun LNG's FERC application and has prepared several responses to FERC Data Requests resulting from the filing.

Represented the owner in the Cryogenic Review and has provided both 49 CFR 193 and NFPA 59A code compliance reviews and support as needed. Most recently prepared a tank crack plan and facility fire protection code compliance review.

- *Cameron LNG Receiving Terminal*. Provides support to Sempra on their Cameron LNG facility in Cameron Parish, Louisiana. Provided code compliance and safety services, including Vapor Dispersion/Thermal Radiation Analyses and Hazard/Threat Analysis. Assisted in the preparation of Resource Reports 11 and 13 for Cameron LNG's FERC Application.

- *Casotte Landing Receiving Terminal.* Provides support to Chevron Texaco on their Cassotte Landing facility in Pascagoula, Mississippi. Performed a preliminary feasibility study, including assisting with the preparation of Resource Reports 11 and 13 for Casotte Landing's FERC Application.

- *Corpus Christi LNG Receiving Terminal.* Provides technical consulting to Cheniere Energy, Inc. for their Corpus Christi facility (CCLNG) in Corpus Christi, Texas. Such services include Feasibility Study, review of preliminary design, permitting report development, code compliance, video development, community relations, and hazard analysis. Assisted in the preparation of Resource Reports 11 and 13 for CCLNG's FERC Application.

- *Creole Trail LNG Receiving Terminal.* Provides technical consulting to Cheniere Energy, Inc. for the Creole Trail LNG facility located in Cameron Parish, Louisiana. Services performed include Feasibility Study, review of preliminary design, permitting report development, code compliance, video development, community relations, and hazard analysis. Assisted in the preparation of Resource Report 13 for CTLNG's FERC Application.

- *Freeport LNG Receiving Terminal.* Provided technical support to the Freeport LNG facility for previous and existing owners. Provided extensive LNG technical support to Cheniere Energy, the initial developers of the Freeport LNG facility, including feasibility study, preliminary design, review, code compliance, video development and hazard analysis. Provided technical support at pubic meetings in Freeport, Texas. Assisted in the preparation of Resource Reports 11 and 13 for Freeport LNG's FERC Application.

- *Port Arthur LNG Receiving Terminal.* Provides support to Sempra Energy on their Port Arthur LNG facility in Port Arthur, Texas. Provided code compliance and safety services, including Vapor Dispersion/Thermal Radiation Analyses and Hazard/Threat Analysis, and assisted in the preparation of Resource Reports 11 and 13 for Port Arthur LNG's FERC Application.

- *Sabine Pass LNG Receiving Terminal.* Provides technical consulting to Cheniere Energy, Inc. on their Sabine Pass LNG facility. Services that have been performed are Feasibility Study, review of preliminary design, code compliance, video development, community relations, and hazard analysis. Represented the owner in the HAZOPs meetings and most recently have prepared Vapor

Dispersion/Thermal Radiation Analysis for the facility expansion. Assisted in the preparation of Resource Reports 11 and 13 for SPLNG's FERC Application.

Proposed LNG Import Facilities Projects (West Coast)

- *Long Beach LNG Receiving Terminal.* Provides technical consulting services to Sound Energy Solutions (SES) on their proposed Long Beach, California LNG facility. Services that have been performed include Feasibility Study, review of preliminary design, permitting report development, code compliance, video development, hazard analysis, community and government relations, liaison with California local and state officials, and assistance in the preparation of Resource Reports 11 and 13 for the facility FERC Application along with providing responses to FERC Data Requests.

- *Northern Star LNG Receiving Terminal.* Assisted Crystal Energy with Community relations in a public open house in Oregon.

- *Point Conception Receiving Terminal.* Prepared an EIR for a proposed LNG import terminal facility at Point Conception, a remote site about 40 miles west of Santa Barbara. The project included 112 miles of 34-inch natural gas pipeline needed to interconnect with existing gas company trunk pipelines. Siting of the project in an area used for ranching, recreational purposes, and low density residential development required an evaluation of impacts involving air and water quality, geo-seismic factors, marine and terrestrial biology, land use, visual aspects, socio-economics, induced growth, cultural resources, transportation impacts, and energy use. Special studies were conducted on important issues of safety and reliability of the project. Coordinated related studies performed by other contractors on marine traffic, facility security and safeguards, and energy alternatives to the project. A number of potential mitigation measures were identified and evaluated for each of the significant impacts.

Peakshaving Facilities/Utilities Projects

- *Keyspan*. Retained by Keyspan to perform a code compliance review and Rollover study of their Greenpoint LNG facility. Assisted an environmental group in preparing a threat analysis and hazard assessment of the facility.

- *South Carolina Pipeline Company (SCPC).* Retained by the SCPC to perform a Facility Code Compliance Audit for their Bushy Park and Salley LNG Peakshaving facilities. Tasks included Code Compliance review and review of existing Operation and Maintenance Procedures.

- *Williams Gas Pipeline (TRANSCO) – Station 240.* Retained by Williams to perform their five year tank inspections of the LNG storage tanks at Station 240 in New Jersey.

- *UGI Energy Services.* Provides technical consulting to UGI, including feasibility, code compliance and FERC application support on proposed LNG storage facility.

- *NFPA 59A, Ch. 9 Fire Code Compliance Audits.* Performed Ch. 9 Fire Code Compliance Audits for the following Peakshaving Facilities:

  - North Carolina Natural Gas
  - Pepco Holdings/Delmarva
  - PSNC Energy
  - Atlanta Gas Light
  - Pepco Holdings
  - Temple LNG
  - Arkansas Western
  - Pine Needle LNG
  - Baltimore Gas & Electric
  - Atmos Energy

- *Safety Analysis of LNG Peakshaving Facility*. Conducted a safety analysis of a nine-year-old LNG peakshaving facility in light of improvements in safety equipment, advances in LNG hazard estimation techniques and potential risks, if any, to a contiguous gas turbine used for peak electrical power generation. While the facility is exempt from compliance with many of the new regulatory requirements, the gas utility asked us to evaluate reasonable modifications in facility design and procedures to improve the level of facility safety.

International LNG Projects

- *AES – Dominican Republic.* Provided preliminary transshipment feasibility study to expand the AES LNG receiving terminal in the Dominican Republic to provide transshipment capabilities. The study provided economic as well as schedule predictions to accomplish modification at varying degrees of investment. Other operation optimizations were also provided.

- *Bear Head LNG Receiving Terminal.* Provided support to Access Northeast Energy, Inc. (ANE), the initial developers of the Bear Head LNG Facility in Nova Scotia. Services to ANE included internal risk assessment and regulatory code compliance. The Bear Head facility was acquired by Anadarko Petroleum. Assisted Anadarko as a third party consultant in the design review of the facility and with community relations in Nova Scotia. Prepared a Rollover Study for the facility.

- *Brass LNG Limited, Nigeria.* Supported the Environmental, Social and Health Impact Assessment of the Brass LNG Project, Nigeria, one of the recently incorporated companies in Nigeria working towards the eradication of gas flaring and economic utilization of Nigeria's vast gas resources. This environmental, social and health impact assessment of a new LNG plant to be built around the Brass River in the Niger Delta. The project includes baseline data gathering and impact analysis for offshore and onshore project environments. A waste management plan is an expected deliverable.

- *Marathon Oil Company, Environmental Monitoring Program Strategic Analysis.* Assisted this multinational oil company by developing a detailed implementation plan for environmental monitoring plan for their planned new LNG facility in Equatorial Guinea. This work involved analysis of the EIA requirements and existing data sources to derive a step by step guide to implement the key elements for the oversight of environmental protections during construction of the facility.

- *Brindisi LNG Receiving Terminal.* Retained by BG Group Italia to develop and produce an LNG Safety and Informational Video for the Brindisi LNG facility on Italy's Adriatic Coast.

- *ChevronTexaco, Multiple EIAs for Natural Gas Pipelines in West Africa.* Prepared a preliminary EIA to gain initial comment from stakeholders, including the World Bank, OPIC, and country and regional representatives. Prepared a Draft Final and Final EIA, as well as EMPs, health and safety plans, and Resettlement Action plans for each of the four countries involved in the project – Nigeria, Benin, Togo, and Ghana. Produced five separate EIAs for the West African Gas Pipeline offshore venture – one of West Africa's most significant and challenging regional energy projects. Slated to deliver natural gas from Nigeria to the other three countries, this joint pipeline project involves six energy resource companies and the governments of all the involved West African nations. The EIA effort includes environmental baseline surveys of the shorelines and impact areas (onshore and offshore), regular stakeholder consultations, impact assessments, and developing mitigation and monitoring measures. Also conducting a complete EIA to World Bank standards for Chevron Texaco Nigeria Limited's Escravos Gas-to-Liquid facility.

- *Enron – Dabhol LNG Receiving Terminal.* Served as Owner's technical advisor on code compliance and troubleshooting of India's Dabhol LNG facility. Other duties included liaison with local regulators, design review and HAZOP support.

- *Government of The Bahamas, Multiple Environmental Impact Assessments (EIAs) and Environmental Management Plans (EMPs) for Three LNG Projects.* Currently retained by the Government of The Bahamas to provide the technical expertise and support required to review, revise, and amend multiple EIAs, and also to develop and implement EMPs and Heads of Agreement (HOAs) for three large-scale LNG projects to be located in The Bahamas. Project proponents intend to import LNG to the Bahamas via marine tankers and offload LNG into cryogenic storage tanks, and produce and transport the following added value products: (1) compressed natural gas via newly constructed high pressure marine pipelines; and (2) desalinated water via newly constructed marine pipelines and LPG via marine tankers. The proposed international projects involve three energy companies as well as numerous government agencies in The Bahamas and the US.

- *Kitimat LNG Receiving Terminal.* Provided a feasibility study and preliminary design review of a Kitimat facility in Northern BC, Canada.

- *New Plymouth (New Zealand) LNG Receiving Terminal.* Provides technical consulting to the consortium Contact Energy Limited and Genesis on the New Zealand LNG facility. Services performed include feasibility study, code compliance and preliminary design.

Miscellaneous LNG Projects

- *Analysis of Market Dynamics and Regulatory Framework Associated with Importing LNG.* Assisted several other LNG import project investor groups to understand the North American gas market dynamics and regulatory framework associated with importing LNG. Using ICF's North American Natural Gas Analysis System, a large linear program of the gas production, transmission, and consuming sectors, we developed forecasts of future market conditions, with and without the LNG. These studies were supplemented by specific pipeline and gas contract assistance. We have briefed investor groups in Europe and South America on U.S. market and regulatory issues relevant to LNG.

- *Analysis of Ocean Transport of LNG*. Conducted a thorough review of the safety, technical, and economic aspects of ocean transport of liquefied natural gas for a consortium of chemical companies. The review included an evaluation of both European and American concepts. The status of each development was carefully analyzed from the standpoint of immediate versus future application; test data were gathered in every instance possible. We also performed a comparative economic analysis.

