SITING STUDY FOR THE GRASSY POINT LNG TRANSSHIPMENT AND STORAGE TERMINAL

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
Telephone: 405-329-7475
Fax: 405-329-7734

07-03-6612
March 1, 2007

QUEST

SITING STUDY FOR THE GRASSY POINT LNG TRANSSHIPMENT AND STORAGE TERMINAL

Table of Contents

List of Tables

List of Figures

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 excellent 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 Z276-01, *Liquefied Natural Gas (LNG)—Production, Storage, and Handling*. This code contains requirements related to siting, design, construction, fire protection, and safety. CSA Z276-01 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 Z276-01 requirements regarding thermal radiation protection 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 to re-liquefy gases generated during transfer operations and as a natural result of heat gain in the tanks and piping. Following compression and refrigeration, the liquefied gases are passed through a 100 m^3 surge tank before returning to storage. Also included in the facility are booster pumps to aid in transferring LNG between a ship and the storage tanks. A 380 m^3 surge tank is to be installed to act as a buffer between the ship's pumps and the booster pumps.

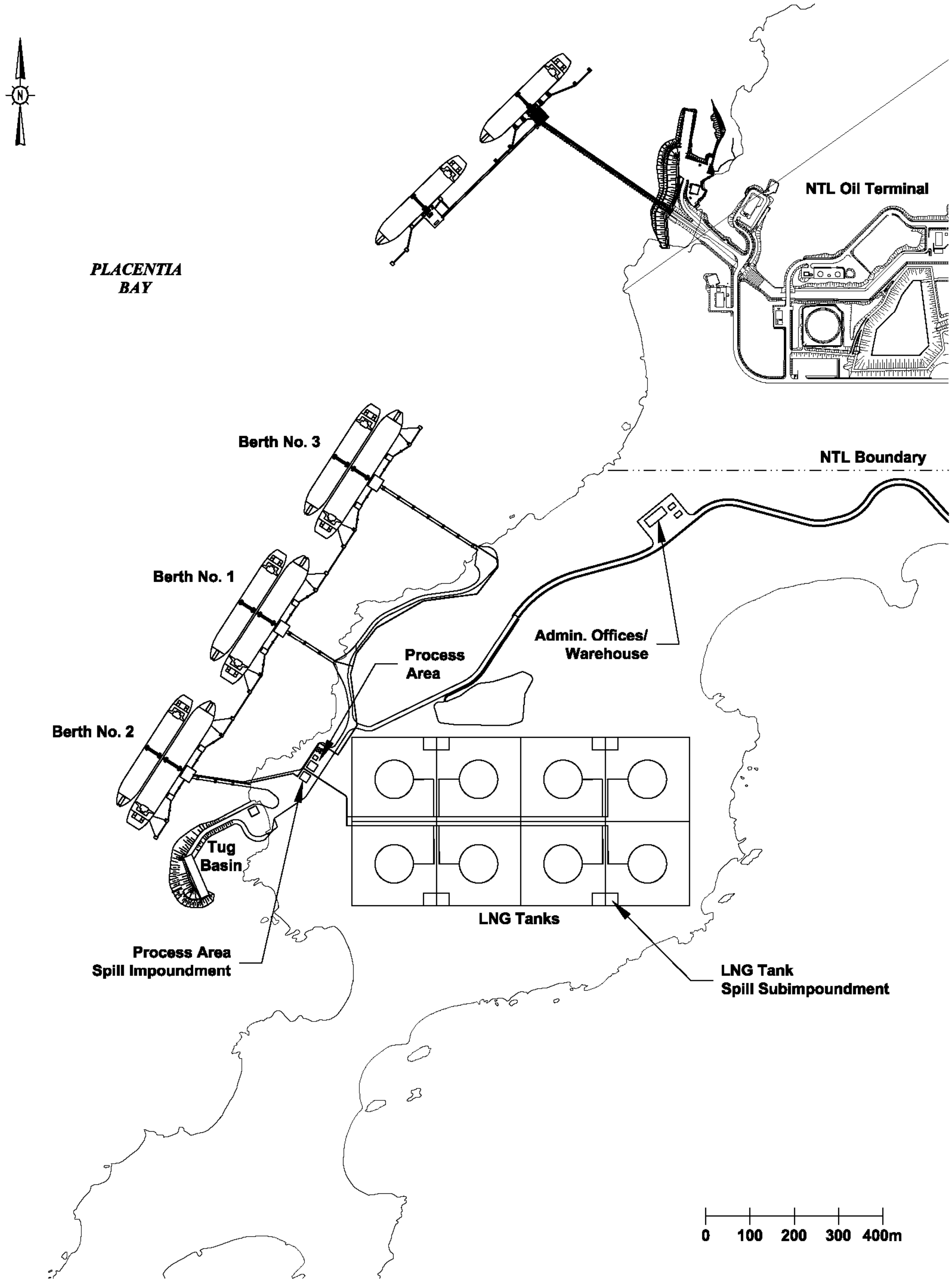

Figure 2-1
Layout of the Grassy Point LNG Transshipment Terminal

3.0 LNG CODE GUIDELINES

This section discusses CSA Z276-01 requirements for siting.

3.1 Impounding Systems Required by CSA Z276-01

CSA Z276-01 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
- Condensed boiloff gas surge tank
- LNG booster pumps
- Booster pumps surge tank
- LNG transfer arms at the pier

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 Z276-01 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), the impoundment sizing requirements are very simple.

> 4.2.2.1 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) for impounding areas serving a single container:
> V = the total volume of liquid in the container, assuming the container is full;

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.

> 4.2.2.2 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 Z-276-01 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 the full rupture of the largest diameter pipe connected to the process equipment.

The liquid containment portion of an LNG spill impounding system required by CSA Z276-01 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 spill impoundments at the following locations within the Grassy Point facility: one for spills in the process area (BOG and booster pumps, including surge tanks), one at each ship berth LNG transfer point, and, optionally, one within each LNG storage tank's diked area (to collect spills from the storage tank discharge piping). This results in a possible total of twelve impoundments basins at the facility.

