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Comparison of Methods to Determine Maritime Safety Zones for LNG Terminals

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Abstract

A Maritime Safety Zone is defined by the U.S. Coast Guard as a water area, shore area, or water and shore area combined to which, for safety or environmental purposes, access is limited to authorized persons, vehicles, or vessels. A Maritime Safety Zone is established to prevent interference with safe navigation and tug maneuvers, to exclude third party access in order to reduce ignition probability, to aid in emergency preparation, and to protect the public from being exposed to potential harm. USCG also defines a Maritime Security Zone for protection against intentional threats, and this is usually larger than the Safety Zone. The USCG requires that a Maritime Safety Zone be defined before a Letter of Recommendation is given. While the Canada Marine Act only suggests that a port authority may establish Traffic Control Zones, the USCG suggests using the Sandia study as guidance for determining Maritime Safety and Security Zones.

Though there are guidance documents, no standard method is currently available for determining site specific Maritime Safety Zones applicable to accidental spills that could occur at the waterfront configuration of the terminal. A common methodology would enable Safety Zones to be more properly defined and create safer waterways. Two types of approaches have been proposed by DNV GL in this paper to determine the Safety Zones surrounding LNG terminals from accidental spills. A deterministic approach is based on a single maximum credible event among a set of representative scenarios that have been modeled. This approach may conservatively produce a very large hazard distance depending on the consequence of the maximum credible scenario. A probabilistic approach is a risk based approach which associates the consequence (the thermal radiation intensities and the flammable vapor dispersion distances) with the likelihood of having such a consequence. A probabilistic approach provides a more realistic basis for making informed decisions.

1 Introduction

Liquefied Natural Gas (LNG) has been used commercially since the 1940s, and since then it has played an important role in U.S. energy markets. International LNG shipping began in 1959 and according to the Federal Energy Regulatory Commission (FERC), as of July 2015 there are more than 110 LNG facilities operating in the U.S. for a variety of purposes [1]. Some facilities serve for exporting natural gas from the U.S. to other countries, some import the natural gas and supply to local distribution companies or the interstate pipeline system; however most are LNG peak-shaving facilities storing the natural gas for periods of peak demand.

Natural gas can be cooled to a liquid state with a volume reduction of approximately 600 times, which makes it efficient for storage and shipping over long distances in large quantities. The large volumes bring concerns about serious potential hazards. The marine safety record of the LNG shipping industry is amongst the best in the world over the last 50 years. Since 1959, a handful of groundings and collisions have been experienced by LNG carriers but none of these accidents has led to a major spill [2]. The most severe onshore LNG terminal accident happened at a peak shaving plant at Cleveland East Ohio in 1944. This gas explosion accident killed 128 people and initiated public awareness and fears of the LNG hazards [3]. Since 1944, the worldwide safety record of onshore LNG terminals identifies 13 serious accidents (directly caused by LNG spill) [4]. Among these accidents, one killed 27 workers and injured 74 others in Skikda Algeria on January 19, 2004, and two caused single fatalities of onsite workers (i.e. one in Algeria in 1977 and another at Cove Point, Maryland in 1979) [4].

LNG regulations are in place to safeguard the public and the environment, and for defining Safety Zones considering the land-side as well as the maritime-side of the LNG terminal. In the following sections of this paper, an overview of the USA and Canada regulations for siting LNG terminals is included with a summary of different requirements and guidance on determination of Safety Zones.

Note that this paper primarily discusses the Maritime Safety Zones of the LNG terminals, associated with the waterfront operating configurations (i.e. jetty pipes, LNG loading arms/hoses, LNG carriers). The maritime-side is less prescriptive as to scenarios and approach than the land-side. A deterministic approach and a probabilistic approach are proposed and compared aiming to enable Safety Zones to be more properly defined and create safer waterways. Finally, an example is given to demonstrate the advantage and disadvantage of the two approaches.

2 USA and Canada regulations for siting LNG terminals

FERC has the exclusive authority to approve or deny an application for the siting, construction, expansion, or operation of an import or export LNG terminal located onshore or in state waters. It is also responsible for the following actions [5]: issuing certificates of public convenience and necessity for LNG facilities engaged in interstate natural gas transportation by pipeline; preparing the National Environment Policy Act (NEPA) analyses for proposed LNG facilities under its jurisdiction. Depending on the location and the use, State utility regulatory agencies may also regulate an LNG facility.

