Journal of Loss Prevention in the Process Industries 22 (2009) 820–829

Contents lists available at ScienceDirect

Journal of Loss Prevention in the Process Industries

journal homepage: www.elsevier.com/locate/jlp

Risk analysis based LNG facility siting standard in NFPA 59A

Phani K. Raj [a,*], Theodore Lemoff [b]

[a] Technology & Management Systems, Inc., 102 Drake Road, Burlington, MA 01803, United States
[b] National Fire Protection Association, 1 Batterymarch Park, Quincy, MA 02169, United States

ARTICLE INFO

Article history:
Received 27 January 2009
Received in revised form
20 August 2009
Accepted 20 August 2009

Keywords:
LNG facility
LNG Standards
Risk analysis
Safety
Probability
Consequences

ABSTRACT

In the United States, liquefied natural gas (LNG) has the unique distinction of being the only flammable or hazardous material whose storage terminal (siting), handling and terminal operations are regulated by the federal government. Regulations are promulgated by the Pipeline and Hazardous Materials Administration (PHMSA) of the U.S. Department of Transportation (DOT). Storage and handling of all other flammable and hazardous materials are regulated by state laws. Current DOT regulations on LNG (49 CFR, part 193) are based on NFPA 59A, "Standard for the Production, Storage, and Handling of Liquefied Natural Gas," 2001 edition. These regulations are very prescriptive and inflexible in that they do not allow alternative safety mitigation considerations for LNG facility siting without applying for a special permit. The types and sizes of accidental releases to be evaluated are prescribed and no deviation is allowed. Without considering a spectrum of events, their likelihood of occurrence and the resultant consequences it is impossible to design proper mitigation actions or emergency response procedures. The benefit of knowing and preparing for a properly evaluated "most likely event" scenario is the resultant correct application of economics, and personnel resources of emergency responders.

The 2009 edition of NFPA 59A includes, in a mandatory annex, an alternative, risk-based requirements to evaluate the safety of land-based LNG facilities. DOT, in its regulations on the transportation of natural gas in interstate pipelines, requires the conduct of a "Pipeline Integrity Management" procedure to ensure public safety from accidental gas releases from interstate pipelines. The regulations refer to this procedure as "risk-based" even though frequencies of accidents or equipment failures are not considered. The National Association of Regulatory Utility Commissioners (NARUC) and the National Association of States Fire Marshals (NASFM) have recently passed resolutions calling on DOT (PHMSA) to initiate steps towards the development of risk-based LNG facility siting regulations.

This paper discusses the risk evaluation approach incorporated into a mandatory annex in the 2009 edition of NFPA 59A and possible other methods of performing a LNG facility risk assessment. Also discussed are the parameters that society has to agree to establish an 'acceptable' level of risk. The paper indicates the risk process used in other countries, particularly in Europe. The results from the application of a risk analysis procedure to a specific case are presented. A comparison of the risk-based results with those obtained from the application of the current prescriptive requirements in NFPA 59A (or 49 CFR, part 193) is indicated. Recommendations are provided for future actions.

1. Introduction

Liquefied Natural Gas (LNG) has the unique distinction of being the only fuel for which specific and detailed requirements exist for storage facility siting and construction in the federal regulations (49 CFR, part 193) of the U.S. Department of Transportation (US DOT). These regulations applicable to LNG facilities have been in existence since 1979. In addition, the National Fire Protection Association (NFPA) publishes NFPA 59A, "Standard for the Production, Storage and Handling of Liquefied Natural Gas". This Standard contains the criteria that should be complied with for plant siting and layout, locations of process equipment, storage container design, safety assessment and calculation of the extent of exclusion zones, fire protection, safety and security, maintenance, personnel training etc. These requirements relate to both construction and operation of LNG plants. The NFPA Standard was originally published in 1971 and included requirements based on lessons learned from the LNG release accident in Cleveland in 1944

* Corresponding author. Tel.: +1 781 229 6119.
E-mail addresses: tmsinc1981@verizon.net (P.K. Raj), tlemoff@nfpa.org (T. Lemoff).