- *Assessment of U.S. LNG Market (Confidential).* Worked with a large middle eastern supplier to assess the market for LNG in the US. This work included a wide-ranging analysis of: 1) the current LNG projects under development and their likelihood of success; 2) the potential future paths for gas prices and the impact that LNG could have on that price; 3) the opportunities to invest in various aspects of the business, including gas supply, shipping, re-gasification, and marketing; 4) the different countries that can provide gas to the US and their relative competitiveness; 5) the key regulations affecting gas importation and marketing and their implications for the client; 6) the key markets for natural gas, both by region and sector, including (in detail) the electric power industry. The project provided a series of strategic recommendations on how the client could proceed to optimize their approach to the US market.

- *Barstow LNG Fueling Station.* Assisted in the design, specification, development and construction oversight for LNG/LCNG fueling facility in Barstow, California.

- *Comision Reguladora de Energia (CRE) Verification for Pipeline.* Represented US GYPSUM to CRE for safety and QA for the verification of their pipeline near Monterrey, Mexico.

- *Evaluation of Introducing Alaskan Gas to the Marketplace.* Assisted the Alaskan North Slope producers to evaluate the effect on North American gas prices and market dynamics of introducing up to 4 billion cubic feet per day of Alaskan gas to the marketplace. The study proved very useful to the clients in developing an understanding of the netback value of the gas (that is the gas value at the wellhead after subtracting all transportation costs from market prices in the end use markets). Moreover, it identified the implications of alternative strategies.

- *FERC Permitting Support, Safety Studies, and Public Involvement for an LNG Terminal*. For Enron, we conducted a number of safety studies for a proposed

LNG terminal in Puerto Rico. This work included the preparation of a LNG safety briefing that was used during the public meeting process to educate people on the safety issues associated with LNG. Prepared a detailed quantitative risk assessment for the LNG terminal that addressed hazard zones associated with the tankers, unloading operations, and onshore terminal. The risk assessment was used as part of the permitting process in Puerto Rico. Assisted Enron with FERC and DOT permitting for the facilities. This included the preparation of a number of technical studies and permit application material. The risk assessment contained several components including hazard identification (HAZOP), failure rate analysis, consequence analysis, and a quantitative risk analysis. Potential hazards to, and posed by, an adjacent refinery were also evaluated.

- *LNG Facility Due Diligence/Recommission.* Assisted Applied LNG Technologies in a due diligence of their LNG liquefaction facility in Willis, Texas for possibilities in selling and moving the facility. Owner decided to recommission facility and we provided technical support during the recommissioning and startup of the facility as well as ongoing technical assistance.

- *LNG Movement/Unloading Risk Analysis and Presentation to FERC*. For an LNG shipping company, we conducted an analysis of risks presented to people and property associated with the movement and unloading of LNG tankers in New York, Boston, and Providence harbors. The analysis included an examination of accident statistics in marine operations, as well as an engineering analysis of the probability of ship tank rupture due to collisions with various other types of vessels. The statistical information and the engineering analysis were integrated to provide a final measure of risk in that particular activity. Members of our staff presented our findings in testimony before FERC.

- *LNG Training Courses.* Retained by the Gas Technology Institute (GTI) to develop 40 hour computer based training courses for LNG Peakshaving Facilities and LNG Import Terminal Operators.

- *LNG Training.* Provided LNG training programs for:

    - Chinese Petroleum Association
    - Oman LNG
    - Egyptian General Petroleum
    - Abu Dhabi LNG
    - Montgomery County (Nova Scotia, Canada)

- *PEMEX Pipeline.* Assisted coordinated PEMEX application and managed design and government permit applications in establishing pipeline spur from PEMEX-NACO line.

- *Safety Audit of LNG Liquefaction Facility*. Conducted an independent operations and maintenance safety audit of a LNG liquefaction facility in Alaska. This work included a review of applicable regulatory requirements and a thorough, onsite review of plant operations, records, plans, and procedures in order to assess compliance with Federal codes and standards. This final safety audit provided a means by which problems involving both human and mechanical failures could be identified, with sufficient time before startup to implement minor modifications in design and procedures to improve safety.

- *Shipping Study.* Provided a review of Market and Regulatory environment for a new import concept to Leif Hoegh.

- *Ship Inspection.* Performed inspection and evaluation, due diligence for acquisition of the LNG Ship *Matthew* for Tractebel.

If you are interested in learning more about ICF's LNG group, please contact:

Technical and Engineering Ms. Sheila McClain 713-445-2016	Environmental Analysis Mr. Henry Camp 781-676-4079	Safety and Security Ms. Lisa Bendixen 781-676-4013
Gas Market Analysis Leonard Crook 703-934-3856	Peak Shaving / Gas Storage Concepts Terry Mitchell 713-445-2000	Communications and Outreach Tony Silva 202-862-1564

James P. Lewis, P.E., PEng **ICF Consulting**
Vice President

EDUCATION

BS, Mechanical Engineering, *Honor Key*, California Institute of Technology, Pasadena, California, 1955

CERTIFICATIONS AND TRAINING

Registered Professional Engineer:
- Texas (1974)
- British Columbia (1982)
- Delaware (2002)

Patent on acoustical emission NDT
Certified Level III, Homeland Security, Forensic Examiners Institute
Chief LNG Advisor, Chinese Petroleum Association

Reliability, North American Aviation
Vacuum Technology, UCLA
Proposal Writing Techniques, UCLA
Cryogenic Engineering, UCLA
Project Management, AIChE
LNG Firefighting School, Texas A&M (instructor)
Non-destructive Evaluation, University of Houston
LNG/Cryogenic Processing, Lehigh University
Programming for Univac 1007

EXPERIENCE OVERVIEW

Mr. Lewis has over 50 years of experience in the industry, including natural gas, LNG, LPG and petroleum facilities as well as thermal and nuclear projects. With over 27 years of LNG consulting experience, his primary focus is on project development, process engineering and instrumentation, cryogenic technology, economics, safety, accident investigation, litigation support, regulatory compliance, testing, quality assurance and personnel training. His primary activities are LNG related, including liquefaction, storage, export/import terminals, peakshaving, remote baseload satellites and LNG for vehicle fuel.

Mr. Lewis has served on several codes, standards and industry facilities committees, including those for LNG and supplemental fuels. He has assisted with contracts and negotiations for LNG and gas sales contracts. Projects have included export, import, peakshaving, satellite and vehicle fuel. Clients have been primarily project owners.

Mr. Lewis has played a key role in several LNG siting studies for projects in the U.S., Mexico, Brazil, New Zealand, British Columbia and Nova Scotia for both on-shore and marine terminals. Mr. Lewis serves on several committees including NFPA 59A (LNG), NFPA 58/59 (LPG), NFPA 52/57 (NGVs) and CSA Z-276 (LNG).

PROJECT EXPERIENCE

<u>Peakshaving Plant, Confidential Client, 2003 – 2005</u>. New LNG peakshaving plant in the US northeast including liquefaction and capability for trucking and barging. Site/environmental evaluation, site acquisition, layout optimization, preliminary design code compliance, gas quality, estimating and government relations.

<u>Gulf Coast Import, Cheniere, 2002 – 2005</u>. Technical support for four US Gulf Coast LNG import terminals including preliminary design, ship handling, code compliance, design review and HAZOPs.

<u>LNG Transhipment Terminal, Confidential Client, 2005</u>. Feasibility study for LNG transhipment to receive LNG from large, long haul LNG carriers with loading smaller LNG carriers to US terminals with draft and receiving capacity limitations.

<u>Long Beach (CA) LNG Import Terminal, Sound Energy Solutions (Mitsubishi/Conoco Phillips), 2002 – 2005</u>. Lead roll in LNG import Project conception, preliminary design, safety analysis, re-siting, seismic, FERC application, interchangeability/stripping and community relations. Liaison with California Energy and Port of Long Beach plus countering opposition of California Coastal Commission and Public Utilities Commission. Contributed safety/security portions of EIS.

Bear Head LNG, Anadarko Pet (and previous owner Access Northeast Energy), 2003 – 2005. Lead role in siting and hazard evaluation on community/government relations for ANE. Design review, code compliance and community relations for Anadarko. Located near Port Hawkesbury in Nova Scotia.

SELECTED PUBLICATIONS AND PRESENTATIONS

Lewis, James, "Satellite Peakshaving with LNG Has Many Economic Advantages", *American Gas Journal*
Lewis, James, "LNG for Vehicle Fuel, Fact of Fancy", *American Gas Journal*
Lewis, James, "Economics of LNG Production and Distribution for Remote Satellite Operations", *Gas Magazine*
Lewis, James, "Imported LNG for Peakshaving in New England Planned by Distrigas", *American Gas Journal*, 1970
Lewis, James, *AGA LNG Information Book*, edited by James P. Lewis and Review Committee, 1972
Lewis, James, "LNG Chapter", *AGA Gas Engineering and Operating Practice Handbook*, edited by James P. Lewis and Review Committee, 1983
Lewis, James, "NGV Program Shows Promise in Uzbekistan", *Natural Gas Fuels*, 1993
Lewis, James, 15 Miscellaneous Articles, *Cold Corner Column/ Natural Gas Fuels*, 1993-1995
Lewis, James, "LNG Facilities – The Real Risks", *LNG Journal*, 2003
Lewis, James, "Satellite Peakshaving and Remote Base Load with LNG", London LNG Conference
Lewis, James, "First LNG Importation Into the U.S.", London LNG Conference
Lewis, James, "High Volume Lifting Equipment and Methods", API Technical Paper 801-37P
Lewis, James, "Progress Report on Distrigas", New England Gas Association, November, 1970
Lewis, James, "Distrigas Readies for First Imports", Pacific Coast Gas Association, May, 1971
Lewis, James, Session Chairman, Operating Division, American Gas Associations
Lewis, James, Keynote Speaker, Joint ASME, API Cryogenics Seminar, September, 1971
Lewis, James, Thermodynamic Properties Handbook, Distrigas, 1971
Lewis, James, Measurement Handbook, Distrigas, 1971
Lewis, James, "A New Correlation of Heating Values for LNG Custody Transfer", Cryogenic Engineering Conference, 1973
Lewis, James, "Mixing and Rollover in LNG Storage Tanks", Cryogenic Engineering Conference, 1973
Lewis, James, "LNG Fundamentals", Lecturer on LNG Terminaling, IGT, 1974
Lewis, James, "Geysering in Large Diameter LNG Lines", AGA Spring Conference, 1975 AGA Operation Section
Lewis, James, "Contingency Plans", Lecturer, IGT Symposium, January, 1975
Lewis, James, "LNG Fundamentals", Texas A&M Marine LNG Firefighting School, 1977, 1978
Lewis, James, "Contingency Planning," Texas A&M Industrial LNG Firefighting School, 1979
Lewis, James, "LNG Properties and Practices", Texas A&M Marine LNG Firefighting School, 1977, 1978
Lewis, James, "LNG Properties and Practices", Marine Safety International LNG Cargo Handling School, 1978
Lewis, James, "Liquefied Natural Gas", Virginia Industrial Development Division, 1977
Lewis, James, "LNG Facilities and Fundamentals", International Society of Fire Service Instructors Annual Meeting, 1979
Lewis, James, "Utilization of Gas Reserves", AGA Spring Conference, 1980
Lewis, James, "A Technical and Economic Evaluation of the Utilization of Offshore Natural Gas Reserves", OTC, 1981
Lewis, James, "Present Practices and Future Uses of LNG", GRI delegation to Peoples' Republic of China, 1982
Lewis, James, "LNG/LPG Storage & Safety", Energy-Sources Technology Conference, February, 1987
Lewis, James, "Evaluation of Decommissioned LNG Storage Tanks at Chula Vista, California", AGA, 1991
Lewis, James, "Liquefied Natural Gas Vehicle Experience of a Large Transit Fleet", Amer. Gas Assoc., May, 1992
Lewis, James, "LNG Safety Symposium Panel", Moderator, Safety Aspects of Alt. Fueled Vehicles, May, 1994
Lewis, James, "Development of Safety Standards for LNG Vehicles and Refueling Facilities", NGV 94, 1994
Lewis, James, "LNG Fundamentals", Short Course, Minneapolis, MN. August, 1995
Lewis, James, "LNG and Other Fuels: A Comparison of Hazards & Risks", Minneagasco LNG Conf. August, 1995
Lewis, James, "Innovations and Progress in Small underground Storage", AGA Operations Conference, 1996
Lewis, James, "Innovations in LNG Underground Storage", Heavy-Duty Transportation, 1996
Lewis, James, "Small Underground LNG Tanks", AGA Operations Conference, Quebec, May, 1996
Lewis, James, "Potential Impact of NGV on World LNG Trade", Gastech '96 Conference, Vienna, Austria, December, 1996
Lewis, James, "Underground LNG Storage System Evaluation", Gas Research Institute, February, 1997