The 10-minute tank pumpout spill impoundment is presented as an option because it is not completely necessary. Spills within the main diked area for each storage tank are impounded by the dike walls. Even though the dike walls provide this function, most LNG facilities provide a separate subimpoundment within the main diked area to limit the spread of small to moderate spills of LNG from the tank's piping. This also serves to reduce the size of the thermal radiation and vapor dispersion distances that must be calculated.

3.2 CSA Z276-01 Design Spills

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 (section 4.2.3.4).

For LNG containers with over-the-top connections, the design spill is defined in 4.2.3.4 (b) as:

> For impounding areas serving LNG containers that have "over-the-top" fill and withdrawal connections and that have no tank penetrations below the liquid level, the design spill shall be defined 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 duration of the design spill shall be 10 min if demonstrable surveillance and shutdown provisions exist; otherwise, the duration shall be the time needed for the initially full container to empty.

For all other locations, the design spill is defined in 4.2.3.4 (d) as:

> For impounding areas serving only vaporization, process, or LNG transfer areas, the design spill shall be defined as flow for 10 min from any single accidental leakage source or for a shorter time, based on demonstrable surveillance and shutdown provisions.

To maintain compliance with CSA Z276-01 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.

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.

There are two primary spill scenarios that could occur in the process area. In the first scenario, a release downstream of the BOG reliquefaction surge tank releases liquid at the reliquefaction rate until the system is shut down, and from the surge tank until the inventory is depleted. The second scenario involves a spill downstream of the booster pump surge tank, at the booster pump suction lines, which can release liquid at the pumping rate until the ship-based pumps are shut down, plus the liquid inventory of the surge tank. Because the normal flow rate through the system and the surge tank volume are larger in this second case, that spill requires a larger impoundment. This analysis is based on the assumption that there will be only one impoundment serving the process area, whose size is based on the booster pump suction line spill.

Table 3-1 presents the sizing and modeling parameters associated with the CSA Z276-01 design spill impoundments.