0950-4230/$ – see front matter © 2009 Elsevier Ltd. All rights reserved.
doi:10.1016/j.jlp.2009.08.019

Table 1
Definitions of Design spill (NFPA 59A-2009).

Container penetration	Design spill	Spill duration
Containers with penetrations below the liquid level without internal shutoff valves	A spill through an assumed opening at, and equal in area to, that penetration below the liquid level resulting in the largest flow from an initially full container	Until all of the liquid above the level of the hole is released
Containers with penetrations below the liquid level with shutoff valves	The flow through an assumed opening at, and equal in area to, that penetration below the liquid level that could result in the largest flow from an initially full container	Until all of the liquid above the level of the hole is released
Containers with over-the-top fill, with no penetrations below the liquid level	No design spill	Not applicable
Impounding areas serving only vaporization, process, or LNG transfer areas	The flow from any single accidental leakage source	For 10 min or for a shorter time based on demonstrable surveillance and shutdown provisions acceptable to the authority having jurisdiction
Full or double containment containers with concrete secondary containers	No design spill	Not applicable

Sources of information in table: NFPA 59A-2009.

(Lemoff, 2008). The 2001 edition of the NFPA 59A Standard has been adopted to form (with minor changes) the current 49 CFR, part 193, DOT regulations. The 59A Standard is revised in approximately 3 year cycles (latest being the 2009 edition)[1].

The important feature of both the NFPA 59A Standard and the US DOT regulations is that they are prescriptive. That is, they specify details of the types of accidents to be considered, the locations, durations and rates of potential LNG releases, quantitative engineering design requirements, types of harm to the public to be taken into account, etc. In addition, the requirements are "geography independent," in that the requirements are applicable irrespective of whether the proposed facility is in a densely populated area or a sparsely populated suburban/rural area. Also, the Standard and the Regulations do not allow considerations of alternative safety mitigation procedures or technologies in LNG facility siting without obtaining, *a priori*, a special permit for specific items from the authority having jurisdiction (AHJ).

The requirements in the U.S. are in stark contrast to regulations in other countries where performance standards are specified in terms of potential risk to the population. The acceptable risk criteria are specified. When the risk posed by a proposed LNG plant is below the acceptability threshold risk the siting of the plant is permitted. However, if the risk is in a "grey area," in between the upper and lower threshold of acceptable risk, then additional mitigation measures may be enforced to reduce the risk to the population. Of course, if the calculated risk is above the maximum allowable risk, the plant is not permitted.

Recently, the NFPA 59A Committee adopted a risk-based LNG sting requirements for inclusion in the 2009 edition of the Standard. However, due to the fact that this was the very first time that NFPA 59A had ventured into a risk-based Standard, the Committee adopted to include the risk requirements in a "Mandatory Annex" rather than in the main body of the document. The intent was to provide an option to an authority having jurisdiction (AHJ) to adopt the risk-based assessment, in lieu of the prescriptive Standard.

The objectives of this paper are to (i) compare the siting requirements in the "prescriptive" and "risk-based" Standards, and (ii) to discuss the details of the recent action by the NFPA 59A Committee to include, in the Annex of the 2009 edition of the Standard, a risk-based alternative Standard. Other risk-based regulatory procedures are indicated only for purposes of discussion and to highlight their features and differences with that included in the 2009 edition of NFPA 59A.

[1] All references to NFPA 59A Standard should be construed as being to the 2009 edition. Other editions, if mentioned, are cited with the publication year.

1.1. LNG siting requirements in the U.S.; NFPA 59A & 49 CFR, part 193

The requirements for safety assessment, in both the NFPA 59A Standard (2001 edition) and the US DOT Regulations are virtually identical. The safety assessment for a LNG plant consists of ensuring that for the "design spill" from a storage tank and under specified atmospheric conditions, (1) the radiant heat flux at the plant "property line that can be built upon" or at the nearest occupancies do not exceed the specified levels, and (2) the average concentration of LNG vapor in air does not exceed 50% of the lower flammability limit (LFL), in the case the vapor cloud generated by LNG release is not ignited but disperses in the atmosphere. For methane the LFL is 5% in air. Only in the case of dispersion of vapors the effects of certain passive migration measures (such as a provision to detain vapor, employing impounding surface insulation, providing water curtains and other methods) can be considered in the calculations, if provided in the design, and when acceptable to the AHJ. Table 1 shows the "design spill" specifications. Table 2 shows the radiant heat flux hazard criteria in NFPA 59A.