FERC relies on the regulations (Title 49, Part 193 of the Code of Federal Regulations (CFR)) established by the U.S. Department of Transportation (DOT) for guidance and determination of the siting requirements, which incorporates and references the NFPA 59A-2001 standard [6]. 49 CFR 193 and NFPA 59A-2001, prescribe the methods and specific models to be used for estimating the land-based Safety Zones to ensure public safety. For a LNG project to be approved by FERC, it must meet the siting requirements of DOT's regulations 49 CFR 193.

The USCG (as a cooperating agency) reviews the Waterway Suitability Assessment (WSA) of the applicant before FERC approves the terminal operations. The USCG considers spills from the waterfront configurations (i.e. jetty pipes, loading arms/hoses and LNG vessels) and takes charge of the WSA to address navigation safety and port security issues associated with LNG vessel traffic. Safety Zones are required to be defined before a Letter of Recommendation can be issued by the USCG. In USCG's WSA guidance (NVIC 01-2011), the Sandia studies are suggested to be used as guidance for determining the Maritime Safety Zones [7, 8, 9].

As of September 2014, Canada has only one operating LNG terminal – Canaport LNG's regasification facility located in Saint John, New Brunswick and no LNG export facilities. However, seventeen LNG export terminals are proposed and under the regulatory review process – sixteen in British Columbia (BC) and one in Nova Scotia (NS) [10].

In Canada, most LNG terminal proposals require both federal and provincial permits via different types of assessment. An export license from the National Energy Board (NEB), Canada's federal energy regulator, authorizes LNG export to overseas markets. A facility permit from the BC Oil and Gas Commission (BCOGC) must be obtained by LNG proponents before construction can start on a British Columbia liquefaction plant. BCOGC requires the applicants to ensure that the siting for the LNG facility conforms to CSA Z276 (Liquefied Natural Gas (LNG) - Production, Storage, and Handling) [11].

Similar to the WSA process in the USA, Canada has implemented a Technical Review Process of Marine Terminal Systems and Transshipment Sites (TERMPOL). The TERMPOL process is carried out under the leadership of Transport Canada. It focuses on the selected routes of vessels, their berthing at terminals and the process of cargo handling between vessels or off-loading from ship to shore [12]. This process assesses both the vessels suitability to navigate and the potential impacts in the waterway. Although this process is voluntary, it is often necessary to perform elements of the TERMPOL Review Process in order to engage effectively with local stakeholders.

3 Guidance on Safety Zone Determination

The main types of LNG hazards can be identified based on the physical characteristics of the LNG and the natural gas, which is summarized in the IMO report as detailed below [2]:

- Pool Fires: LNG pool fires burn more rapidly and with greater emitted heat than oil or gasoline fires. Furthermore, they cannot easily be extinguished before all the LNG is consumed. Due to the high temperatures, it may pose significant thermal hazards to unprotected people and property for considerable distances.
- Vapor clouds: If not immediately ignited, the evaporating natural gas may form a dense flammable cloud upon mixing with the air. If the cloud ignites within an enclosed or open but congested space, an explosion could occur. Otherwise, it will become a flash fire (which has a lesser hazard range) and burn its way back to the spill source and continue as a pool fire.

49 CFR 193 (land-based Safety Zone)

The code of federal regulation 49 CFR 193 governs siting, design, installation, or construction of LNG facilities and is more relevant to determine the land-side Safety Zones. According to

Section 193.2051 of 49 CFR, each LNG facility designed, constructed, replaced, relocated or significantly altered must be provided with siting requirements in accordance with the requirements of NFPA 59A. Section 193.2057 and Section 193.2059 of 49 CFR 193 state that each LNG container and LNG transfer system must have a thermal Safety Zone in accordance with Section 2.2.3.2 of NFPA 59A-2001 and a dispersion Safety Zone in accordance with Section 2.2.3.3 and Section 2.2.3.4 of NFPA 59A-2001. A regulatory review for LNG siting requirements and methods in USA and Europe can also be found in Licari and Weimer [13], and Kohout [14].