Table 3-1
Design Spill Subimpoundment Modeling Parameters

Description	LNG Flow Rate [m^3/hr]	Duration [minutes]	Impoundment Size [meters]	Basis
10-minute tank pumpout spill subimpoundment	15,000	10	29 x 29 x 3	Full pumpout rate
Process area impoundment	15,000*	3	19 x 19 x 3	Booster pump suction line
Marine transfer area impoundment	15,000	1	30 x 30 x 0.3	Single loading arm failure

* The surge vessel will increase this rate until the inventory is depleted

3.3 CSA Z276-01 LNG Pool Fire Scenarios

Paragraph 4.2.3.1 of CSA Z276-01 requires thermal radiation protection distances be calculated for each impounding area required by 4.2.2.1 and for ignition of the design spills defined in 4.2.3.4. Impounding area calculations are based on the assumption that the impounding area contains a volume of LNG equal to the minimum volume computed in accordance with 4.2.2.1 or 4.2.3.4 (a), (b), (c), or (d) (whichever is applicable) and the LNG is burning.

Paragraph 4.2.3.1 also states that the provisions of paragraph 4.2.3.2 and 4.2.3.7 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. The code does not, however, exclude vapor dispersion calculations. This discrepancy is not found in NFPA 59A (from which CSA Z276 is derived). 59A excludes both the thermal radiation and vapor dispersion calculations for marine transfer areas. Due to this uncertainty, this study includes the thermal radiation and vapor dispersion distance calculations for the marine transfer area, regardless of whether they are required or not. Thus, five thermal radiation calculations were made: one for the marine transfer area, one for the process area impoundment, two for the ten-minute storage tank pumpout spill (one with and one without a subimpoundment), and one for a fully-involved storage tank impoundment fire.

3.4 CSA Z276-01 LNG Vapor Dispersion Scenarios

For the LNG tank design spills defined in 4.2.3.4, Clause 4.2.3.3 of CSA Z276-01 requires "Consideration shall be given to controlling the possibility of a flammable mixture of vapors from a 'design spill,' as defined in Clause 4.2.3.4, Item (a) or (b), as appropriate, of reaching a property line that may be built upon at an elevation above grade, which would result in a distinct hazard." The term "Item (a) or (b)" likely refers to Items (a) through (d) of the referenced Clause.

Four vapor dispersion protection distance calculations were included in this study: one for the marine transfer area (see discussion in section 3.3), one for the process area impoundment, and two for the ten-minute storage tank pumpout spill (one with and one without 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 Z276-01. 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 Z276-01 requires that thermal radiation distances be calculated using the model described in the GRI Report 0176, i.e., LNGFIRE3, or 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 protection distances.

The note at the end of paragraph 4.2.3.3 refers to a vapor dispersion model described in the GRI Report 0242. This model is known as the DEGADIS vapor dispersion model. Although its use is not required by CSA Z276, the vapor dispersion protection 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 Z276-01 requires the calculation of fire radiation based on the use of weather conditions found in paragraph 4.2.3.2.2:

Wind speed	0 m/s
Air temperature	21ºC
Relative humidity	50%

The use of zero wind speed is an apparent contradiction to the requirement that the model used for calculating thermal radiation distances account for wind speed. In addition, thermal radiation distances generally increase as wind speed increases. In light of these points, the thermal radiation distances were calculated using the average annual wind speed for the site, 6 m/s. This provides longer hazard distances than zero wind speed.

The wind speed, atmospheric stability, and relative humidity to be used when calculating the extent of each flammable vapor cloud are not specified in CSA Z276-01. 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 (maximum expected summer temperature for the site)
Relative humidity	50% on land; 70% over water (assumed values)

4.2 Hazard Endpoints

CSA Z276-01 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.

Paragraph 4.2.3.3 states that "consideration shall be given to controlling the possibility of a flammable mixture of vapors…." This is interpreted to specify the use of the lower flammable limit (LFL) as the dispersion endpoint for all design spills.