Lewis, James, “Rollover Update of Current Technology”, Gas Research Institute, September, 1995
Lewis, James, “Cellular Glass Foam Insulation Analysis and Life Extension Factors for LNG Storage Tanks”, GRI, 1996
Lewis, James, “LNG Technology & Operations”, 5 Day Course: Oman LNG Jan. 1997, ADGAS March, 1997
Lewis, James, LNG Plant Operator Training, Gas Technology Institute (GTI) 2002
Lewis, James, “LNG, The Real Risks”, Gastech 2002, Doha, October, 2002
Lewis, James, “LNG Security, Reality & Practical Approaches”, SRI LNG Conference, Houston, Texas, January, 2003
Lewis, James, “LNG, The Real Risks”, AIChE Spring Meeting, New Orleans, Louisiana April, 2003
Lewis, James, LNG Technology and Construction Risks Seminar, Client, April, 2004
Lewis, James, “Critical Path for Terminal Development and the Costs and Benefits of Expediting It”, Zeus Workshop Lewis, James, “Expediting U.S. LNG Terminal Construction”, July, 2004
Lewis, James, “LNG Safety for LNG Import Terminals”, Municipality of Montgomery County, NS, July, 2004
Lewis, James, “LNG Ship Safety”, National Academy of Science, August, 2004
Lewis, James, LNG Safety Symposium, Passamaquody Indian Tribe, Perry, ME, February 2005
Lewis, James, “LNG Fundamentals and Codes” Cheniere Petroleum Society, Beijing, March 2005
Lewis, James, LNG Fundamentals Lecture and Line Demonstration, Cathlemet WA, May 2005
Lewis, James, “Distributed Gas Storage Using LNG” Florida Utility Group, May 2005
Lewis, James, “LNG Safety and Security” National Academy of Science, Washington DC, June 2005
Lewis, James, Video “LNG” for Brindisi Import Terminal, Italy, June 2005
Lewis, James, “LNG Terminal Security”, EU LNG Terminal Conference, Barcelona, Spain, July 2005
Lewis, James, “LNG Characteristics and Safety Issues” Port Hawkesbury and For First Nations communities, Nova Scotia, September 2005

AWARDS

Honorable Mention, Monument to American Civil Engineering, ASCE Foundation, 2004

PROFESSIONAL AFFILIATIONS

American Society of Mechanical Engineers (ASME)
American Institute of Chemical Engineers
Society of Naval Architects and Marine Engineers (SNAME)
National Fire Protection Association (NFPA)
Canadian Standards Association (CSA Z276)
American Gas Association
Gas Research Institute (GRI)
American National Standards Institute (ANSI)
Railroad Commission of Texas
New York Academy of Sciences
International Association of Natural Gas Vehicles (IANGV)
Natural Gas Vehicle Coalition
American Society for Testing Materials (ASTM)
American Society for Metals
Seismological Society of America
Earthquake Engineering Research Institute
Texas A&M Firefighting School
International Society of Fire Service Instructors

EMPLOYMENT HISTORY

ICF Consulting	Vice President	2005-Present
Project Technical Liaison Associates, Inc.	Chairman/CEO	1978-2005
Transco Energy Company	Manager, LNG Projects	1972-1978
Distrigas Corporation	Technical Director	1969-1972
Cosmodyne Corporation	Assistant Chief Engineer	1962-1969
Richfield Oil Corporation	District Mechanical Engineer	1955-1962

Rebecca S. Wyman, P.E. **ICF Consulting**
Principal

EDUCATION

MS, Chemical Engineering, Rice University, Houston, Texas, 1980
BS, Chemical Engineering, Rice University, Houston, Texas 1979

EXPERIENCE OVERVIEW

Ms. Wyman has over 25 years of experience in chemical and natural gas industry with a primary focus on process engineering. Her broad experience in the design and construction of a wide variety of process and chemical plants has provided valuable contributions to the LNG industry. She is considered an expert in LNG hazard analysis (thermal radiation and flammable vapor dispersion), risk analysis and code compliance. She is active in the technical committees for both the U.S. and Canadian LNG codes. Ms. Wyman has prepared safety portions of several LNG plant applications to U.S. and Canadian government. She also provides vapor dispersion/thermal radiation analysis and serves as liaison to clients and regulatory agencies.

PROJECT EXPERIENCE

LNG Receiving Terminal (Canada), 2006. Using Canadian codes and Nova Scotia regulations, developed redesign concepts for consequence analysis and risk reduction.

LNG Receiving Terminal (New Zealand), 2005-2006. Developed hazard consequence analysis and risk assessment for placing LNG berth in existing industrialized port and LNG storage adjacent to an existing power plant.

LNG Storage Facility (US), 2005-2006. Developed innovative diking system to allow exclusion zones to be contained on a restricted site.

Cheniere Sabine LNG Initial Project and Expansion, Cheniere Energy, 2003-2005. Performed vapor dispersion and thermal radiation calculations, prepared RR13 Spill Containment report for Environmental Impact Statement, threat analysis, and Fire and Hazard Drawings, Matrix and wording for RR13.

Cheniere Creole Trail LNG, Cheniere Energy, 2004-2005. Performed vapor dispersion and thermal radiation calculations, prepared RR13 Spill Containment report for Environmental Impact Statement and Fire and Hazard Drawings, Matrix and wording for RR13.

Cheniere Corpus Christi Trail LNG, Cheniere Energy, 2003-2004. Performed vapor dispersion and thermal radiation calculations, prepared RR13 Spill Containment report for Environmental Impact Statement and Fire and Hazard Drawings, Matrix and wording for RR13.

Freeport LNG Initial Project and Expansion, Cheniere Energy, 2003-2005. Performed vapor dispersion and thermal radiation calculations, prepared RR13 Spill Containment report for Environmental Impact Statement and Fire and Hazard Drawings, Matrix and wording for RR13.

Cameron LNG Initial Project and Expansion, Sempra, 2003-2005. Performed vapor dispersion and thermal radiation calculations, prepared RR13 Spill Containment report for Environmental Impact Statement, threat analysis and Fire and Hazard Drawings, Matrix and wording for RR13.

Broadwater LNG Project, TransCanada, 2005. Performed vapor dispersion and thermal radiation calculations, prepared RR13 Spill Containment report for Environmental Impact Statement, Reviewed RR13 Sections on Fire and Hazard, Regulatory Compliance, ESD Systems.

OTHER RELEVANT EXPERIENCE

Ms. Wyman has been instrumental in developing more sophisticated risk assessment techniques which take into account the risk impact of wind direction and occurrence frequency as an option to omni directional conventional practice.

EMPLOYMENT HISTORY

ICF Consulting	Principal	2005-Present
Project Technical Liaison Associates, Inc.	Engineering Analyst	2003-2005
Jacobs Engineering	Senior Process Engineer	2001-2003
Herzog Hart/CDI	Senior Process Engineer	1999-2000
CE&IC, Inc.	Senior Process Engineer	1998-1999
Onyx Engineering	Senior Process Engineer	1996-1997
S&B Engineers and Constructors	Senior Process Engineer	1989-1996
The M.W. Kellogg Company	Process Engineer	1980-1982
Coastal States Petrochemical Co.	Process Engineer	1979
Celanese Chemical Company	Process Engineer	1978

APPENDIX C

Quest Consultants Siting Study

SITING STUDY FOR THE GRASSY POINT LNG TRANSSHIPMENT AND STORAGE TERMINAL

FINAL

Prepared For

Newfoundland LNG LTD.
Suite 302, Baine Johnston Centre
10 Fort William Place
St. John's, NL
Canada A1C 1K4

Prepared By

Quest Consultants Inc.®
908 26th Avenue N.W.
Norman, Oklahoma 73069
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07-11-6654
November 1, 2007

QUEST

SITING STUDY FOR THE GRASSY POINT LNG TRANSSHIPMENT AND STORAGE TERMINAL

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SITING STUDY FOR THE GRASSY POINT LNG TRANSSHIPMENT AND STORAGE TERMINAL

1.0 INTRODUCTION

Newfoundland LNG Ltd. has proposed the Grassy Point LNG transshipment terminal, to be located on Placentia Bay, Newfoundland. Although the proposed facility's function is unique among LNG terminals, the potential hazards are similar to the many active LNG import and export terminals around the world. The historical safety record of these facilities has been excellent—not a single member of the public has ever been fatally injured as a result of a spill, fire, or explosion at any liquefied natural gas import facility. This record is due in part to the design codes followed by the designers, constructors, and operators of these facilities. The code referenced in this report is CSA Z276-07, *Liquefied Natural Gas (LNG)—Production, Storage, and Handling*. This code contains requirements related to siting, design, construction, fire protection, and safety. CSA Z276-07 is closely modeled after NFPA 59A. NFPA 59A is designated as a supplementary standard for this project, and as so, will be referenced in this study as needed.

This report presents the results of a study conducted to:

- determine if CSA Z276-07 requirements regarding thermal radiation exclusion zone distances and flammable vapor clouds could be met by the facility design, at the Grassy Point site;
- provide hazards analysis results that might be of assistance in the general layout of the facility.

The scope of this analysis covers the transshipment facility in its fully built-out future state (Stage 3D), which includes three ship berths, eight LNG storage tanks, boil-off gas handling equipment, booster pumps, and the code-required impounding or drainage systems for each of these areas.

