MARY KAY O'CONNOR PROCESS SAFETY CENTER
TEXAS A&M ENGINEERING EXPERIMENT STATION

19th Annual International Symposium
October 25-27, 2016 • College Station, Texas

Risk Benchmarking for Onshore and Offshore LNG Developments

Vijay Raghunathan and Robin Pitbaldo
DNV-GL Group.
vijay.raghunathan@dnvgl.com, robin.pitblado@dnvgl.com
Mukudray Dave
Bechtel Oil, Gas and Chemicals Inc.
mndave@bechtel.com

Abstract

With the continuing growth in the global LNG trade and an increased activity of liquefaction projects proposed within North America, safety risk management is gaining more focus both from regulators and public. Multiple Stakeholders, new technologies, tighter deadlines, cost efficiency and an increased focus on safety are some of the key factors driving these projects. As the industry is moving towards adopting principles of inherent safety, earlier in the projects, complex design decisions are being made with relatively less design data or input. This poses an endless challenge to both the project management making investment decisions and the design team making design decisions. Hence, the aim of this paper is to draw examples from previous LNG projects worldwide and provide best practice guidance on risk assessment processes.

The first part of the paper will focus on differences in regional regulatory requirements within North America and an understanding of the risk criteria being used. The uncertainties to be considered in an LNG QRA are covered in this section, which forms the key to early design decisions. The second part of the paper will summarize the qualitative risk results and discuss the top risk contributors from LNG projects including the band of individual risk observed.. Since likelihood of failure events usually plays a major role in the evaluation of risks, it is important to align these with the risk criteria used to ensure risk reduction decisions (ALARP decisions) are effectively made in the right order of priority i.e. focus on the top events first. Overall, this paper will serve as a risk benchmarking tool for both onshore and offshore LNG (FLNG) developments in arriving at key decisions earlier in the design.

Introduction

The significant changes in the oil industry over the past year have indeed affected the gas industry dynamics. LNG projects approved several years ago in a more robust pricing environment are now coming on stream. The supply abundance has affected gas hub and spot

LNG pricing levels. LNG contract prices are trending downward, driven by traditional oil-linked formulas (IGU, 2016). Most projects under construction remain active toward planned schedules as the engineering, construction, and procurement contractors have committed to construction schedules and could incur a penalty if they are late.

Similarly, many projects that have already made arrangements for their upstream feedstock would incur penalties if production is not received. While these commitments remain, the LNG stakeholders are constantly working to balance the risks vs price challenge. Extended commissioning and start-up periods, reduced performance, logistical challenges, cost overruns and other problems can all significantly affect a project's economics. The risks are significant and the underlying causes span political circumstances and unclear interfaces, to technology that does not deliver. LNG projects are large and complex, with advanced technology, and de-risking the project at evert stage of development has never been more critical. This paper aims at highlighting the experience gained previous LNG liquefaction developments to manage and mitigate risks for future projects at an early stage.

North America LNG Risk Management Regulations

Currently there are no enforced regulations that require the use of risk assessments for assessing safety hazards of new onshore or offshore LNG developments. Within the U.S. regulatory scheme, responsibilities for regulating safety of onshore LNG facilities with respect to potential releases of LNG and offsite hazards is shared according to jurisdictional requirements of two principal Federal agencies, the U.S. Federal Regulatory Commission (FERC) for siting and certification of onshore facilities serving LNG marine terminal activities and the U.S. Department of Transportation (DOT) for other large onshore facilities, Facilities outside the Federal jurisdiction, most simply characterized as facilities not part of the interstate natural gas system in the U.S. are covered by state and local requirements, which often refer to 49 CFR 193 requirements for offsite hazards as well as to NFPA 59A .The U.S. Coast Guard (USCG) is responsible for assuring the safety of marine operations in U.S. coastal waters under provisions of the Ports and Waterways Safety Act and also the Maritime Transportation Security Act (MTSA). The USCG also regulates the design, construction, and operation of LNG ships and the duties of LNG ship officers and crews (Ted A. Williams).