Table 4-1
Thermal Radiation Flux Endpoints

Source	Flux Level [kW/m^2]	Description
CSA Z276-01	30	Maximum flux at a property line that can be built upon for an impounding area containing a volume, V, of LNG determined in accordance with Clause 4.2.2.1 (storage tank impoundment).
	9	Maximum flux 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 4.2.2.1 (storage tank impoundment).
	5	Maximum flux 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 4.2.2.1 (storage tank impoundment).
		Maximum flux at a property line that can be built upon, for ignition of a design spill (as specified in Clause 4.2.3.4).

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 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. For releases from tanker unloading, we have assumed an LNG superheat equivalent to a tank operating pressure of 1.15 bara (2 psig). This is equivalent to a flash of 1.0 percent (by weight). As the amount of superheat increases, the percentage of LNG that will flash to vapor (upon release) also increases. Releases downstream of the LNG tank pumps were found to have an LNG flash of 1.0 percent. 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.

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 (section 4.2.3.4). Using these assumptions, distances from each of the site LNG impoundment areas to the LFL vapor concentration were computed.

Table 4-2 presents the computed flammable mixture dispersion distances for the CSA Z276-01 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 vulnerability 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 vulnerability zone circles, are shown on the plot plan in Figures 4-2 and 4-3.

Table 4-2
CSA Z276-01 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 LFL [meters]
10-minute spill from LNG tank outlet piping into impoundment	191 x 191 x 8*	620
	29 x 29 x 3	†
3-minute spill downstream of booster pump surge tank into process area impoundment	19 x 19 x 3	350
1-minute spill from failed loading arm into impoundment	30 x 30 x 0.3	480

* This scenario assumes that there is no subimpoundment available for the design spill; all spilled liquid is allowed to spread within the main diked area; vapor release is from the 191 x 191 area.
† A spill into a subimpoundment within the main diked area results in no flammable concentrations beyond the limits of the main diked area.

Table 4-3
Thermal Radiation Analysis Summary for Design Spills
(6 m/s Winds, 21°C, 50% r.h.)

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	29 x 29	80†	115†	135
Fire following the 10-minute LNG tank pumpout spill, no subimpoundment	50 x 50*	120†	170†	205
Fire over the process area impoundment	19 x 19	60†	85†	100
Fire over the marine transfer area impoundment	30 x 30	80†	115†	140†
Fire over LNG storage tank containment (diked area)	191 x 191	295	480	605

* This scenario assumes that there is no subimpoundment available for the design spill; approximate fire dimensions are given for collection of liquid at low spot in diked area
† This calculations not required for siting purposes by CSA Z276-01