2.0 DESCRIPTION OF THE LNG FACILITY

The site of the proposed Grassy Point transshipment terminal is on a peninsula in Placentia Bay, approximately 2 kilometers southwest of the town of Arnold's Cove. A general site layout showing the facility and surrounding area is presented in Figure 2-1. The facility, in Stage 3D, will include three LNG tanker berths, each capable of berthing one 265,000 m^3 tanker, and one 140,000 m^3 tanker. This allows direct ship-to-ship transfers of LNG. Each berth will also be equipped with five articulated metal loading/unloading arms to transport LNG from a tank ship to LNG storage tanks, or to a tanker at another berth, at rates up to 15,000 m^3/hr. The terminal will store LNG in up to eight 160,000 m^3 cryogenic storage tanks. The storage tanks are to be single containment design with a dike wall surrounding each tank. Each diked area will be capable of holding the entire contents of the tank it surrounds. The tanks are to use submersible, in-tank pumps, with all inlet and outlet connections passing through the domed roof of the tank (i.e., over-the-top connections).

The Grassy Point facility will be equipped with boil-off gas (BOG) handling equipment and a nitrogen-cycle liquefaction unit to re-liquefy gases generated as a natural result of heat gain in the storage tanks. Following compression and refrigeration, the liquefied gases are returned to storage. Four desuperheater vessels use a small supply of LNG to chill vapors going to the BOG system and to each of the three vapor return lines at the unloading platforms. Also included in the facility is a small vaporization system that provides fuel gas for power generation.

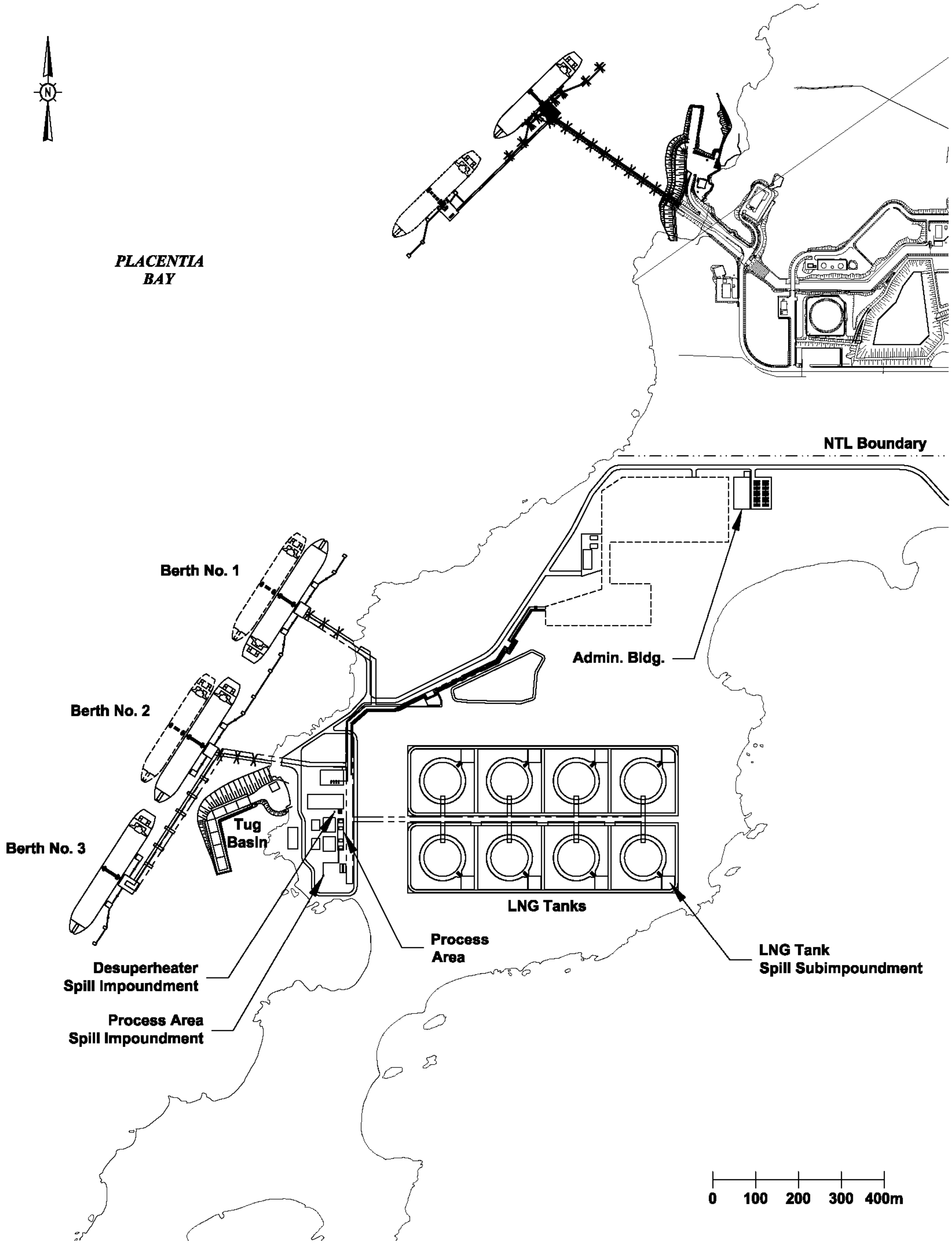

Figure 2-1
Layout of the Grassy Point LNG Transshipment Terminal

3.0 LNG CODE GUIDELINES

This section discusses CSA Z276-07 requirements for siting.

3.1 Impounding Systems Required by CSA Z276-07

CSA Z276-07 requires any LNG container, process area, vaporization area, or transfer area to have an impounding system capable of containing the quantity of LNG that could be released by a credible incident involving the component served by each particular impounding system. According to the definitions in the code, an LNG container is any vessel used for storing liquefied natural gas. A transfer area is defined as any area where LNG or other flammable liquid is introduced to or removed from the facility. Transfer areas do not include permanent plant piping. Process areas would include pump installations and process vessels that contain LNG, but are not used for LNG storage. Thus, within the scope of this analysis, for the Grassy Point transshipment facility, LNG spill impounding systems would need to be provided for the following equipment.

- LNG storage tanks
- LNG storage tank pumps
- BOG desuperheater vessel
- Liquefaction cold box
- LNG pumps and vaporizer for fuel gas system
- Desuperheater vessel for vapor return at each jetty head
- LNG transfer arms at each jetty head

Each of the areas listed above must have an LNG spill impounding system, although each one is not required to have its own, separate impounding system. CSA Z276-07 does not prohibit one impounding system from serving two or more areas. In such cases, spills of LNG would be directed to one or more shared impounding basins by the use of curbing and drainage trenches (channels).

For LNG containers (i.e., storage tanks) that do not share impoundments, the impoundment sizing requirements are very simple.

> 5.2.2.1 Impounding areas serving LNG containers shall have a minimum volumetric holding capacity, V, including any useful holding capacity of the drainage area, and with allowance made for the displacement of snow accumulation, other containers, and equipment, in accordance with the following:
>
> (a) 110% of the LNG container's maximum capacity, for impounding areas serving a single container, or
> (d) 100% in lieu of 110% .... if the impoundment is designed to account for a surge in the event of a catastrophic failure.

This requirement is satisfied at the Newfoundland LNG site by a 149 meter by 149 meter diked area surrounding each LNG storage tank. To provide 110% of the storage tank's volume, the dike walls must be approximately 8 meters tall.

Requirements for impounding systems for process areas and transfer areas are basically the same. Therefore, the following discussion pertains to the impounding systems for all of them.

> 5.2.2.2 Impounding areas, if provided to serve only vaporization, process, or LNG transfer areas, shall have a minimum volumetric capacity equal to the greatest volume of LNG, flammable refrigerant, or flammable liquid that can be discharged into the area during a 10 minute

> period from any single accidental leakage source or during a shorter time period based upon demonstrable surveillance and shutdown provisions.

Although CSA Z276-07 does not require impounding systems to be provided for permanent piping, the single accidental leakage source normally assumed for the purpose of computing the minimum acceptable volumetric capacity of an impounding system for process equipment is taken to be the full rupture of the largest diameter pipe connected to the process equipment. Impoundment sizing for design spills is discussed in section 3.2.

The liquid containment portion of an LNG spill impounding system required by CSA Z276-07 need not be located such that it surrounds the container or piece of equipment that is assumed to be the leak source, so long as that container or piece of equipment is surrounded by a drainage system that will direct any released LNG to an impounding area of sufficient volume. Such systems are often used for impounding spills from process or transfer areas. This analysis is based on having a total of thirteen impoundments basins at the following locations within the Grassy Point facility:

- One impoundment serving the fuel gas LNG pumps and vaporizer in the process area
- One impoundment serving the BOG desuperheater vessel
- One at each ship berth LNG transfer point (also collects spills from the desuperheater vessel)
- One within each LNG storage tank's diked area (to collect spills from the storage tank discharge piping).

3.2 CSA Z276-07 Design Spills and Impoundment Sizing

Release rates from the LNG storage tank, process, and transfer areas were taken as the flow from a single accidental leak source with pumps delivering at their full rated capacity, as based on Table 2 in CSA Z276-07, referenced in section 5.2.3.4.

According to Z276 Table 2, for an impounding area serving a single-containment LNG container with over-the-top connections, and no penetrations below the liquid level, the design spill is defined in as:

> The largest flow from any single line that could be pumped into the impounding area with the container withdrawal pump(s) considered to be delivering the full rated capacity.

The design spill duration is to be set at 10 minutes if "demonstrable surveillance and shutdown provisions exist," otherwise the duration shall be "the time needed to empty a full container, where demonstrable surveillance and shutdown provisions do not exist."

For all other locations (impounding areas serving vaporization, process, or LNG transfer areas), the design spill is defined in Z276 Table 2 as "the flow from any single accidental leakage source." Table 2 also says to "[u]se flow from 10 min, or a shorter time, where demonstrable surveillance and shutdown provisions exist."

To maintain compliance with CSA Z276-07 requirements, this LNG facility will be equipped with a comprehensive spill detection system and an emergency shutdown system. In the event of a large LNG spill, these systems should be capable of detecting the spill and initiating an emergency shutdown (thereby isolating the release source) in less than three minutes. Thus, the sizes of design spills and volumes of impounding systems for process and transfer areas could be based on a three minute spill time, with allowances for drainage of LNG from piping and for rainwater. The ten-minute duration is the minimum value for the storage tank pumpout spill, although the surveillance and shutdown systems should be able to detect and isolate this spill long before ten minutes has elapsed.

To minimize a possible LNG spill from the loading arms at the marine transfer area, powered emergency release couplings (PERCs) will be installed in the loading arms. PERCs are standard design for modern LNG terminals. With these devices, a leak or rupture within the transfer system can be quickly shut down. Because this area is continuously manned during transfer operations, and the PERC devices can be triggered based on several signals, (e.g., gas detection, low temperature, ship movement), a large spill would be unlikely to last longer than one minute. Thus, a one-minute duration was selected for this spill scenario. In order to contain a one-minute spill from a failed loading arm, each marine transfer area (jetty head) will require some type of impoundment. This is normally accomplished by using a curb on the loading/unloading platform, underneath the loading arms. Based on the dimensions of the loading/unloading platforms, a curbed area of 25 meters by 15 meters was assumed. In order to contain a one-minute spill at the full unloading rate, the curb should be 0.7 meters tall.