There are more than 110 LNG facilities operating in the U.S. performing a variety of services. Some facilities export natural gas from the U.S., some provide natural gas supply to the interstate pipeline system or local distribution companies, while others are used to store natural gas for periods of peak demand. Depending on location and use, an LNG facility may be regulated by several federal agencies and by state utility regulatory agencies **(**FERC**)**.

The FERC is responsible for authorizing the siting and construction of onshore and near-shore LNG import or export facilities under Section 3 of the Natural Gas. FERC requirements include detailed site engineering and design information, evidence that an LNG facility will safely receive or deliver LNG, and delineation of a facility's proposed location and geologic risk, if any.

Risk Based vs Consequence Based

Tolerability of consequences and risk is a contentious issue, but it has been addressed in many countries by various means. The following section describes the differences between a consequence-based and a risk based approach and its application.

Consequence Basis

Consequences are normally developed in one of two formats and there are sensible arguments for each

- Maximum Credible Event
- Worst Case Event

Maximum Credible Events (MCE) do not have a precise definition, but they are the maximum size event that is believed credible for the facilities in some realistic timeframe, say 2 to 5 plant lifetimes. It is larger than would be expected in the single lifetime of the facility under discussion. There is judgment involved in defining the MCE.

Worst Case Events also do not have a precise definition, but it is often easier to define a worst case compared to an MCE. The worst case would also give very large consequence zones, both from the operating facilities and from the shipping activities.

The simplest approach to establish tolerability is to calculate potential consequences and if the siting is sufficiently remote or population exposure small, then a site can be regarded as tolerable.

Siting criteria for LNG Facilities in the U.S. are established on a consequence basis in both NFPA 59A and in U.S. federal regulations 49 CFR 193. U.S. siting requirements appear stringent as these are based on a 10 minute worst case release from the largest pipe under full flow conditions. This will usually be the export pipeline from the LNG storage tank. Such a spill must be contained in a suitable impoundment nearby, and the vapour dispersion from the impoundment must not extend beyond the fence line at a concentration of ½ LFL for specified weather conditions. This is to define the downwind flammable envelope which might impact anyone caught within the cloud if it were ignited – termed a flash fire. Normally there are no safety impacts beyond the actual flash fire limit. Strictly the flammable limit is the LFL – Lower Flammable Limit, but it is generally acknowledged that there are uncertainties in prediction of the flammable distance, and the best models are generally only accurate within a factor of 2 either way (over or under estimate), hence ½ LFL is used to be conservative. There are also separate thermal criteria, but these are rarely the deciding separation distance.

The approach also requires that a formal validation exercise meeting PHMSA (Pipeline and Hazardous Materials Safety Administration) specifications. This must be submitted to PHMSA for approval. Currently, only 3 models have been approved by this process – DNV GL Phast, Gexcon FLACS, and the public domain DEGADIS. The validation is described by Witlox (3).

Risk Basis

Given the divergence in approaches for consequences and the very large distances possible with worst case events, many countries and developers now prefer to use a risk-based approach. The general method is described in the U.S. CCPS (Center for Chemical Process Safety) Guideline for Chemical Process Quantitative Risk Assessment (4). The advantage of the risk approach is that it focuses not on the worst case event, but instead the accumulation of the whole range of events from minor to worst case, but linking each event with its likelihood of occurrence. Thus catastrophic but very rare events are considered, but due to their low frequency the actual risk may be dominated by medium scale events which happen more frequently. Generally people plan their own lives using a mental model of the risk involved, not the possible worst case consequences – think of driving a car or riding in an elevator. If we based our decision on worst case – which would be death, we would never do either. Instead, we rely on good design and manufacturing practices, industry standards, and an effective regulatory regime to ensure that sufficient safeguards are in place that the risk of the activity is very small.