NFPA 59A-2001 [6]

As required by NFPA 59A-2001 Section 2.2.3.2, provisions shall be made to prevent thermal radiation flux from a fire from exceeding the following limits when atmospheric conditions are 0 (zero) wind speed, 70°F (21°C) temperature, and 50 percent relative humidity.

- 1,600 Btu/hr/ft^2 (5,000 W/m^2) at a property line that can be built upon for ignition of a design spill,
- 1,600 Btu/hr/ft^2 (5,000 W/m^2) at the nearest point located 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[1],
- 3,000 Btu/hr/ft^2 (9,000 W/m^2) 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 as assembly, educational, health care, detention and correction or residential for a fire over an impounding area,
- 10,000 Btu/hr/ft^2 (30,000 W/m^2) at a property line that can be built upon for a fire over an impounding area.

Per 49 CFR Section 193.2059 and NFPA 59A-2001 Section 2.2.3.3, the spacing of an LNG tank impoundment to the property line that can be built upon shall be such that, in the event of an LNG design spill, an average concentration of methane in air of 50 percent of the lower flammability limit (LFL) does not extend beyond the property line that can be built upon. While these Safety Zones seem quite clear, Havens and Spicer [15] have noted many inconsistencies in calculations contained in early public submissions.

Although the proponent can select a design accidental event based on a 10-minute spill of the largest pump rate, which might imply great difference in hazard zones, in practice, the calculated hazard zones do not vary much due to the factor that they are dominated by boil-off from the impoundment.

The thermal Safety Zone is essentially the 5,000 W/m^2 thermal radiation zone generated from an impounding fire (LNG pool fire over an impounding area); the vapor cloud dispersion Safety Zone is defined by the ½ LFL concentration zone from a design spill over an impoundment. Note that when adopting the consequence based approach, ½ LFL provides a margin to account for uncertainties in the dispersion distance calculation.

[1] Impounding Area-an area defined through the use of dikes, sumps or the site topography for the purpose of containing any accidental spill of LNG or flammable refrigerants [16].

NFPA 59A-2013 [16]

In the latest version of NFPA 59A (2013 edition), an alternative method using a performance (risk assessment) based approach is included for LNG facility siting and layout analysis. This method requires LNG plants be designed and located in such areas as to not pose intolerable risks to the surrounding populations, installations, or property. The calculated individual risk (expressed in number of realizations per year) and societal risk (F-N curve) shall fall below the risk acceptability criteria.

This method itself seems fairly reasonable with regard to the events to be included, hazard and consequence assessment modeling, and the risk tolerability criteria. However, the suggested component annual failure frequencies to be used in risk assessment are too optimistic and approximately two orders of magnitudes lower than the failure frequency data recognized by the industry [17, 14].

CSA Z276-2011 [18]

The Canadian Standard CSA Z276 has historically aligned itself to and incorporated the NFPA 59A revisions. CSA Z276-2011 requires the thermal safety distances be calculated as described in Section 5.2.3.2, and the dispersion safety distance be estimated using the guidance from Section 5.2.3.3. Those two sections from the CSA standard are very similar to the corresponding sections (Section 2.2.3.2 and 2.2.3.3) in NFPA 59A-2001. A newer version of this standard (CSA Z276-2015) is published by CSA recently, which is not reviewed and compared with the latest NFPA 59A (2013 edition) standard.

33 CFR 165 (maritime-based Safety Zone)

Unlike the DOT 49 CFR 193, the USCG 33 CFR 165 prescribes regulations for different types of zones of concern (i.e. Safety Zone and Security Zone during specified conditions) and regulated navigation areas. Note that this paper focuses on the Safety Zone since it is more relevant to accidental spills. According to Section 165.20 of 33 CFR, a Safety Zone is a water area, shore area, or water and shore area to which, for safety or environmental purposes, access is limited to authorized persons, vehicles, or vessels. It may be stationary and described by fixed limits or it may be described as a zone around a vessel in motion.

Examples of fixed safety zones currently in place around liquefied gas carriers while they are moored pier side in U.S. ports include (49 CFR 193, Subpart F-Specific Regulated Navigation Areas and Limited Access Areas):

- Distrigas LNG Facility, Everett, MA: 400-yard radius of any LNGC vessel moored at the dock.
- Bath Iron Works, Bath, Maine: 150-yard radius of the Bath Iron Works dry dock on the Kennebec River.
- Chesapeake Bay, MD: 500 yards in all directions from the Cove Point LNG terminal structure
- Savannah River, Savannah, GA: 200-foot radius around Garden City Terminal.
- Portsmouth Harbor, NH: 500-yard radius of any Liquefied Petroleum Gas (LPG) vessel while it is moored at the LPG receiving facility on the Piscataqua River.