There are three spill scenarios that could occur in the process area. In the first scenario, a release downstream of the BOG reliquefaction cold box releases liquid at the reliquefaction rate until the system is shut down (assumed to be 3 minutes). The second scenario involves a release from the Fuel gas vaporizer system, anywhere between the LNG pump and the vaporizer. The spill rate from this scenario is equal to the pumping rate, and is assumed to last 3 minutes. The last scenario is a spill from the LNG line supplying the BOG desuperheater, at the rate it is supplied to this vessel, also for 3 minutes. Due to the physical separation between the desuperheater and the cold box and vaporizer system, the desuperheater requires its own spill impoundment.

Table 3-1 presents the sizing and modeling parameters associated with the CSA Z276-07 design spill impoundments.

Table 3-1
Design Spill Impoundment Modeling Parameters

Description	LNG Flow Rate [m^3/hr]	Duration [minutes]	Impoundment Size [meters]	Basis
10-minute tank pumpout spill subimpoundment	15,000	10	30 x 30 x 3	Full pumpout rate
Process area impoundment	109	3	2.5 x 2.5 x 1	Cold box outlet (also contains the vaporizer system spill)
Desuperheater impoundment	46	3	2.2 x 2.2 x 0.5	Liquid supply to desuperheater
Marine transfer area impoundment	15,000	1	25 x 15 x 0.7	Single loading arm failure (also contains the desuperheater supply line spills)

3.3 CSA Z276-07 LNG Pool Fire Scenarios

Clause 5.2.3.2.1 and Table 1 of CSA Z276-07 require thermal radiation exclusion zone distances be calculated for each impounding area required by 5.2.2.1 and for ignition of the design spills defined in 5.2.3.4. Impounding area calculations are based on the assumption that the impounding area contains LNG (based on the design spills or a storage tank failure) and the LNG is burning.

Paragraph 5.2.3.1 also states that the provisions of paragraph 5.2.3.2 through 5.2.3.7 do not apply to impounding areas serving only marine transfer areas. This exclusion means that a siting study need not calculate thermal radiation distances for fires at marine transfer areas. Thus, four thermal radiation calculations were made: one for each process area impoundment, one for the ten-minute storage tank pumpout spill into a subimpoundment, and one for a fully-involved storage tank impoundment fire.

3.4 CSA Z276-07 LNG Vapor Dispersion Scenarios

For vapor dispersion exclusion zones, clause 5.2.3.3 of CSA Z276-07 requires that

> The spacing of an LNG tank impoundment area relative to a property line that can be built upon shall be such that, in the event of a design spill as defined in Clause 5.2.3.4, an average concentration of methane in air of 50% of the lower flammability limit (LFL) does not extend beyond the property line that can be built upon at an elevation above grade.

Clause 5.2.3.3 only specifically requires vapor dispersion calculations for "LNG tank impoundments," but it is assumed that the intent of the code would include vapor dispersion exclusion zone calculations for all design spills specified in clause 5.2.3.4. According to clause 5.2.3.1, no vapor dispersion calculations are required for the impoundments located at the marine transfer areas. Thus, four vapor dispersion exclusion zone distance calculations were included in this study: one for each of the spills that could flow into the process area impoundment, one for the desuperheater impoundment, and one for the ten-minute storage tank pumpout spill into a subimpoundment.

4.0 CONSEQUENCE MODELING

The focus of this analysis was to estimate potential hazards resulting from releases of LNG, as required by CSA Z276-07. The hazards include thermal radiation and flammable vapor dispersion, whose effects are to be evaluated to ensure that they do not adversely affect areas outside of the facility's property line.

CSA Z276-07 requires that thermal radiation distances be calculated using the model described in the GRI Report 89/0176, i.e., LNGFIRE3, <u>or</u> by using a model that accounts for impoundment configuration, wind speed, humidity, and atmospheric temperature, and has been validated with experimental test data. This study used the LNGFIRE3 model for calculating all thermal radiation exclusion zone distances.

The note at the end of paragraph 5.2.3.3 refers to a vapor dispersion model described in the GRI Report 89/0242. This model is known as the DEGADIS vapor dispersion model. Although its use is not required by CSA Z276, the vapor dispersion exclusion zone distance calculations in this study used the DEGADIS model. This DEGADIS is the original version (as described in the GRI report) that has been made available on the U.S. EPA's website. It has not been modified or upgraded in any way.

4.1 Modeling Parameters

CSA Z276-07 requires the calculation of fire radiation exclusion zones based on the use of weather conditions as defined in paragraph 5.2.3.2.1.

> (a) the wind speed producing the maximum exclusion distances shall be used, except for wind speeds that occur less than 5% of the time based on recorded data for the area; and
> (b) the ambient temperature and relative humidity that produce the maximum exclusion distances shall be used, except for values that occur less than 5% of the time based on recorded data for the area.

Weather data for the Arnold's Cove area was found in the AMEC Earth & Environmental report *Physical Environmental Description of the Grassy Point LNG Terminal*, dated 13 July 2007. The values that were determined for compliance with 5.2.3.2.1(a) and (b) are:

Wind speed	12 m/s
Air temperature	-10ºC
Relative humidity	30%

Hourly observations of wind speed over a 20 year period were available to determine the 5% exceedance value. Air temperature data were not available in this form, and no data was provided for relative humidity. The requirements of 5.2.3.2.1(b) are intended to force the use of the reasonable lowest value of absolute humidity (the true amount of water in the air due to a relative humidity at a temperature). Low absolute humidity results in higher radiative flux values at a distance due to lower amounts of radiation being absorbed by water vapor in the atmosphere. With this basis, -10°C and 30% relative humidity were chosen as reasonable low values, taking into account the annual average recorded low and monthly extreme minimum temperatures for the area.

The wind speed, atmospheric stability, and relative humidity to be used when calculating the extent of each vapor dispersion exclusion zone are not specified in CSA Z276-07. For this study, the following conditions (representing severe weather conditions for dispersion, and specified in NFPA 59A) were used for all vapor dispersion calculations.

Wind speed	2 m/s
Atmospheric stability	Pasquill-Gifford Class F
Air temperature	15ºC (summer temperature for the site)
Relative humidity	50% on land; 70% over water (assumed values)

4.2 Hazard Endpoints

CSA Z276-07 provides specific guidelines with respect to the maximum thermal radiation flux levels that are acceptable at specific locations. Table 4-1 provides a list of the endpoints used in this analysis (30, 9, and 5 kW/m^2), and their associated meanings, taken directly from Z276's Table 1.

Table 4-1
Thermal Radiation Flux Endpoints

Flux Level [kW/m^2]	Thermal Radiation Exposure Limit Location
30	At a property line that can be built upon, for a fire over an impounding area containing a volume, V, of LNG determined in accordance with Clause 5.2.2.1 (storage tank impoundment).
9	At the nearest point of the building or structure outside the owner's property line that is in existence at the time of plant siting and used for occupancies classified by NFPA Standard 101 as assembly, educational, health care, detention or correction, or residential, for a fire over an impounding area containing a volume V, of LNG as determined in accordance with Clause 5.2.2.1 (storage tank impoundment).
5	At the nearest point outside the owner's property line that, at the time of plant siting, is used for outdoor assembly by groups of 50 or more persons, for a fire over an impounding area containing a volume, V, of LNG determined in accordance with Clause 5.2.2.1 (storage tank impoundment).
	At a property line that can be built upon, for ignition of a design spill (as specified in Clause 5.2.3.4).

Paragraph 5.2.3.3 states that “an average concentration of methane in air of 50% of the lower flammable limit (LFL)” cannot “extend beyond a property line that can be built upon.” Thus, ½ LFL is defined as the vapor dispersion endpoint for all design spills.

4.3 Results for LNG Storage and Impoundment Scenarios

The size of the flammable vapor cloud created by a release of LNG depends on several factors, including the rate at which LNG vapor is introduced into the air and the weather conditions. The rate at which LNG will vaporize upon release is the sum of the vaporization rate due to flashing and the rate of vaporization due to heat transfer from the impounding system. The rate of vaporization due to heat transfer from the impounding system to the LNG depends on the release rate and the size, shape, materials of construction, and surface temperature of the impounding system. The vaporization rate due to flashing is controlled by the LNG release rate and the temperature of the LNG prior to its release. If the LNG is superheated, some of the released LNG will flash to vapor. As the amount of superheat increases, the percentage of LNG that will flash to vapor (upon release) also increases. For example, releases downstream of the LNG tank pumps were found to have a flash of 1.0 percent.

LNG release rates in the LNG storage tank and process areas were taken as the flow from a single accidental leak source with pumps delivering at their full rated capacity (as required by clause 5.2.3.4). Using these assumptions, distances from each of the site LNG impoundment areas to the ½ LFL vapor concentration were computed.

Table 4-2 presents the computed flammable mixture dispersion distances for the CSA Z276-07 design spills considered in this study. Each spill impoundment was assumed to be constructed of regular concrete (i.e., low-density or insulating concrete was not used). Figure 4-1 shows the flammable vapor cloud exclusion zones superimposed on a plot plan of the Grassy Point facility.

Table 4-3 presents the predicted thermal radiation hazard distances for the LNG design spill pool fire scenarios considered in this study. These distances, displayed as exclusion zone circles, are shown on the plot plan in Figures 4-2 and 4-3.

Table 4-2
CSA Z276-07 LNG Vapor Dispersion Analysis Summary for Design Spills
(2.0 m/s Winds; F Atmospheric Stability)

Description	Impoundment Dimensions [meters]	Distance from Center of Impoundment to ½ LFL [meters]
10-minute spill from LNG tank outlet piping into impoundment	30 x 30 x 3	†
3-minute spill from the liquefaction cold box outlet	2.5 x 2.5 x 1	132
3-minute spill from the fuel gas vaporizer LNG supply line		111
3-minute spill from the desuperheater supply line	2.2 x 2.2 x 0.5	69

† A spill into a subimpoundment within the main diked area results in no flammable concentrations beyond the limits of the main diked area.