Major hazard process facilities are the same. We rely on good design and manufacture, that suitable codes are used throughout, and that the regulatory regime ensures all necessary safeguards are in place.

There are two main means to estimate risk quantitatively, either by Location Specific Individual Risk (LSIR) or by Societal Risk.

Individual Risk is normally calculated by defining all risk events – usually loss of containment events and for a large facility there can be hundreds of these. Each event is calculated for its possible consequences – dispersion, fire, explosion taking account of the possible wind direction and atmospheric stability, and all the various ignition sources. The event likelihood is estimated, usually from historical records of past leak events and then all the outcomes are summed to generate the risk at all locations around the facility. This is shown graphically as iso-risk contours (called LSIR contours) – similar to elevation contours on a map. The inner contour is the highest risk (often 1E-03 or 1E-04 per year) and normally contours are plotted in declining order of magnitude circles until some very low level of risk is predicted, often 1E-06 or 1E-07 per year. Generally, Individual Risk requires detailed calculations, beyond the scope of a High Level Assessment.

Societal risk is more complex and it is plotted as a so-called F-N graph – a log-log plot of Frequency of occurrence vs. the Number of people affected. It requires detailed calculations linking people affected by their location to all the events and this cannot be done for a High Level Risk Assessment. Other facility results only apply to the population distribution around those sites and that is always different for a new site.

Societal risk is most appropriate where there are large numbers of people potentially affected; that is not the case here and thus Individual Risk is more appropriate for this evaluation.

Risk Benchmarking

Risk benchmarking is an exercise to compile the common hazards that are key to designing a safe facility and this section of the document will split this into two parts. Part 1 will highlight the hazards, their qualitative risk impact that can be used for understanding the LNG hazards both onshore and offshore and de-risk the project at an early stage. The second part presents anonymized individual risk results from some LNG sites around the world to benchmark any new design either before or after a preliminary risk assessment.

Qualitative Benchmarking

For any onshore or offshore LNG development, an early HAZID is an important step in identifying the major accident hazards and the risk impact. The following table presents some of the key hazards, their associated risk impact and the safeguards that could be considered at an early stage of the project.

Typical Onshore and Offshore (FLNG) Hazards and Safeguards

Hazard	Risk Impact	Safeguard
Topside Layout	Offshore (FLNG): • A very long topside layout can have the design and technology limits stretched • Structural Load assessment could be a challenge while trying to design for complex combination of loads imposed by motion of tides • If the vessel is high sided it could be subject to wind loads (high windage) Onshore: N/A	• Technology qualification or Approval in Principle at an early stage could help identify issues early • Usual safeguard for FLNG is to weathervane and present bow to wind load, in this option that is not possible with fixed mooring
Safety Gaps	Offshore • There is a need for safety gaps between modules to mitigate potential vapour cloud explosion (VCE) risk. An increased safety gap could cost significant amounts due to increased vessel dimension requirements, hence a balance is required. • There are no widely-accepted criteria in the industry on optimum safety gaps for FLNG; however DNV GL from its previous experience has seen 7-15 m gaps between congested modules. Currently a joint industry research project is being led by	• A layout review and a design QRA to evaluate the effect of safety gaps

Hazard	Risk Impact	Safeguard
	Gexcon with DNV GL participating by running the large scale experiments at our Spadeadam test site. Onshore: • Safety Gaps may not be usually an issue in case of onshore developments given the availability of space, however combining of adjacent congested units should still be minimised to reduce VCE risk.	
Manning / Control Centre	Offshore • Manning offshore could be more of a challenge due to space constraints. • Other than the impact to manning at the main control center, the control center is safety critical and losing its functionality onboard an FLNG due to fire or explosion could lead to severe escalation. Onshore • The impact to control center is equally critical like an offshore set up but due to less space constraints can be managed better.	• A design QRA to evaluate personnel risk • Careful review of manning needs and location for control center
Flare	Offshore and Onshore • Height and orientation need to be considered carefully to make sure it doesn't distract any offsite activity or impact onsite workers. Also the flare is an active ignition source, hence location is critical. • A flare close to the airport flight path may cause distraction for pilots.	• The height of the flare must assure low thermal radiation onto nearby elevated process equipment and avoid ignition of flammable clouds. • If close to high hazard modules, the flare structure has to be designed to survive any immediate explosion effects and serve its