No obvious consistency can be concluded by looking at the size (safety distance) of each Safety

Zone. The sizes of Safety Zones are sometimes limited by the water dimensions. For example, a narrow waterway usually has a smaller zone otherwise the waterway will be no longer navigable.

WSA NVIC 01-2011 and SANDIA

Guidance on conducting a Waterway Suitability Assessment (WSA) published by USCG suggests using the "Zones of Concern" from Sandia National Laboratory's study (SAND2004-6258 and SAND2008-3253) or other zone sizes acceptable to the Vessel and Facility Operating Standards Division (CG-OES-2) to determine the main areas of concern along the waterway [7, 8, 9].

The Guidance on Risk Management for LNG Operations over Water documented in the Sandia Study (Sandia Report SAND2004-6258) provides the Zones of Concern analysis, which is accepted by the USCG for defining the safety zones [8]. The following definitions are taken from Sandia, which are based on detailed fire and dispersion analyses for a variety of realistic accidental and terrorism events; the following zones of concern correspond to the accidental events [8]:

Zone 1 - These are areas in which LNG shipments transit narrow harbors or channels, pass under major bridges or over tunnels, or come within approximately 250 meters of people and major infrastructure elements, such as military facilities, population and commercial centers, or national icons. Within this zone, the risk and consequences of an accidental LNG spill could be significant and have severe negative impacts. Thermal radiation poses a severe public safety and property hazard, and can damage or significantly disrupt critical infrastructure located in this area.

Zone 2 - These are areas in which LNG shipments and deliveries occur in broader channels or large outer harbors, or within approximately 250 m – 750 m of major critical infrastructure elements like population or commercial centers. Thermal radiation transitions to less severe hazard levels to public safety and property. Within Zone 2, the consequences of an accidental LNG spill are reduced and risk reduction and mitigation approaches and strategies can be less extensive.

Zone 3 - This zone covers LNG shipments and deliveries that occur more than approximately 750 m from major infrastructures, population/commercial centers, or in large bays or open water, where the risks and consequences to people and property of an accidental LNG spill over water are minimal. Thermal radiation poses minimal risks to public safety and property.

World Association for Waterborne Transport Infrastructure (PIANC) [19]

The World Association for Waterborne Transport Infrastructure (PIANC) advises on required spaces for safe berthing, which includes clearance between vessels moored at adjacent berth(s) or manoeuvring berths, distance between navigational channel and moored vessels, and safety zone around manifolds of berths and tankers.

It recommends that a safety zone centered on the tanker's manifold should be determined from the risk assessment to enable the tanker to berth and unberth without the safety zone on an adjacent vessel being breached. Factors to be considered would include:

- Cargo type – flammability, density and toxicity of product and gases (Chemical, LNG or LPG)
- Event scenario – loss of containment, such as cargo transfer hose or mechanical arm

failure, vent release, penetration of outer hull and breach of inner hull structure, or failure of tanker or jetty equipment

- Product spillage dispersion modelling including whether air or waterborne and whether gas density is heavier or lighter than air
- Installed safety systems that can mitigate the effects of an event including; ESD (emergency shutdown), ERS (emergency release system), vapor detection, etc.
- Prevailing environmental conditions – relative wind speed and direction, current and waves, etc.
- Spacing to avoid escalation of potential incident at a berth to other berths, facilities or vessels

Typical ranges for safety zones are 30 m from ship's offshore side, as used in Japan for gas terminals (small release) and can extend to 200 - 300 m from the manifold for some LNG and LPG terminals.

4 Compared Approaches for Determining Safety Zone on the Waterway

The establishment of a safety zone and limiting public access to areas on the waterway is to limit the potential for collision from errant vessels, reduce the frequency of ignition by excluding uncontrolled and controlled ignition sources (passing vessels) from the zone for a certain time for safety or environmental purposes. It also aids in emergency preparation and provides necessary warning as the third parties' vessel approaching the safety zones, which will prevent the public from being exposed to the potential harm.