It is noted that the only types of "spills" considered are the releases from the storage tank with a hole size equal to size of penetration of the tank, and the release from a transfer piping (liquid withdrawal pipe) at the full flow rate. NFPA Standard assumes that there is no potential for release from a double containment tank with a concrete secondary container; however, the US Federal Energy Regulatory Agency (FERC) requires the

Table 2
Radiant heat flux limits to property lines and occupancies.

Radiant heat flux		Exposure
$Btu/hr/ft^2$	W/m^2	
1600	5000	A property line that can be built upon for ignition of a design spill
1600	5000	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 in an impounding area
3000	9000	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 assembly, educational, health care, detention and correction, or residential occupancies for a fire in an impounding area
10,000	30,000	A property line that can be built upon for a fire over an impounding area

Sources of information in table: NFPA 59A-2009.

evaluation of the radiant heat effects due to roof collapse and a liquid pool fire on top of the tank. Clearly, the scenarios, types, locations, sizes and durations of potential releases to be considered are limited and very specific, irrespective of the any safety features and systems that may be included in the plant design. Also, no credence is given to how often (or the annual probability of) any type of release and the subsequently resulting LNG behavior scenarios will occur. All possibilities are weighted equally. Finally, no assessment of the possibility of ignition of a dispersing vapor, between the release location and the point at which the vapor concentration falls below ½ LFL, is allowed.

1.2. Elements of a risk-based assessment

There are many excellent books and monographs on risk analysis, its elements, procedure for calculating the risks to a given population from specified activities, risk communication and differences between voluntary and involuntary risk in the context of exposing a population to hazards (Glickman & Gough, 1990; Morgan (1993); Breyer (1993); CCPS (1999)).It is not, therefore, the intent in this paper to discuss these subjects in detail but to touch upon the salient concepts so that the application of the risk analysis principles to siting a LNG facility can be understood.

Risk analysis as applied to a LNG facility siting has five components. The first step is the assessment of the types of potential accidents/incidents that can lead to the release of LNG. The second step is the estimation of the location, size, rate and duration of releases. The third step is the determination of the probability of the different types of releases identified earlier and the conditional probability of each type of possible LNG behavior (or hazard) associated with each type of release. The fourth step is the determination of the consequences of each type of release in terms of specific hazard criteria or exposure of people and property. The last and final step is the comparison of the calculated risk with risk acceptability criteria. This process is schematically illustrated in Fig. 1.

Risk is often defined as the product of probability of occurrence of a detrimental event and its consequences (measured in accepted units). The overall risk is the sum of all risks from different elements and potential release modes. Equation (1) and equation (2) below represent the above concepts in mathematical form.

$$\text{Risk} = [\text{Frequency of occurrence of event, i.e. }\#/\text{year}] \times [\text{Consequence of the event}] \quad (1)$$

$$\text{Total Risk} = \sum_{\text{All events}} \text{Individual Event Risk} \quad (2)$$

Of the two elements on the right hand side of the above risk equation (1) the evaluation of the consequences of releases of hazardous materials has received much attention. The values for the frequency of occurrence of failures (mechanical or human caused) are much harder to estimate, especially where historical failure data are sparse or non-existent (as in the case of LNG industry and LNG plants). Generally, data for failures are obtained from experience base in other industries with similar plant constructions, equipment and operational features. One source for component failure rates for LNG risk assessment is the publication by the British Government agency, Health and Safety Executive (HSE, 2003, chapter 6k).

1.3. Risk acceptability criteria

Risk analysis can be conducted to evaluate both the individual risk and the societal risk to people living around a proposed facility. The following definitions of the two types of risks are generally used in the literature (Bottelberghs, 2000).