Hazard	Risk Impact	Safeguard
		function (e.g. blowdown is critical).
Single Train Option	Offshore and Onshore • Losing any part of a single liquefaction and fractionation units, may result in shut down causing more operational pressure on operators/maintenance to keep units running.	• Design and reliability review for more inherent safe options • QRA to assess impact of liquefaction area design
Mixed Refrigerant	Offshore and Onshore • There are potential detonation hazards if ethylene or any double bonded chemical is used part of the refrigeration cycle. • Unlike deflagration, detonation involves the entire mass of the flammable cloud and not just the cloud congested volume and hence produces higher overpressure.	• Evaluating potential for an inherent safe design substituting ethylene with ethane for example.
Cryogenic Spill	Offshore • Spills can cause cryogenic damage especially to the deck and hull, could impair the trestle as an escape way, and also affect access to lifeboats if they are downwind • Large cryogenic spill overboard could allow flammable gases to blow back onto the vessel. Onshore Cryogenic Spills might be easier to handle onshore due to less space constraints but there is a still a risk of both localised personnel and equipment damage.	• Cryogenic Spill Philosophy • Safeguard could be deck drainage and collecting spills using an insulated channel and diverting to an impoundment on the trestle.

Hazard	Risk Impact	Safeguard
Storage	Offshore • LNG storage could be Prismatic Type B or membrane, Spherical tanks are not practical • If condensate and/or LPG is stored onboard (may be in the hull), then additional cargo vessels will be visiting as well contributing to higher unloading risk. • Pressurized refrigerant storage and LPG on-board could pose additional hydrocarbon risk (BLEVE). Onshore Storage tank options are similar but the spills can be contained much easier and isolated from other units.	• Double-walled hull will protect against tank impacts from collision. • Cryogenic spill philosophy to divert spills quickly away from the process deck will minimize structural damage to hull deck and tanks below. • For inherent safety on FLNG, store refrigerant at safe location onshore and transfer from an ISO-container as needed to the FLNG barge (transfer of refrigerant would be required in any case if the refrigerant was stored onboard).
Escape and Evacuation & Rescue	Offshore • Very large congested vessel could pose a situational awareness problem, no visual clues about potential leak/incident on one end of the barge for personnel working on other end. • If Trestle connections are used to escape from the vessel onshore, they could be prone to structural damage from fire or explosion. Onshore • Escape and Evacuation route impact can be much less severe in an onshore arrangement due to less space constraint.	• Safety of escapeways for the full range of events needs to be part of the layout QRA. • Lifeboats may be necessary for potential evacuation for personnel located at each end of the vessel due to large flammable events preventing access to trestle and hence land. • Means to enhance situational awareness for staff at locations remote from escape needs to be considered (e.g. strobe Alarms). • Trestle escapeway structural design to withstand potential fire

Hazard	Risk Impact	Safeguard
		and blast accidental loads and ability to shelter staff • Multiple connection points between trestle and FLNG providing multiple egress options
LNG Carrier Pulling up aside	Offshore • Potential extra congestion source to any potential drifting vapour cloud posing higher explosion risk due to gas collecting between the vessels Onshore : Not applicable	• Deck drainage and collecting spills using an insulated channel and diverting to an impoundment on the trestle (opposite side of carrier position) • Shutdown of electrical sources upon flammable gas detection
Trestle vehicle movement	Offshore and Onshore • This could pose an additional ignition source given that there could be significant vehicle movement to move personnel and heavy equipment.	• Active control of the number of vehicle trips especially during loading could help mitigate the risk.
Moored vs Weathervaning	Offshore • Weathervaning is a standard safety measure for offshore FLNG facilities; however an onshore FLNG is moored and cannot weathervane.	• Safeguards would be to locate any accommodation / control room module upstream of the predominant wind direction to reduce the potential impact of drifting vapour clouds. • Layout review to assess predominant wind directions against possible ignition sources.
General Layout / Piping runs	Offshore	• Design review to optimise piping runs