The following two types of approaches to determine the safety zones are compared in this paper:

- Deterministic approach: the safety zone is determined by a consequence analysis methodology, where a set of representative scenarios are selected and the worst thermal radiation and flammable vapor dispersion hazard zones are predicted; this approach may produce very large or very small hazardous distances depending on selection of the representative scenario(s).
- Probabilistic approach: the safety zone is calculated by using a risk based approach; this approach associates the consequence impacts (the thermal radiation intensities and the flammable vapor dispersion distances) with the frequency of having such hazards. A probabilistic approach may yield shorter distances than in a deterministic approach.

Deterministic Approach

Using this approach, the safety zone is conservatively determined based on the thermal and flammable dispersion consequence from the representative LNG spill scenarios.

The selection of these scenarios is based on the initial hazard identification, which focuses on hazards that can result in a loss of containment at the terminal during the loading of the LNG cargos. It reflects the general project specific factors which include, but are not limited to:

- LNG transfer rates and inventory inside the LNG cargo,
- Transfer (loading) status (e.g. loading start-up with empty cargo tank, towards the end of loading with high filling percentage of the cargo tank, and loading finished ready to leave),
- Implemented safeguards,
- Properties of the LNG inside the tank (inventory, pressure, temperature, LNG filling level),

- Vicinity to other targets of interest (onshore facility, water way, and etc.),
- Location specific and representative weather conditions.

The selected maximum credible scenario is determined on a conservative, but realistic basis considering the operation and the implemented safeguards. Typical scenarios might be LNG cargo tank release due to vessel collision or grounding at the terminal, loading arm disconnection resulted from ranging failure, or LNG loading pipe rupture from trestle structure failure. The maximum effect of the thermal radiation and the flammable gas dispersion hazards is modelled using DNV GL's Phast software [20]. Phast is approved for use in LNG siting studies in the PHMSA validation exercise for dispersion models.

Probabilistic Approach

A risk-based approach considers both the severity and the likelihood of all identified release events. It begins with modeling the consequence (thermal radiation and the gas dispersion) of each credible scenario and then combines it with the frequency of having such hazards. Using this method, the Safety Zone is presented as an area exposed to a thermal radiation level or a flammable gas concentration (consequence end-points) with a predefined frequency level or higher (frequency threshold). Details can be found in Section 6 – Case Study.

This requires a probabilistic assessment of all release scenarios from the waterfront configuration, including (if applicable):

- Jetty side LNG loading/unloading pipe
- Jetty side LNG circulation pipe – this circulates in the main lines to keep them cold
- LNG transfer arm(s)/hose(s)
- Jetty Manifolds
- Jetty side LNG vapor return pipe and arm
- LNG Carrier cargo tank.

The probabilistic based approach provides a more realistic basis for making informed decisions as it considers the full range of events than an approach based on single, large event scenarios (which must incorporate expert judgement, that may or may not be accepted by all) as in the deterministic approach. It reflects the same general project specific factors as applied in the deterministic approach. In addition, the probabilistic approach takes explicit consideration of the likelihood of the full range of credible events; the assessment is thus based on both the consequence estimates and the probability for quantity of release, location of release, and probability of ignition as a function of time after the release, and environment factors such as the local wind rose distribution.

5 Case Study – Safety Zone Determination at a LNG Export Terminal

A demo case is used to compare the Safety Zones determined for a LNG export terminal via the two different approaches. The key assumptions, scenario summary, end-point criteria, and safety distance calculation are detailed in the following sub-sections.

5.1 Key Assumptions

The study boundary is represented by the waterfront configuration up to the first onshore ESD (at the shore side end of the access trestle), which includes the LNG carrier, loading arms/vapor return arm, trestle piping, and the onshore and jetty ESDVs. Key assumptions regarding the terminal facility and operation, meteorology data, ignition sources, leak frequency, representative hole sizes, and release locations are detailed in the table below.