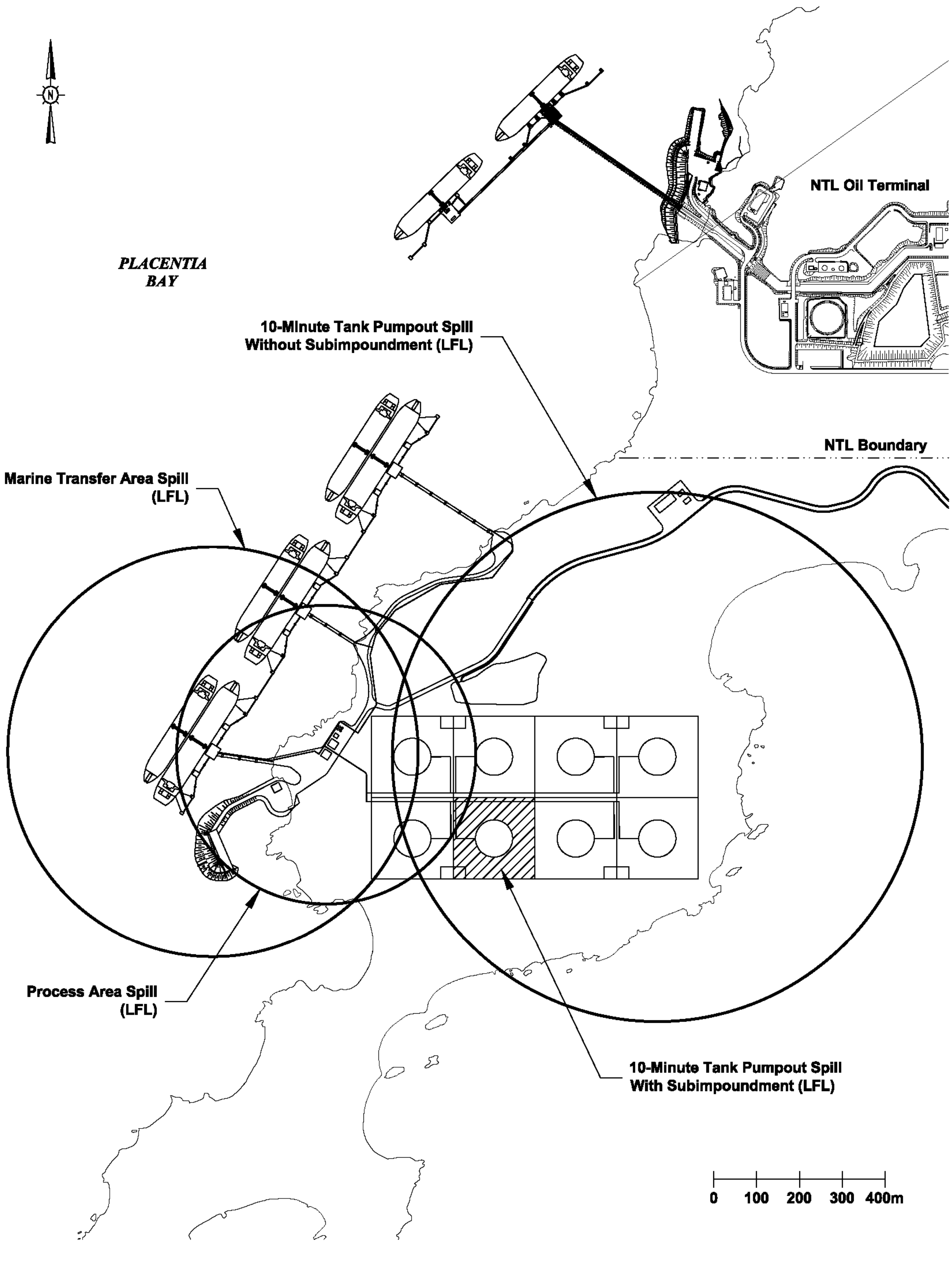

Figure 4-1
Flammable Vapor Vulnerability Zones for CSA Z276-01 Design Spills