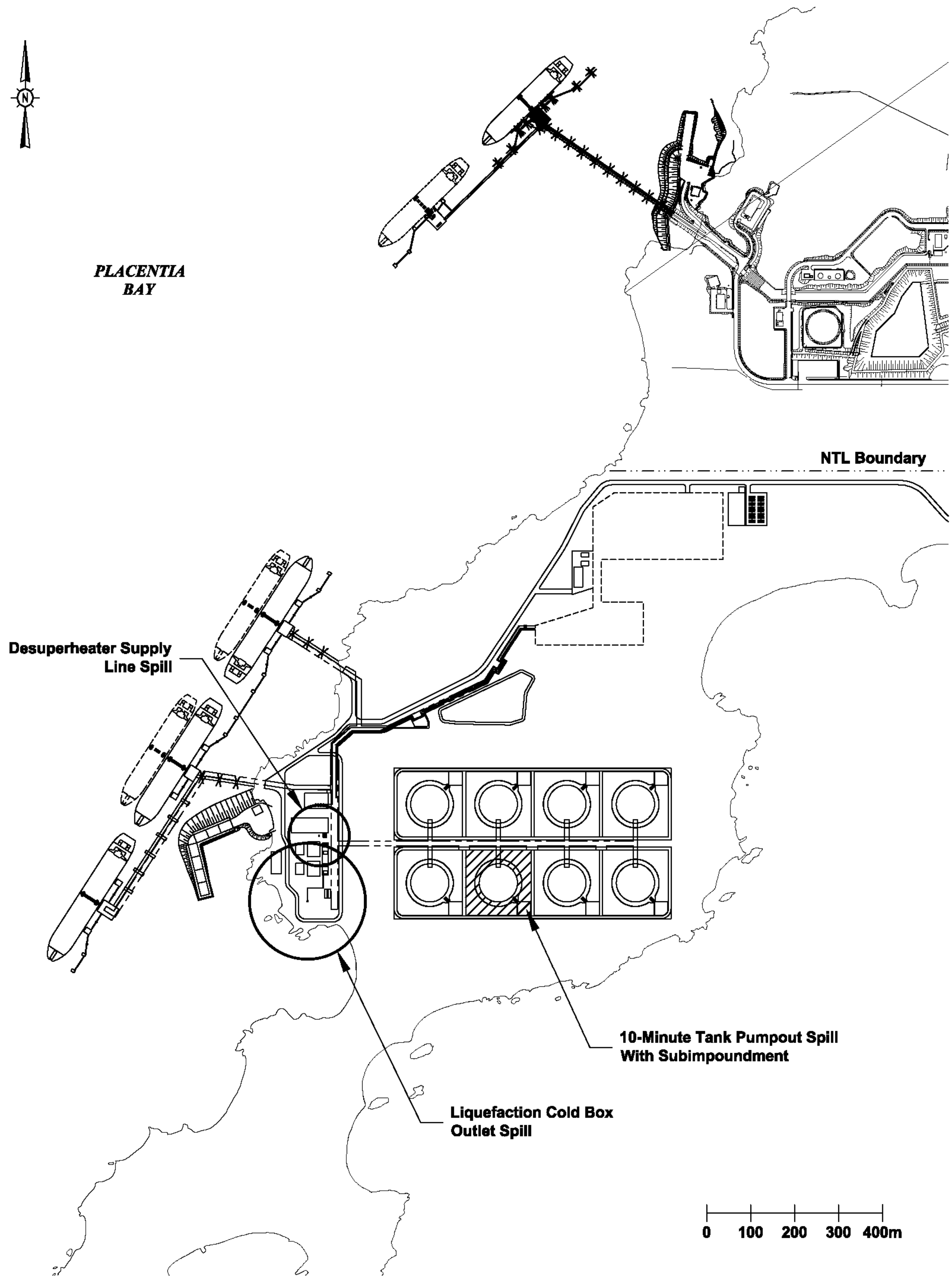

Figure 4-1
½ LFL Flammable Vapor Exclusion Zones for CSA Z276-07 Design Spills

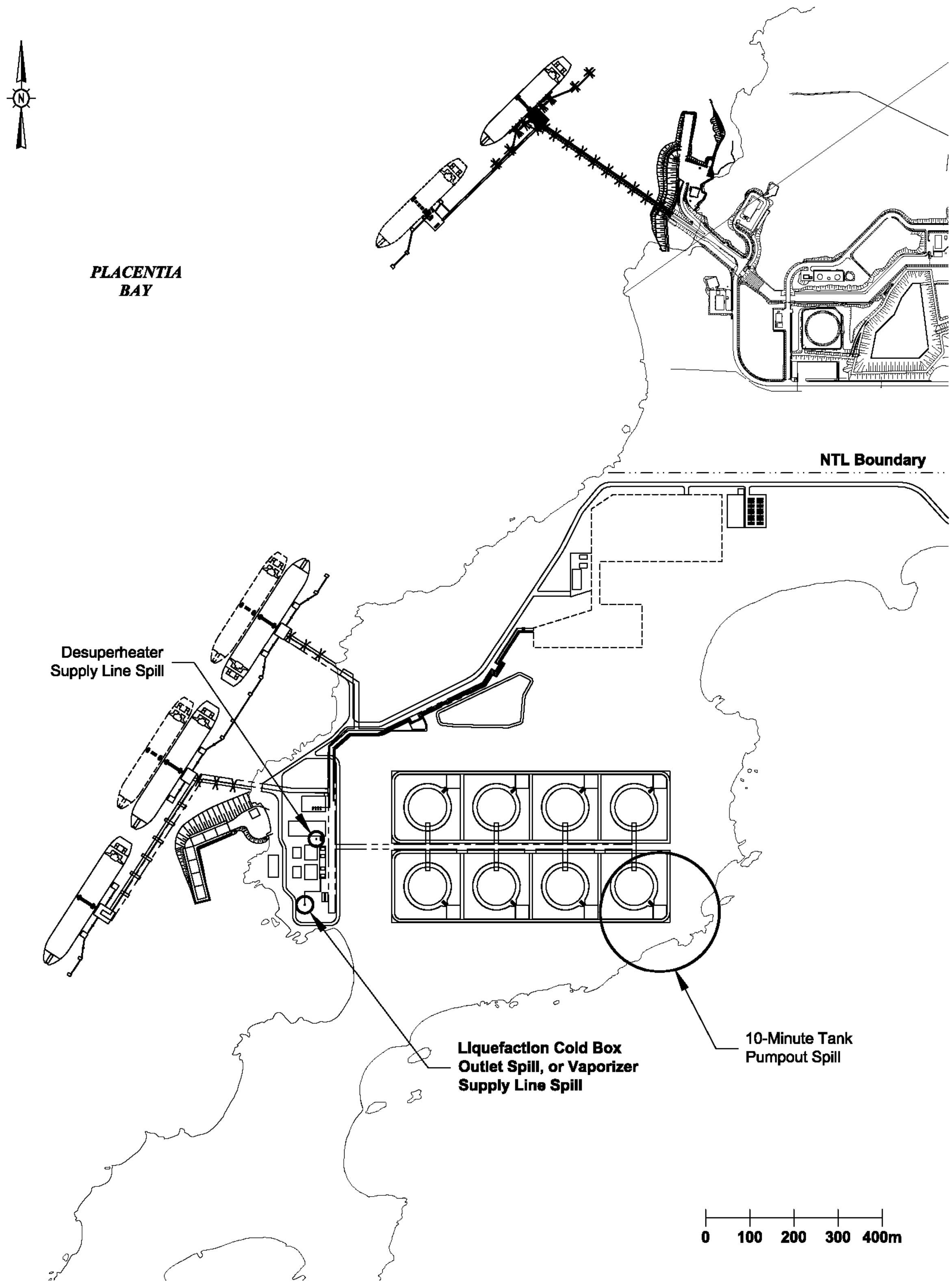

Figure 4-2
5 kW/m^2 Thermal Radiation Exclusion Zones for Fires over Design Spill Impoundments

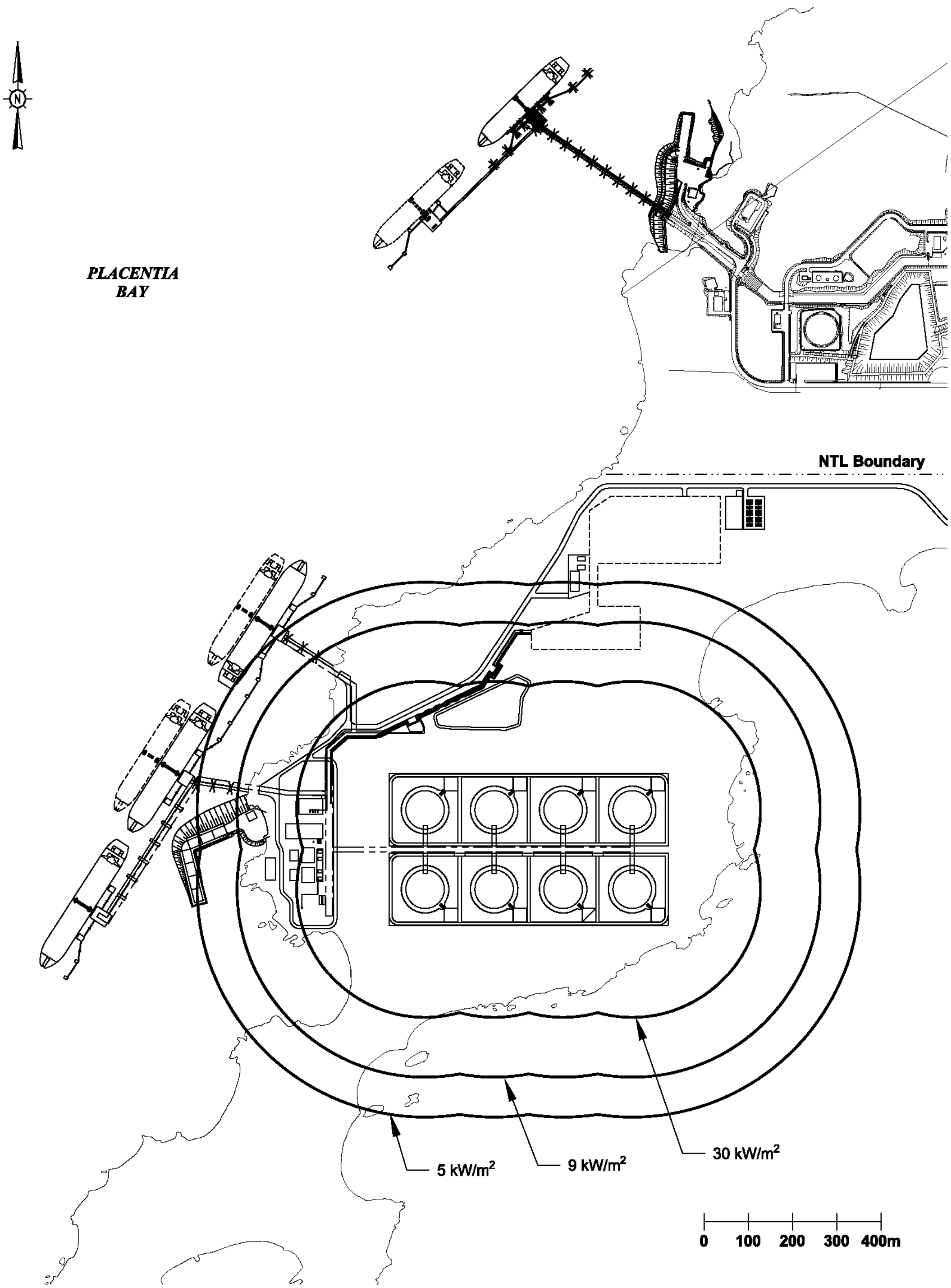

Figure 4-3
Composite Thermal Radiation Exclusion Zone for Fires over the LNG Storage Tank Impoundments (Main Dike Fires)

Table 4-3
Thermal Radiation Analysis Summary for Design Spills

Description	Fire Dimensions [meters]	Maximum Downwind Distance [meters] from the Center of Impoundment to Thermal Radiation Endpoint		
		30 kW/m^2	9 kW/m^2	5 kW/m^2
Fire over the 10-minute LNG tank pumpout spill subimpoundment	30 x 30	95†	130†	150
Fire over the process area impoundment	2.5 x 2.5	14†	17†	19
Fire over the desuperheater impoundment	2.2 x 2.2	12†	15†	17
Fire over LNG storage tank containment (diked area)	149 x 149	290	425	515

† These calculations not required for siting purposes by CSA Z276-07

5.0 ACCEPTABILITY OF GRASSY POINT SITE

With regard to public safety, CSA Z276-07 would judge a site for an LNG facility to be acceptable if the facility can be placed on the site without violating any of the siting restrictions, particularly those related to flammable vapor clouds and fire radiation exclusion zones.