Table 1 Key Assumptions

	Description	Assumption Details
Facility Operation	Major equipment on the jetty loading platform (12 m above sea level)	• two (2) loading arms (16 inch) • one (1) vapor return arm • Emergency Shutdown Valves (ESDVs) • vessel monitoring system • gangway tower • product delivery and vapor return pipe racks
	Access trestle (180 m) - provides structural support from shore to the loading platform	• LNG product and circulation piping • vapor return piping • auxiliary mechanical and electrical systems, • access roadway
	Vessel calls	140 LNG carriers per year
		Total vessel port time: 29 hours, including 2 hours preparation for departure and 3 hours at turning basin
	Representative LNG carrier	Capacity: 170,000 m^3, draft: 12 m, # of tanks: 4
	Loading operation	Maximum loading rate: 10,000 m^3 per hour
		Duration of each transfer: 12 to 18 hours, including approximately 2 hours for ramp up to and down from the normal loading rate
		Loading starts 6 hours after berthing at the port
Meteorology Data	Atmospheric temperature	10 $^{\circ}$C used as average ambient air temperature
	Relative humidity	70 % used as average humidity.
	Solar Flux	Day - 350 W/m², Night - 0 W/m²
	Surface temperature	Same as atmospheric temperature
	Prevailing wind direction	Day: NNW, Night: SSE, Windrose considered
Terminal equipment release sizes	A range of hole sizes are modeled	The full range of possible hole sizes (small, medium, large, very large, and rupture)
Cargo tank release sizes	Three representative release sizes are modeled	250 mm diameter hole for a small release
		750 mm diameter hole for a medium release
		1,100 mm diameter hole for a large release
Frequency	Equipment (piping, flange and valve) leak frequency	HCRD generic failure frequency data (Bolsover et al. [17])
	Loading arm failure frequency	ACDS data [21]

	Description	Assumption Details
	LNG cargo spill frequency	An energy model used to estimate the conditional probability of tank breach with attendant LNG release
Ignition probability	Immediate ignition probability	UKOOA immediate ignition probability
	Delayed ignition probability	Site specific ignition sources are identified-0.001
Detection & Isolation	Time to isolate	Small: 5 minutes, Medium: 2 minutes, Large and above: 1 minutes
	Probability of isolation failure	P_isolation failure = 10% assumed

5.2 Scenario Summary

Table 2 summarizes the scenarios considered for calculating the safety distance, which is used to determine the Safety Zones based on accidental scenarios. The deterministic (or consequence-based) approach will only assess the maximum credible scenario caused by ship collision, which is the accidental spill with effective breach area of $1m^2$ from one cargo tank due to hull structure penetration. Using the probabilistic (or risk-based) approach, all the identified credible scenarios (as shown in Table 2) are included, taking into account both the likelihood and the consequences (thermal radiation as well as natural gas dispersion) of each event.

Table 2 Terminal Waterfront Release Scenarios

Scenarios Description	Operational Mode	Release Phase	Release Origin	Release Location
Marine Terminal Release Scenarios (Trestle)				
Loading line from downstream of the onshore ESD to the jetty ESD	Loading and holding	Liquid	Pipeline	Over water
			Onshore	On land
			Jetty	Contained within impoundment
Vapor return line from downstream Jetty ESD to the onshore ESD	Loading	Vapor	Pipeline	N/A
			Onshore	N/A
			Jetty	N/A
Circulation line from downstream of the onshore ESD to the Jetty ESD	Loading and holding	Liquid	Pipeline	Over water
			Onshore	On land
			Jetty	Contained within impoundment
Marine Terminal Release Scenarios (Loading Platform)				
LNG piping to loading arms	Loading	Liquid	Pipeline	Contained within impoundment
LNG loading arms release	Loading	Liquid	Loading arm	Over water
Vapor to return arm	Loading	Vapor	Pipeline	N/A
Vapor arm release	Loading	Vapor	Loading arm	N/A
Marine Terminal Release Scenarios (LNG Carrier)				
Ship collision on LNGC	Loading	Liquid	Cargo tank	Over water

5.3 End-point Criteria

A thermal radiation level of 5,000 W/m^2 was adopted for generating the thermal Safety Zone since it is typically considered as a maximum level of radiation heat flux for individuals to be exposed to and still be able to escape. The thermal Safety Zone can help to understand potential impacts to others.

The LFL concentration level is selected for generating the gas dispersion Safety Zone, which can be used for limiting the public access in order to reduce the likelihood of a release reaching an ignition source.