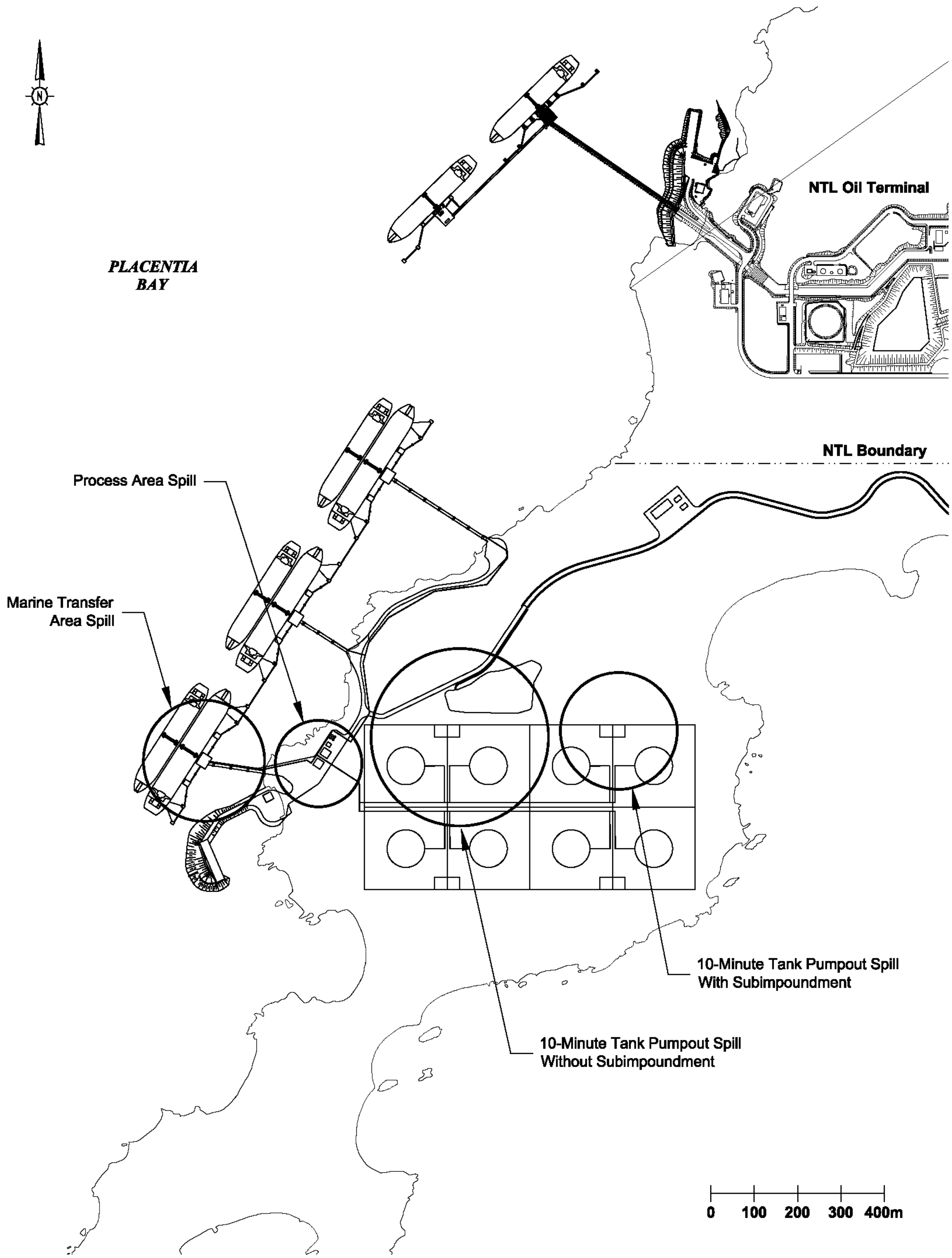

Figure 4-2
5 kW/m^2 Thermal Radiation Vulnerability Zones for Fires over Design Spill Impoundments