The **individual risk** for a point-location around a facility or a hazardous activity is defined as the (annual) probability that an average, unprotected, person permanently present at that point-location would get exposed to a hazardous level of harm (or suffer fatality) due to all types of accidents at the facility or, the hazardous activity.

The **societal risk** from a facility or a hazardous activity is the (annual) probability that a group of more than N persons would be exposed to hazardous level of harm (or suffer fatality) due to all types of accidents at the facility or, the hazardous activity.

The "individual risk" is dependent on only the location with respect to the facility and not on the characteristics of any individual or the density of population surrounding a facility. The "societal risk," on the other hand, is dependent on both the density of people surrounding a facility and the location of population with respect to the facility. The societal risk is generally presented in the form of a curve, on a log–log plot, expressing the relationship between the annual probability (F) of exceeding a given number of fatalities or other harm (N) and the number N.

In most countries the risk assessment is performed on the basis of potential fatalities to the exposed population. Different countries use slightly different criteria for risk acceptability. In the UK, the Health and Safety Executive (HSE) guidelines are to use the individual risk as the principal measure of risk and also use the societal risk criteria (for land use planning). The acceptability criteria levels for risks for facilities in the UK are specified by HSE (1989). Facilities are permitted only when these (published) criteria are met. In the Netherlands, however, both the individual risk criteria and the societal risk criteria have to be met when considering (in risk assessment) those events whose hazardous effects extend to such distances at which the conditional probability for lethality is higher than 1% (Bottelberghs, 2000). The risk tolerability criteria for fatalities established in various countries for both individual risks and societal risks are summarized in Table 3 below.

1.4. Why risk-based assessment may be preferable

The current criteria in the U.S. Standards for potential hazardous exposure from LNG facilities are defined only with a single exposure measure (such as the radiant heat flux in the case of fire exposure) where multiple measures (such as the time of exposure or dose) are needed to specify, correctly, the effect of the hazard. In addition, the hazard criteria are based on threshold injury only. The calculation of the threshold injury distances do not consider natural mitigating circumstances (such as, shadows of buildings and other objects that reduce/eliminate radiant heat effects in the case of fires and enhance the mixing of vapor with air in the case of dispersion of vapors, and naturally occurring ignition sources in an industrial/urban neighborhood which will ensure the quick ignition of a vapor cloud thus limiting its penetration distance). Last, but not the least, several other types of behaviors of LNG releases are not required to be considered. These types of LNG behavior include (i) Ignition of a dispersing vapor cloud in the presence of obstructions which enhance turbulence effects and lead to a deflagration type vapor cloud fire, (ii) Ignition of a dispersing vapor cloud in the presence of obstructions which enhance turbulence effects and lead to a possible vapor cloud explosion, (iii) Spill of LNG during transfers (say, at the dock) onto or into water and the consequences there from, (iv) LNG release in the form of a jet from a defect or leak in a pipeline and formation of a jet fire, etc. When these limitations are compared with the assessment process included in a risk analysis, it is seen that the latter approach will provide a better representation of the realistic hazard potential to the public from a LNG facility. It is, of course, necessary that risk