The impact frequency for evaluation is 1E-04 per year, equivalent to once every 10,000 years. This is a typical frequency threshold used broadly and accepted by the industry in Europe. This should be subject to any regulatory requirement or company internal guidance.

5.4 Maritime Safety Zones from Accidental Releases

Maritime Safety Zones for this example case determined by these two approaches are presented and compared below. Note that the maritime Safety Zones are the circular area (on the water side) with the radius equal to the safety distances and centered on the jetty area.

Deterministic Approach – Consequence-based Method

The maximum credible scenario identified at the terminal is the LNGC cargo tank breach due to ship collision with an equivalent hole diameter of 1,100 mm (1m^2 spill area with one tank breached) [8]. This scenario predicts a maximum LFL dispersion distance of approximately 1,600 m under the most unfavored wind condition. The downwind distance to the pool fire radiation level of 5,000 W/m^2 is about 700 m.

Table 3 Safety Distances (Safety Zone Radius) Determined by the Deterministic Approach

Impact Criteria	Safety Zone Radius (m)	Maximum Credible Event
Lower Flammable Limit (LFL)	1,600	LNG spill from 1 m^2 spill area with one tank breached
5,000 W/m^2	700	

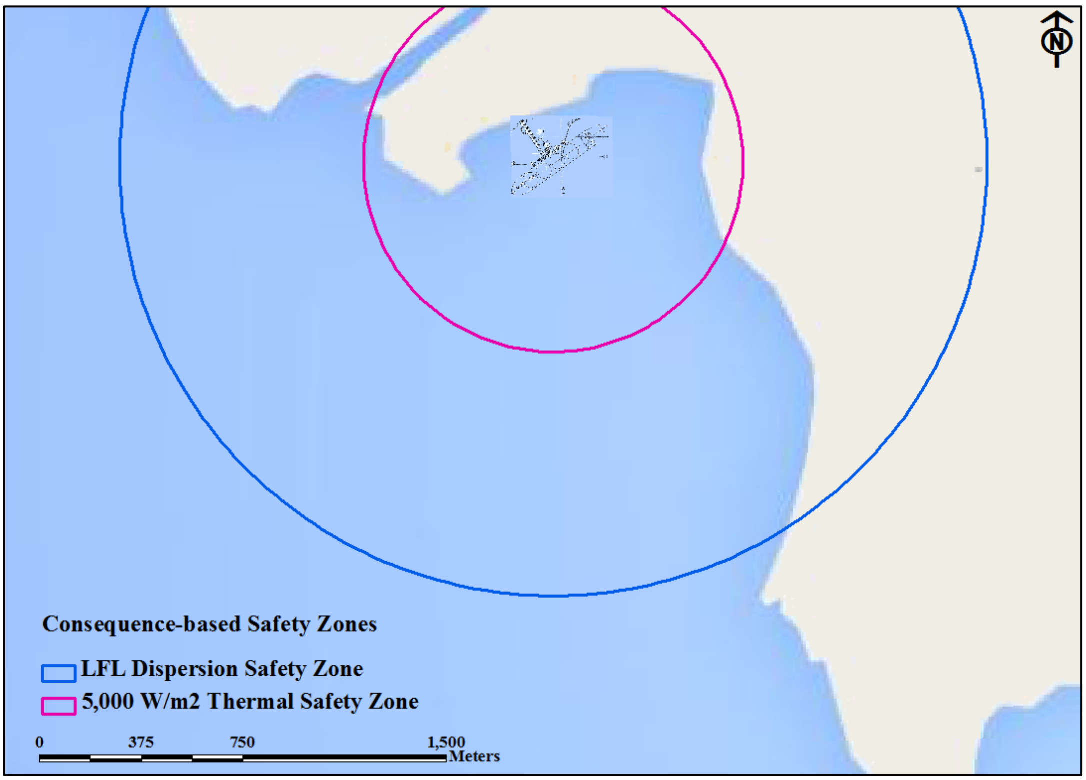

Figure 1 Dispersion and Fire Safety Zones – Deterministic Approach

Probabilistic Approach – Risk-based Method

Using the probabilistic approach, all scenarios defined in Table 2 are modelled considering and the safety distance determined using the risk-based method is presented in the table below (Table 4).