Hazard	Risk Impact	Safeguard
	• Increased piping runs and hence increase congestion and could create more potential leak points. • Insufficient separation between process and accommodation modules Onshore • The same hazard applies but less of an issue due to more space available.	• A design QRA to evaluate separation gaps
SIMOPS	Offshore • If the FLNG is producing and offloading at the same time, this could impose structural stresses on the vessel with improper tank fill/export procedures. Example of such a vessel structural failure was the Betelgeuse incident in 1979 in Ireland. Onshore • In this case SIMOPS may be more of constructing multiple trains while one is producing.	• Management of loading operations including offloading of the LNG carrier could help mitigate the risk. • Classification structural review with extra strengthening to mitigate any cargo handling error • Better ignition source control during SIMOPS • A design QRA to understand the increased risk profile due to increased manning
Crane Location	Crane location to lift heavy equipment with respect to jetty location could be a dropped object hazard	• Material handling study will address this scenario and a subsequent dropped object study could help identify hazards of dropping and damaging the deck / equipment
Collision	Offshore • Interaction with fishing vessels, other recreational crafts; navigational equipment on those vessels might not	• Marine Traffic study and Collision Risk Assessment to better mitigate collision risks (TERMPOL study)

Hazard	Risk Impact	Safeguard
	be that sophisticated as other passing heavy vessels Onshore: Not applicable	addressing need for nav-aids or radar coverage.
Tide range	Offshore If connections to jetty need to accommodate a very high tidal range (approximately 5-6m) and this could be a safety issue. Onshore: Not applicable	Marine hazard assessment and Jetty design review
Manoeuvring	Offshore • Running aground could be an issue when tidal range could generate high local currents.	• Dredging / blasting of maneuvering area • Restrict berthing to slack tide only and daytime only in early operational phase.
Emergency Response	Offshore • Firefighting access from tugs or from the jetty could be difficult if the vessel is high sided vessel. Difficult to throw foam high in the air.	• Dedicated tugs designed specially to throw the water • Towers for firewater and foam delivery on the jetty side
Hydrocarbon Hazards	Offshore and Onshore • Any hydrocarbon release source like refrigerant storage or LNG loading or feed gas coming from onshore could pose flammable risk (Jet fires, BLEVEs from storage, flammable dispersion risk)	• A design QRA to better understand the risk to personnel and occupied buildings/areas.
Class Safety Requirements	Offshore Class requirements might apply in case of a FLNG barge	• To evaluate class requirements early in the design phase (Approval in Principle)
Seismically active area	Offshore and Onshore Earthquake/ Tsunami resulting equipment damage	Seismic review of design for foreseeable earthquake and tsunami hazards

Quantitative Risk Benchmarking

Any quantitative risk assessment will aim to cover the major process safety/major loss of containment hazard issues.