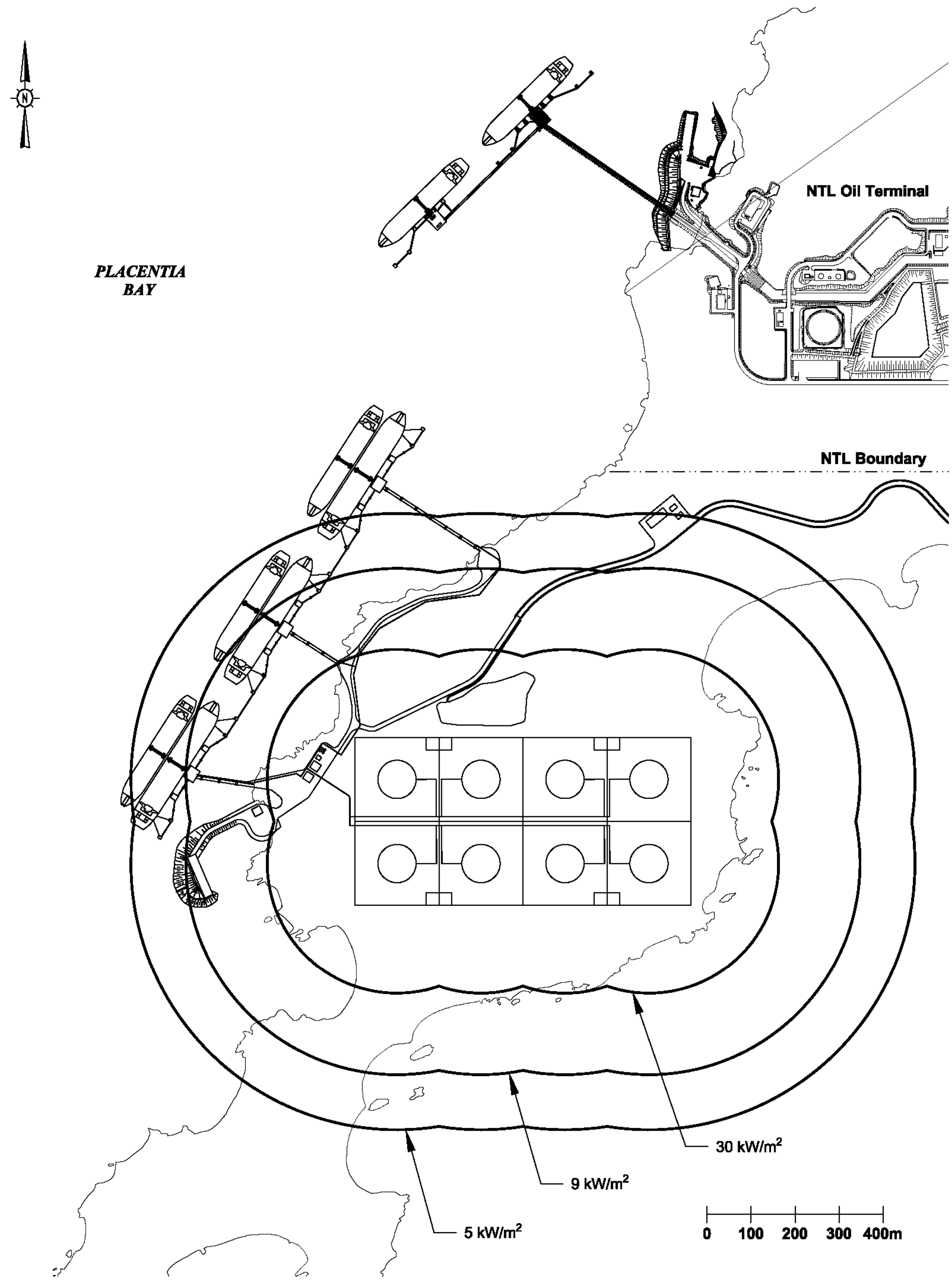

Figure 4-3
Composite Thermal Radiation Vulnerability Zone for Fires over the LNG Storage Tank Impoundments
(Main Dike Fire)

5.0 ACCEPTABILITY OF GRASSY POINT SITE

With regard to public safety, CSA Z276-01 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 hazard 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 vulnerability zones associated with the code-required design spills. A review of Figure 4-1 shows that all flammable dispersion vulnerability zones associated with CSA Z276-01 design spills are contained within the proposed facility boundaries. This includes the 10-minute tank pumpout scenario, with and without a subimpoundment in the main diked area.

5.3 Thermal Radiation Protection Distances

To be in compliance with the siting requirements of CSA Z276-01, the thermal radiation flux associated with fires involving design spills specified in paragraph 4.2.3.1 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 Figure 4-2 and Table 4-3 shows that the fire radiation vulnerability zones for the design spill impoundments do not impact excluded zones beyond the property line, as defined by the code. This includes the 10-minute tank pumpout scenario, with and without a subimpoundment in the main diked area.

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, 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.

4.2.3.7 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 the marine transfer area impoundment.)

4.2.4.1 The minimum separation distance between LNG containers or tanks containing flammable refrigerants shall be ¼ of the sum of the diameters of adjacent containers.

4.2.6.1 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.
- control room, offices, shops, and other occupied structures.

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

4.2.7.1 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.

These 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 Z276-01. 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 flammable mixture dispersion distance requirements of CSA Z276-01.

The facility appears to meet the fixed spacing requirements of CSA Z276-01 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 Z276-01 (2001), *Liquefied Natural Gas (LNG)—Production, Storage, and Handling*. Canadian Standards Association, 178 Rexdale Boulevard, Toronto, Ontario M9W 1R3, Canada, November 2001.

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.