5.1 Adjacent Activities and Land Use

The site for this facility is located in a generally undeveloped area, on a peninsula. The site is bordered by water to the south, east, and west. To the north is the NTL crude oil transshipment terminal. Road access to the site is at the far northwest corner of the property. The town of Arnold’s Cove is approximately two kilometers to the northeast of the site, across the Arnold’s Cove waters.

5.2 Flammable Mixture Dispersion Distances

Table 4-2 and Figure 4-1 presented the vapor dispersion exclusion zones associated with the code-required design spills. A review of Figure 4-1 shows that all flammable dispersion exclusion zones associated with CSA Z276-07 design spills are contained within the proposed facility boundaries.

5.3 Thermal Radiation Exclusion Zone Distances

To be in compliance with the siting requirements of CSA Z276-07, the thermal radiation flux associated with fires involving design spills specified in paragraph 5.2.3.2.1 of the code cannot produce damaging effects (specified as 5 kW/m^2) at a property line that can be built upon. In addition, the radiant heat flux from any fully-involved LNG impounding area fire cannot exceed the values specified in Table 4-1.

A review of Figures 4-2 and 4-3, and Table 4-3, shows that the fire radiation exclusion zones for the design spill impoundments and the LNG storage tank impoundments do not impact excluded zones beyond the property line, as defined by the code.

5.4 General Site Layout Considerations

CSA Z276 siting requirements related to LNG vapor clouds and fires are intended to help prevent injuries to persons outside the LNG facility boundary. These requirements affect the layout and spacing of equipment within the facility boundary only to the extent that LNG spill impounding systems must be located far enough from the boundary to ensure that the radiant heat flux levels from fires and vapor concentration levels due to dispersion of flammable vapors do not exceed acceptable limits at the plant boundary. In addition to these requirements, Z276 contains several requirements pertaining to layout and spacing that are not based on model calculations. Some of those that apply to the facility are paraphrased below.

4.4.2(a) The control centre, from which operations and warning devices are monitored, must be protected from the LNG facilities (even if by spacing) such that it remains operational in the event of a "controllable" emergency.

5.2.1.4 Flammable liquid and flammable refrigerant storage tanks cannot be located within an LNG storage tank's impounding area.

5.2.3.5 LNG storage tank impoundments cannot be located such that the heat flux from an impounding area fire is capable of causing structural damage to an LNG tank ship which could prevent its movement.

5.2.3.7 The distance from the nearest edge of impounded liquid to a property line that can be built upon or from the near edge of a navigable waterway must be at least 15 meters. (This does not apply to marine transfer area impoundments.)

5.2.4.1 The minimum separation distance between LNG containers or tanks containing flammable refrigerants shall be ¼ of the sum of the diameters of adjacent containers. The minimum distance between an LNG tank impoundment and a property line that can be built upon is 70% of the tank diameter.

5.2.6.1 Process equipment containing LNG, flammable refrigerants, flammable liquids, or flammable gases must be located at least 15 meters from:

- sources of ignition,
- facility property line that can be built upon, or
- control rooms, offices, shops, and other occupied structures.

5.2.6.2 Fired equipment and other sources of ignition must be located at least 15 meters from any impounding area or spill drainage system.

5.2.7.1 Marine vessels being loaded or unloaded must be at least 30 meters from a bridge crossing a navigable waterway. The unloading manifold must be at least 61 meters from the bridge.

5.2.7.2 LNG and flammable refrigerant loading or unloading connections must be located at least 15 meters from the following items (except for equipment or structures that are directly associated with transfer operations):

- sources of ignition,
- process areas,
- storage containers, or
- control rooms, offices, shops, and other occupied structures.

The location of the control centre is currently unspecified and should therefore be evaluated further to ensure compliance with 4.4.2(a). The remaining conditions seem to be met by the layout and spacing proposed for the Grassy Point facility.

6.0 CONCLUSIONS

This analysis was performed only for the purposes of determining if the Grassy Point facility site could meet applicable siting requirement of CSA Z276-07. The results presented in this report are based on currently available project information and are subject to change if the facility layout, property lines, or certain design parameters are modified.

Based on information currently available, the Grassy Point LNG transshipment facility layout meets the thermal radiation and vapor dispersion exclusion zone requirements of CSA Z276-07.

The facility appears to meet the fixed spacing requirements of CSA Z276-07 with the current layout and spacing of equipment. These requirements should be verified when the design and layout of the facility is in its final stages.

REFERENCES

CSA Z276-07 (2007), *Liquefied Natural Gas (LNG)—Production, Storage, and Handling*. Canadian Standards Association, Mississauga, Ontario, Canada, July 2007.

GRI (1990a), *LNG Vapor Dispersion Prediction with the DEGADIS Dense Gas Dispersion Model*. Gas Research Institute, GRI-89/0242, April 1988-July 1990.

GRI (1990b), *LNGFIRE: A Thermal Radiation Model for LNG Fires*. Gas Research Institute, GRI-89/0176, June29, 1990.

NFPA 59A (2006), *Standard for the Production, Storage, and Handling of Liquefied Natural Gas (LNG)*. National Fire Protection Association, Boston, Massachusetts, 2006.

APPENDIX D

Quest Consultants Qualifications

Introduction to Quest Consultants Inc.

Quest Consultants Inc., formed in 1989, is an engineering consulting firm dedicated to providing process safety and risk management services to the petroleum and chemical industries. Our professional staff members are recognized leaders in process hazards analysis, consequence modeling, risk analysis, and safety-related research and testing. Many of Quest's staff have been involved in the process safety community for 20-30 years. Our beginnings, through the companies that preceded Quest, started with safety concerns surrounding liquefied fuels such as LNG and LPG. Through the development of process safety services that naturally extended into the entire petrochemical industry, Quest has grown into a company that offers a broad range of services that are supported with state-of-the-art consequence and risk analysis software.

Quest's Background and Experience in LNG

Quest was formed in 1989, but our experience in liquefied gas safety goes back much further. Some members of our staff have been consulting on LNG and LPG projects since the mid-1970s. These early projects included safety studies for the proposed Elba Island LNG receiving and regasification terminal (1974); an analysis of *Fire Safety Aboard LNG Vessels* for the U.S. Coast Guard (1976); and conducting LNG spill and fire tests for the American Gas Association (1973), manufacturers of fire control equipment (1975), and the U.S. Coast Guard (1976).

Since those early days, our personnel have consulted on approximately seventy existing or proposed LNG facilities around the world, ranging from some of the largest LNG liquefaction and export facilities to some of the smallest LNG satellite facilities. This experience in the LNG industry allows Quest to offer a broad range of safety-related services for LNG facilities. Beginning with siting/safety studies and process hazards analysis, Quest's capabilities with LNG issues extend through quantitative risk analysis, code-compliance reviews, safety audits, regulatory support, training, and field testing.

Although most of our LNG work has been for industrial clients, Quest has conducted code compliance and safety audits of LNG facilities on behalf of state and federal government regulatory agencies. In addition, since 1981, Quest personnel have been selected by the U.S. Department of Transportation to conduct an annual course on the federal regulations for onshore LNG facilities (49 CFR 193) for state and federal inspectors of such facilities.

David W. Johnson
Principal Engineer
Quest Consultants Inc.®

EDUCATION

1969 Ph.D., Chemical Engineering
University of Oklahoma, Norman, Oklahoma

1965 B.S., Chemical Engineering
University of Texas, Austin, Texas

EXPERIENCE

1989 - Present Quest Consultants Inc., Norman, Oklahoma
Principal Engineer

Facilitated HAZOP, SIL, What If?, HazID, and HEMP (bowtie) reviews for numerous projects, including:

- Chemical complex
- Oil and gas processing facilities
- Refinery units
- LNG baseload (export) facilities
- LNG import facilities
- Offshore oil and gas processing

Performed consequence modeling for siting and safety studies of several liquefied natural gas (LNG) facilities. Involved in numerous consequence analysis, risk analysis, and facility siting studies involving refineries, gas plants, pipelines, and petrochemical plants.

Responsible for Quest's testing and research programs, and for the development and implementation of analytical models for predicting accidental release rates, aerosol formation, pool spreading, heat transfer, and vaporization rates.

Directed all major aspects of several experimental programs involving releases of hazardous fluids.

- On-site tests conducted to determine if the flammable cloud produced by emergency venting of ullage gas from a crude oil pipeline surge tank could reach associated process areas.
- Two field-test programs conducted to evaluate the efficacy of additives designed to reduce the amount of aerosol formed during accidental releases from HF alkylation units.
- Release tests conducted for the Petroleum Environmental Research Foundation (PERF) to determine the potential for a hydrocarbon/sulfuric acid emulsion to form an aerosol upon its release.
- Aerosol release tests conducted for the CCPS at the DOE Nevada Test Site.

Assisted in development of RMPPs for several refinery units in California, including alkylation, hydrotreating, hydrocracking, catalytic cracking, delayed coking, and product storage. This work included a review of unit HAZOPs, selection of potential release scenarios, estimation of accident frequencies, and supervision of hazard modeling.

1983 - 1989 Energy Analysts, Inc., Norman, Oklahoma
Principal Engineer

Conducted HAZOP study for a proposed refinery expansion in the Philippines. Trained refinery personnel as HAZOP leaders for future HAZOP studies.

Responsible for the technical content of the final safety analysis report (FSAR) for the Big Hill Strategic Petroleum Reserve (SPR) site. Tasks completed included identification and analysis of hazards; review of site layout and design; and equipment, piping, and instrumentation evaluation. Made recommendations to improve site operations.

Developed risk models in the areas of fire and thermal radiation, rate of fluid release from containment, and Gaussian dispersion for EAHAP hazards analysis computer code.

Designed and participated in several large-scale outdoor fire and fluid release tests designed to determine the burning and release characteristics of hydrocarbon fluids.

1977 - 1983 Applied Technology Corporation, Norman, Oklahoma
Vice President

Developed mathematical models in the areas of fire radiation, vapor dispersion, and heat transfer. Applied these models to LNG facility safety studies.

Designed and conducted several large-scale outdoor tests involving fire and materials combustion. Tests included the burning and subsequent extinguishment of hexane, LPG, and carbon disulfide pool fires.

1970 - 1977 University Engineers, Inc., Norman, Oklahoma
Senior Engineer

Project manager of a semi-works seawater desalination project utilizing direct contact heat transfer and freezing to produce potable water.