The main process safety / major hazard issues relate to:

1. VCE-Vapor cloud explosions (due to ignition of flammable clouds in congested spaces). In congested places, hydrocarbon leaks can occur filling both the source unit and adjacent units, allowing a vapor cloud to be ignited in one unit with flame speeds accelerating to VCE levels and then propagating to adjacent congested units before the flame speed has substantially reduced. Too close spacing effectively means the two units become one generating a higher overpressure, whereas greater spacing allows the overpressure to dissipate as it travels between the two units. While the next congested unit can cause the flame speed and hence overpressure to build up again, its starting point is close to zero and the maximum overpressure is less than when the two volumes combine. DNV GL participated in a TNO rule set reassessment in a project for BP and these generate less conservative results and have a clear rule set for when adjacent units combine (R. Pitblado, 2014). Key rules applicable here include – congested volumes should be based on the unit footprint but with the height limited to 25ft (7.6m). Two adjacent units will combine if their separation is less than 30ft (9.1m). However adjacent process structures such as the central piperack can connect two separated units – if the piperack base is less than 25ft (7.6m) high. A current Joint Industry Research Project coordinated by Gexcon and being carried out at DNV GL's Spadeadam test site is assessing congested space separations (termed safety gaps) and to allow CFD models – such as FLACS – to model these better than at present.
2. BLEVE- Boiling Liquid Expanding Vapor Explosion. If there are large pressure vessels containing liquid hydrocarbons at pressure (mainly the refrigerant liquids and heavies) and these can BLEVE if subjected to fire exposure – especially jet fires. BLEVE's have both overpressure and thermal impacts. BLEVE fireball diameters can easily exceed 100m at ground level and then rise due to buoyancy. These can impact the personnel spread across uniformly the facility.
3. Jet fires- The Cold box exchangers, usually operate at high pressure, in the range of 35 barg to 80 barg. Hence these units can generate liquid or vapor jet fires. The inlet natural gas source, the gas turbines, the gas treatment and the refrigeration trains also have a potential to generate vapor jet fires. Liquid jets are more serious (for a given pressure and hole size) as the mass discharge rate of liquids tends to be 10 times the mass rate of the same vapor. Jet fires could be mitigated by the blast wall if this also has a jet rating.
4. Pool fires- There could also be multiple sources of low pressure liquids –Boil-off gas units and spills from the loading/offloading system. Pool fires of LNG tend to be hotter than other hydrocarbons and to generate a thinner but taller flame – based on the large scale

Sandia trials 4-5 years ago. Pool size can be limited by deck drainage arrangements and allowing spills to fall freely overboard into the sea – if environmental regulations permit this. If regulations require spills to be retained in curbed areas and directed to an oily water tank – then the potential for longer lasting pool fires exists.

5. Flammable vapors. These can be generated in all areas, but natural gas is buoyant when close to ambient temperature to leaks from the gas turbines and regeneration units will tend to dissipate upwards, other cold natural gas or dense refrigerant leaks will be dense and spread through the units and either.

6. Cryogenic Releases- A cryogenic release hazard from a vapor cloud, spray or spill could have the potential to cause fatality or cryogenic embrittlement impact to the asset. All release scenarios which have a final discharge temperature < -29 deg C are assumed to have a cryogenic hazard potential. This threshold temperature of -29 deg C could cause immediate liquid cryogenic burns and permanent damage to the lungs from inhaled vapor and also damage to carbon steel. Main impact potential scenarios and assumptions captured in this assessment are cold unignited vapor cloud and fog causing impairment to humans resulting in fatalities or blocking escapeways and escalation potential across modules for cryogenic pools or sprays.

Some of the key factors that need to be taken into account while estimating the quantitative risk for a LNG facility are as follows.

- The number of process equipment affects the leak frequency. Liquefaction using mixed refrigerants will lead to higher hydrocarbon leak frequency than non-hydrocarbon refrigerants (e.g. nitrogen). However, use of nitrogen will have an impact in terms of asphyxiation that needs to be quantified.
- In terms of release frequency, there could be some uncertainty associated with the use of offshore frequency data (e.g. UK HSE's HCRD) for LNG equipment, however there is very little LNG-specific leak frequency data.
- Higher the operating pressure, the consequence zones will be higher and hence the immediate, escape & evacuation fatality fraction will be higher and this could lead to high risk values.