Table 4 Safety Distances (Safety Zone Radius) Determined by the Probabilistic Approach

Impact Criteria	Safety Zone Radius	Frequency

	(m)	threshold
Lower Flammable Limit (LFL)	500	1E-04 per year
5 kW/m^2	230	1E-04 per year

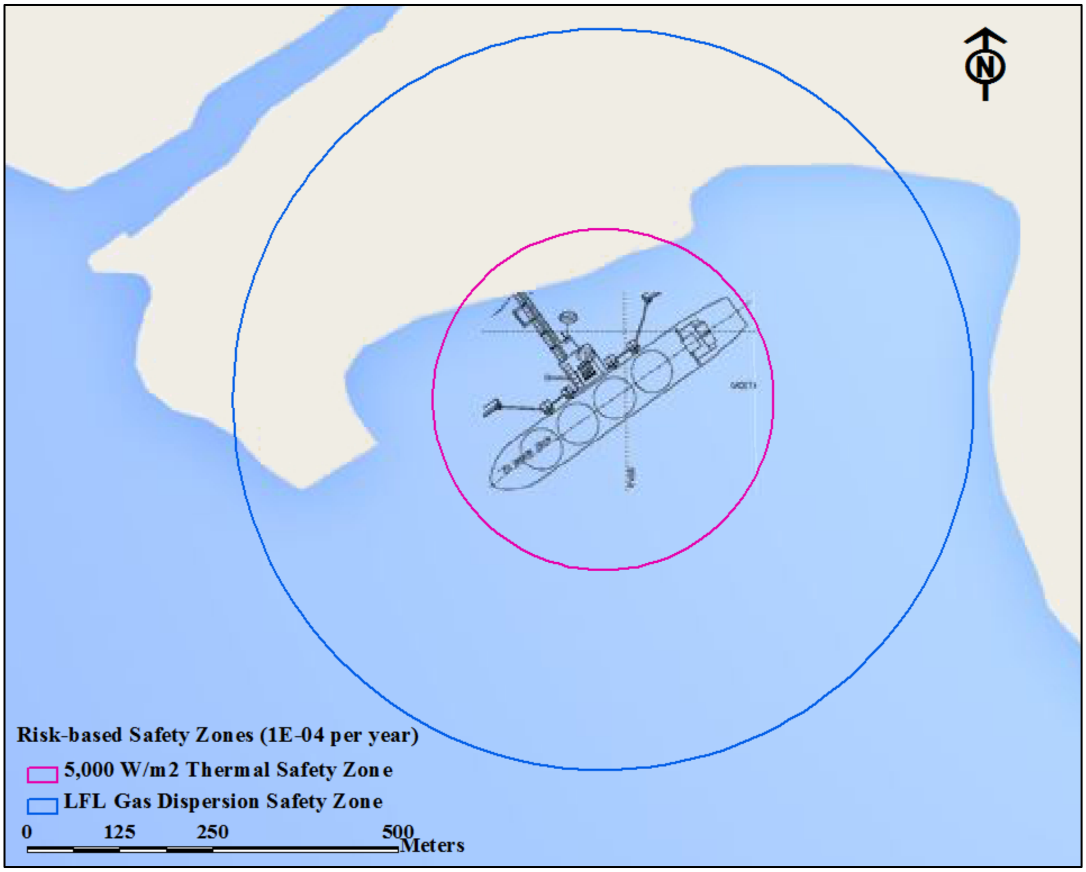

Figure 2 Dispersion and Fire Safety Zones – Probabilistic Approach

6 Conclusions

The consequence-based safety distances (used to generate the deterministic Safety Zones) are often greater than the risk-based safety distances, and are based on some assumption of maximum credible event. Therefore, the Safety Zones defined using the deterministic approach often covers more waterway area. This is the most conservative way of defining the Safety Zones with less details of the LNG facility needed; however, the estimated safety distance can be very large which is entirely based on one single large event without taking into account the likelihood of the event.

Although more information and effort are required to produce the risk-based safety distance used for defining the Safety Zones, it provides a more realistic basis for making risk reduction recommendations and focuses on site specific data related to all aspects of the operation (i.e. LNG loading and circulation, vapor return, LNG transfer, LNGC approaching/preparing for leaving). The risk based approach is more realistic because it considers the full range of the possible events, and combining the possible consequences with the likelihoods.

7 References

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