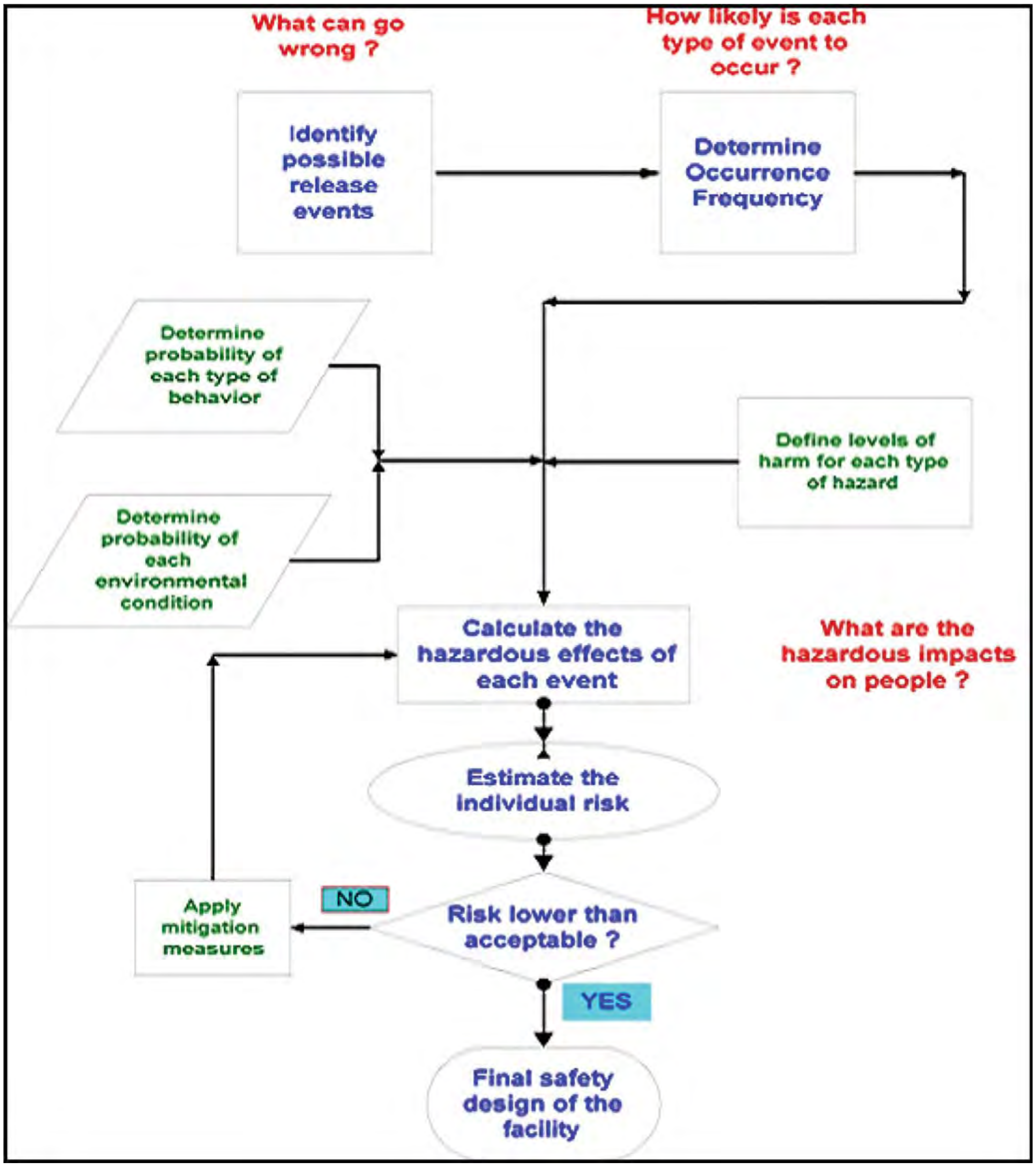

Fig. 1. Schematic illustration of Risk Assessment Procedure.

assessment should be conducted on a site-specific basis, which will take into account the specific nature of the topography, population distribution in the proposed plant vicinity, existence of physical structures immediately beyond the plant property line (that may mitigate some of the potential hazards), types of industrial or commercial activity in the neighborhood that may mitigate or amplify the potential for hazard, etc. Such specificity to a particular location of a proposed plant is, generally, absent in prescriptive standards.

In a risk-based approach, all types of failures and accidental conditions are considered. More importantly the release scenarios are weighted by the likelihood of occurrence, which provides a proper estimate of the potential (and realistic) sizes of accidents that need to be considered and, perhaps, responded to. Also, local conditions and distribution of occupancies, including densities of population in the surrounding areas, are taken into account. Risk analysis also provides a means of testing, *a priori*, the effect of any type of mitigation approaches in the extent of reduction of the risk. The process also lends itself to input from local authorities which can lead to optimal decision-making. The risk-based assessment and review of granting permits for new LNG and other facilities has been successfully employed in most other countries where there is a boom in LNG facilities construction.