Individual Risk

- The exposure time of personnel will have an influence on Individual Risk, e.g. Control center staff spending no time in the process areas will have a much lower than Maintenance crews
- Other secondary factors will be effectiveness of gas detection, ignition sources, emergency shutdown, blowdown delay time that could affect end event fire frequencies. These will have a key role in terms of asset risk and impact on escape routes and living

quarters. They will a more limited influence on individual risk as it is usually driven by immediate fatalities.

- For non-process risks, ship collision depends on the location of the facility and no. of offloading operations, other supply vessel visits.
- Transportation risk depends on flying time only assuming standard offshore shift pattern
- Occupational Risk depends on the FAR values for different personnel a category which again is quite standard for offshore operations.

Societal Risk

- All of the points mentioned above for individual risks apply for societal risk. In addition the PLL depends on the manning distribution across the different hazardous process areas.
- For transportation, occupational and ship collision risk, more manning, more trips needed by helicopter, hence higher group risk.

Temporary Refuge Impairment Frequency (TRIF)

- In addition to the frequency and consequence comments that were mentioned in the individual risk above section, the location of the Temporary Refuge (TR) plays a key role. The location of the TR with respect to the process areas and the prevailing wind direction is key for addressing smoke hazards.
- The TR fire or blast rating is also a factor for determining its impairment.

Escape route Impairment Frequency

- Another issue is the availability of escape routes, due to the relatively narrow width compared to the length of FLNGs explosion and fire events have the potential to impair both escape routes at the same time, and hence escape route redundancy via the cargo deck can be usually be useful.

Risk Criteria

- Risk assessment is the process of comparing the level of risk against a set of criteria as well as identifying major risk contributors. In the risk assessment stage, the quantified risk results are compared to pre-established risk criteria (from governmental regulatory requirements, recommended guidelines, or corporate guidelines) to indicate whether the risks are tolerable or to make some other judgment about their significance.
- The critical point to note is the risk criteria picked must be closely aligned with the risk criteria to allow a meaningful assessment. Using very low failure frequency data and

comparing it with lenient risk criteria could result in incorrect judgement of the high risk contributors.

Individual Risk Benchmarking Example

DNV GL has conducted several LNG QRA's around the world. A simple benchmarking exercise has been conducted using this data to provide a better understanding and comparison of onshore LNG risk results. There are several parameters that affect the nature of the risk results:

- The number of process equipment (including number of LNG trains) directly affects the leak frequency.
- Variation in operating pressures can result in widely different risk results. Greater operating pressures are correlated to greater release frequencies and result in larger consequence zones.
- The geographic location of the plant could also affect the dispersion risk results.
- The end point criteria assumptions like flash fire fatality criteria (LFL or 0.5 LFL) could make a difference to the risk results.

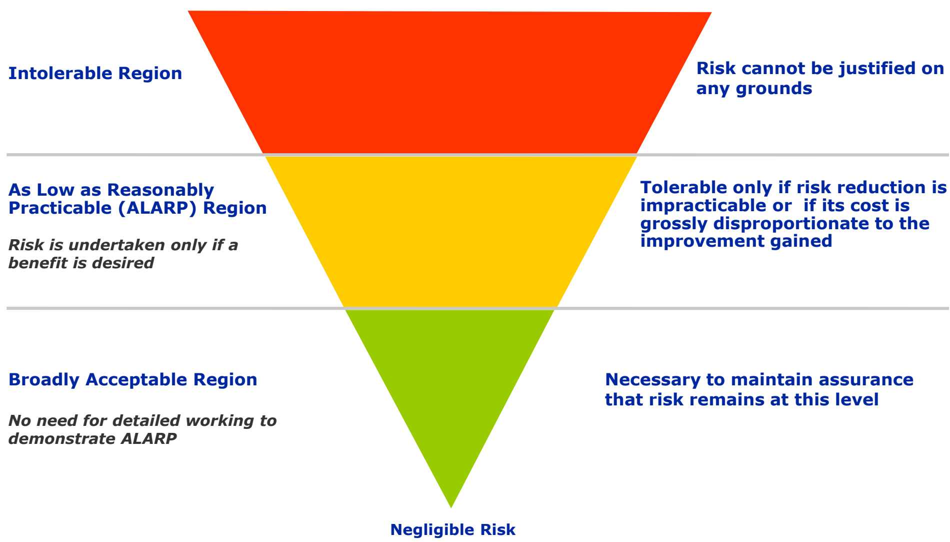
The individual risk (IR) results from eight onshore LNG facilities around the world are presented in the table below. For the different studies, the average radius of the LSIR contours (10-2 to 10-7) measured sideways and lengthways was collected.