Involved in several large-scale outdoor fire tests to study the flammability characteristics of thermal insulation products.

1965 Celanese Fibers Corporation, Rock Hill, South Carolina
Development Engineer

Adapted existing plant equipment for new and more productive uses, developed computer models describing machine operations, and assisted in plant start-up.

David W. Johnson

PROFESSIONAL MEMBERSHIPS

National Society of Professional Engineers
American Institute of Chemical Engineers
Oklahoma Society of Professional Engineers

PUBLICATIONS

Authored more than twenty-five papers in the areas of physical properties, kinetics, and process plant safety.

RELEVANT PROJECT EXPERIENCE

Training Federal and State Inspectors of U.S. LNG Facilities: Since 1989, Dr. Johnson has assisted in conducted an annual training course for federal and state employees who are responsible for inspecting/auditing LNG facilities that are under the jurisdiction of the U.S. Dept. of Transportation. This course covers all aspects of Title 49 of the Code of Federal Regulations, Part 193. The course is updated each year to reflect any changes in the regulations. *Client: DOT's Transportation Safety Institute.*

Siting Safety Study for Proposed LNG Liquefaction and Export Terminal in Alaska: ***Project Engineer*** for safety study to determine if the proposed LNG facility could be sited at the proposed location and meet all applicable DOT and FERC safety regulations. This involved consequence analysis of several hypothetical releases of LNG, assistance in selecting fire protection systems, and participating in public meetings held by FERC. *Client: Yukon Pacific Corp., Anchorage, Alaska.*

Safety Audits of LNG Liquefaction and Export Facilities: Conducted several safety audits of LNG facilities. Some of these were routine audits that were conducted annually. Others were pre-start-up safety audits of new liquefaction trains, LPG extraction facilities, and LNG storage tanks. *Clients: P.T. Badak Natural Gas Liquefaction Co., Bontang, Indonesia.*

LNG Spill and Fire Test Programs: Participated in large-scale field tests involving controlled releases of LNG. Data taken on vapor dispersion from unignited pools of LNG, fire radiation from LNG pool fires, and the efficacy of vapor dispersion and fire radiation mitigation methods (e.g., water spray and high-expansion foam). *Client: U.S. Coast Guard.*

LNG Facility Siting Safety Study: ***Project Engineer*** for a study to determine if the proposed (now under construction) LNG liquefaction and export facility could be constructed near Darwin, Australia, and comply with all applicable safety regulations (including Australian standards, and NFPA 59A). This involved vapor dispersion, fire radiation, and vapor cloud explosion modeling for numerous hypothetical releases of LNG and flammable refrigerants. *Client: Bechtel Corporation.*

LNG Facility Siting Safety Study: ***Project Engineer*** for a study to determine if a proposed LNG peakshaving facility located in British Columbia, Canada would meet all Canadian codes and standards with respect to safety. Served as a technical advisor during public hearings covering the safety of the facility.

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Support for LNG Facility Siting: ***Siting advisor*** during the design, siting, and regulatory approval phases of the LNG import terminal at Point Peñuelas, Puerto Rico (the first and only LNG import terminal constructed in the U.S. or its territories since 49 CFR 193 was adopted as U.S. law in 1980).

LNG Facility Siting Safety Study: ***Project Manager*** for a study to determine if the proposed LNG import facility near St. John, N.B. would meet Canadian safety and environmental standards. This involved vapor dispersion, fire radiation, and vapor cloud explosion modeling for numerous hypothetical releases of LNG and flammable refrigerants. *Client: Irving Oil.*

Hazard Assessment Modeling Support: Developed mathematical models to simulate the release of fluids from pipelines. The models are capable of computing the release of gas, liquid, or two-phase fluids from pipelines of varying lengths. The models have been used in hazard assessments and Quantitative Risk Analysis (QRAs) for several clients.

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Presentations and Published Articles
by David W. Johnson

1. "Extinguishment and Control of LPG Fires," W. E. Martinsen, D. W. Johnson, and J. R. Welker. *Proceedings of the Second U.S. Department of Energy Environmental Control Symposium*, Vol. 2, March, 1980: pp. 547-560 (NTIS No. CONF-800334/2).

2. "Effectiveness of Fire Control Agents on Chemical Fires: Phase 1 Test Methodology and Baseline Hexane Tests," J. R. Welker, W. E. Martinsen, D. W. Johnson, and J. N. Ice. Final Report on U.S. Coast Guard Contract No. DOT-CG-42, 355A, Task 6, June, 1980 (NTIS No. AD-A089 585/4.)

3. "Control and Extinguishment of LPG Fires," D. W. Johnson, W. E. Martinsen, W. D. Cavin, P. D. Chilton, H. P. Lawson, and J. R. Welker. Final Report to the U.S. Department of Energy on Contract No. DE-AC-05-78EV06020, June, 1980 (NTIS No. DOE/EV/06020-T3).

4. "Fire Safety of LPG in Marine Transportation," W. E. Martinsen, D. W. Johnson, and J. R. Welker. Final Report to the U.S. Department of Energy on Contract No. DE-AC-05-78EV06020, June, 1980 (NTIS No. DOE/EV/06020-T4).

5. "LPG Safety Research," J. R. Welker, D. W. Johnson, and W. E. Martinsen. *Liquefied Gaseous Fuels Safety and Environmental Control Assessment Program: Second Status Report*, Vol. 3, October, 1980: pp. U-1 - U-41 (NTIS No. DOE/EV-0085, Vol. 3 of 3).

6. "Fire Control Agent Effectiveness for Hazardous Chemical Fires: Carbon Disulfide," D. W. Johnson, W. D. Cavin, H. P. Lawson, and J. R. Welker. Final Report on U.S. Coast Guard Contract DOT-CG-841340-A, January, 1981.

7. "Effectiveness of Fire Control Agents for Hexane Fires," J. R. Welker, W. E. Martinsen, and D. W. Johnson. *Fire Technology*, Vol. 22, No. 4, November, 1986: pp. 329-340.

8. "BLEVE's: Their Causes, Effects and Prevention," W. E. Martinsen, D. W. Johnson, and W. F. Terrell, *Hydrocarbon Processing*, Vol. 65, No. 11, November, 1986: p. 141.

9. "Hazard Control Methods for High Volatility Chemicals," L. E. Brown, D. W. Johnson, and W. E. Martinsen. Presented at the International Symposium on Preventing Major Chemical Accidents, Washington, D.C., February, 1987.

10. "Comparison of Turbulent Jet Model Predictions with Small-Scale Pressurized Releases of Ammonia and Propane," D. B. Pfenning, D. W. Johnson, and S. B. Millsap. Presented at the International Conference on Vapor Cloud Modeling, Boston, Massachusetts, November, 1987.

11. "Investigation of Fire Hazard Potential of Automotive Onboard Refueling Vapor Recovery Systems," D. W. Johnson. Final Report to the American Petroleum Institute, December, 1987.

12. "Potential Fire Hazards of Lowering Gasoline Volatility," D. W. Johnson, D. B. Pfenning, and S. B. Millsap. Final Report to the American Petroleum Institute, January, 1988.

13. "Determining Spacing by Radiant Heat Limits," W. E. Martinsen, D. W. Johnson, and S. B. Millsap. *Plant/Operations Progress*. Vol. 8, No. 1, January, 1989: pp. 25-28.

14. "Siting Considerations for Liquefied Gas Facilities," L. E. Brown, W. E. Martinsen, and D. W. Johnson. Presented at the 1989 Spring National Meeting and Petrochemical Expo '89 of the American Institute of Chemical Engineers, April, 1989.

15. "Risk Analysis Methodology for Gas Pipelines," J. B. Cornwell, W. E. Martinsen, and D. W. Johnson. Presented at PETRO-SAFE '89, Houston, Texas, October, 1989.

16. "Relief Valves and Vents: How Exit Conditions Affect Hazard Zones," J. B. Cornwell, D. W. Johnson, and W. E. Martinsen. Presented at the American Institute of Chemical Engineers 1990 Summer National Meeting, San Diego, California, August, 1990.

17. "Prediction of Aerosol Formation from the Release of Pressurized, Superheated Liquids to the Atmosphere," D. W. Johnson and R. Diener. Presented at the Hazards XI, Institution of Chemical Engineering Symposium, Manchester, United Kingdom (April, 1991). *Hazards XI: New Directions in Process Safety*, Institution of Chemical Engineers Symposium Series No. 124, 1991: pp: 87-104.

18. "The AIChE/CCPS Aerosol Test Program at the DOE Liquefied Gaseous Fuels Spills Test Facility," D. W. Johnson and R. Diener. Presented at the HAZMAT Conference, Chicago, Illinois, April, 1991.

19. "Prediction of Aerosol Formation from the Release of Pressurized, Superheated Liquids to the Atmosphere," D. W. Johnson. Presented at the International Conference/Workshop on Modeling and Mitigating the Consequences of Accidental Releases of Hazardous Materials, New Orleans, Louisiana, May, 1991.

20. "Sulfuric Acid Release Report," D. W. Johnson. Presented at the 1994 National Petroleum Refiners Association Annual Meeting, San Antonio, Texas, March 20-22, 1994.

21. "Effectiveness of Mitigation Systems in Reducing Hazards of Hydrogen Fluoride Leaks," J. B. Cornwell and D. W. Johnson. Presented at the First Risk Control Engineering Seminar, Maracaibo, Venezuela, October 19-20, 1995.

22. "The Use of Comparative Quantitative Risk Analysis in Evaluating Proposed Hydrogen Fluoride Mitigation Systems," J. B. Cornwell, D. W. Johnson, and J. D. Marx. Presented at the 1998 Process Plant Safety Symposium, Houston, Texas, October 26-27, 1998.

23. "A Method for Evaluating Hazards of Low Volatility Toxic Liquids," T. A. Melton and D. W. Johnson. Presented at the 1998 Process Plant Safety Symposium, Houston, Texas, October 26-27, 1998.

24. "RELEASE - An Aerosol Model with Potential," D. W. Johnson. Presented at the 1999 International Conference and Workshop on Modeling Consequences of Accidental Releases of Hazardous Materials, San Francisco, California, September 28 - October 1, 1999.

25. "The Importance of Multiphase and Multicomponent Modeling In Consequence and Risk Analysis," David W. Johnson and Jeffrey D. Marx. Presented at the Mary Kay O'Conner Process Safety Center 2002 Annual Symposium, Texas A&M University, College Station, Texas, October 29-30, 2002.

26. "The Importance of Multicomponent Modeling in Consequence and Risk Analysis," David W. Johnson and Jeffrey D. Marx. *Journal of Hazardous Materials*, Vol. 104, November, 2003: pp. 51-64.

27. “The Importance of Multicomponent Modeling in Consequence and Risk Analysis,” J. B. Cornwell and D. W. Johnson. Presented at the American Society of Safety Engineers 6th Professional Development Conference and Exhibition, Manama, Bahrain, October 4-8, 2003.

28. “Modeling LNG Spills on Water,” J. B. Cornwell and D. W. Johnson. Presented at the AIChE Spring National Meeting, New Orleans, Louisiana, April 25-29, 2004.