Risk Results	Plant A	Plant B	Plant C	Plant D	Plant E	Plant F	Plant G	Plant H
LNG train area (meters)								
Radius - 10^{-2} pa				236				100
Radius - 10^{-3} pa						113		
Radius - 10^{-4} pa			180	317	130	176	35	422
Radius - 10^{-5} pa	79		355	507	228	388	279	556
Radius - 10^{-6} pa			405	573				
Radius - 10^{-7} pa	158		545	669	319	664	528	1200
Loading area (meters)								
Radius - 10^{-3} pa						57		

Radius - 10^{-4} pa		41		201		266	147	56

Conclusion

Risk Management is a Continuous process and the above presented benchmarking discussions can be used as a good starting point. As part of ongoing risk management ALARP (As Low as Reasonably Practicable) is a principle that can form the basis of a risk management system. It is philosophy for how one should treat risk and gives a goal to the risk management process. The CCPS defines ALARP as follows: The concept that efforts to reduce risk should be continued until the incremental sacrifice (in terms of time, effort, cost, or other expenditure of resources) is grossly disproportionate to the value of incremental risk reduction achieved.



An ALARP process is a systematic risk treatment process where potential risk reducing measures are collected, evaluated qualitatively or quantitatively and finally rejected or accepted. There is no single correct way in which to demonstrate risks are ALARP. However it is expected that for each major accident hazard identified for the facility, the demonstration will contain steps of the following process.

1. Identification and consideration of a range of potential measures for further risk reduction,
2. An ALARP register is established for the projects to keep track of identification, evaluations and decisions made related to a proposed risk reducing measure,
3. Systematic analysis of each of the identified measures and a view formed on the safety benefit associated with each of them,
4. Evaluation of the reasonable practicability of the identified measures,
5. The implementation (could be planned implementation) of the identified reasonable practicability measures,
6. Rejecting a risk reduction measure should be justified and well documented.

7. Recording of the process and results and update the ALARP register accordingly.

REFERENCES

American Institute of Chemical Engineers. (2000). *Guidelines for Chemical Process Quantitative Risk Analysis, 2nd ed.* New Year.

CSA Group. (Jan 2016). *CAN/CSA-Z276-15 Liquefied Natural Gas (LNG) – Production, Storage and Handling.* Standards Council of Canada.

FERC. (n.d.). http://www.ferc.gov/industries/gas/indus-act/lng.asp.

(2016). *http://www.marinetraffic.com/en/ais/home/shipid:1775/zoom:10.*

IGU. (2016). IGU World Gas LNG Report — 2016 Edition.

LNG Technical Symposium, A. S. (April 2012). *Witlox, H.W.M., Harper, M., and Pitblado, R., "Validation of Phast dispersion model as required for USA LNG Siting Applications".*

R. Pitblado, J. A. (2014). Facilitating consistent siting hazard distance predictions using the TNO Multi-Energy Model. *Journal of Loss Prevention in the Process Industries*.

Ted A. Williams, N. A. (n.d.). *RISK-BASED LNG FACILITY SITING AND SAFETY ANALYSIS IN THE U.S.: RECENT DEVELOPMENTS.* American Gas Association.