It is because of these advantages with the risk-based sting of LNG facilities that the NFPA 59A-2009 Standard incorporated an alternative risk-based assessment (more details on this in section 3). Also, recently, both the National Association of Regulatory Utility Commissioners (NARUC) and the National Association of State Fire Marshals (NASFM) have adopted resolutions supporting the concept of Risk-based LNG facility siting (NARUC, 2008; NASFM 2009). This resolution recommends that the US DOT:

1 Evaluate and develop alternatives and risk-based regulations as a supplement to its existing LNG facility siting regulations, and
2 Perform the appropriate research and other activities as may be needed, including but not limited to, comparative analyses of alternative (including the Risk-Based Alternative Standards approach approved by NFPA's LNG Standards (59A) Committee), public workshops, and other studies.

Table 3
Summary of fatality risk tolerability criteria.

Country/Agency	Criterion Annual probability	Remarks	Reference
Individual Fatality Risks (IFR)			
UK/HSE	IFR $\leq 10^{-6}$	Tolerable "fatality" criterion for the public & workers	HSE (2001)
	IFR $\geq 10^{-4}$	Unacceptable "fatality" criterion for the public	
	IFR $\geq 10^{-3}$	Unacceptable "fatality" criterion for the worker	
Netherlands	IFR $\geq 10^{-6}$	Not acceptable for new housing	Bottelberghs (2000)
	IFR $\geq 10^{-5}$	Not acceptable for office buildings, restaurants, etc.	
Ireland/HSA	IFR $\leq 5 \times 10^{-6}$	Acceptable for non-residential structures	**New Facilities**: HSA (2006)
	IFR $\leq 10^{-6}$	Acceptable for nearest residential property	
	Zone 1: IFR $\leq 10^{-5}$	*Not permitted* – Residential, office and retail	**Existing Land use:** HSA (2006)
		Permitted: Occasionally occupied developments (ex., pump houses, transformer stations, etc).	
	Zone 2 $10^{-6} \leq$ IFR $\leq 10^{-5}$	*Not permitted*: Shopping centers, large scale retail outlets, restaurants, etc	
		Permitted: Work places, retail and ancillary services, residences in areas of 28–90 persons/ha density.	
	Zone 3: $3 \times 10^{-7} \leq$ IFR $\leq 10^{-6}$	*Not permitted*: Churches, schools, hospitals, other major public assembly areas and other sensitive establishments.	
		Permitted: All other structures and activities	
Societal Fatality Risks			
UK/HSE	$F = 2 \times 10^{-4}$, $N = 50$ Slope $= -1$	Unacceptable above the line in the previous column	HSE (2001)
	$F = 2 \times 10^{-6}$, $N = 50$ Slope $= -1$	Broadly acceptable below the line in the previous column	
	ALARP	Acceptable with review in the region between the two lines above	
Netherlands	$F = 10^{-5}$, $N = 10$ Slope $= -2$	Unacceptable above the line in the previous column	Ball and Floyd (1998)
Hong Kong	$F = 10^{-4}$, $N = 10$ Slope $= -1$	Unacceptable above the line in the previous column	
	$F = 10^{-6}$, $N = 10$ Slope $= -1$	Broadly acceptable below the line in the previous column	

2. Current risk-based assessments related to natural gas systems

The US DOT, in its regulations (49 CFR, part 192, Sub part O) concerning safety in gas transmission pipelines, requires an assessment of the pipeline integrity by a methodology, which it terms as 'risk-based." Unfortunately, the term "risk-based" used in this regulation is a misnomer since neither the probability of pipeline accident occurrence nor the consequences of each size accident is used in the assessment. To highlight what this regulation requires and why it is not a true risk assessment, a brief review of the requirements in this regulation is indicated below. The European Standard for the siting of LNG facilities requires, primarily, a risk-based approach to evaluating the site safety (al though a prescriptive, hazard based approach can also be used). These two approaches are described below in brief.

2.1. DOT pipeline integrity management

The pipeline integrity management system (PIMS) is intended to ensure the safe operation of a gas transmission pipeline without causing potential danger to the surrounding population or structures. The principal element of PIMS (49 CFR §192.911) includes the development of a baseline plan consisting of (i) identification of all high consequence areas along the pipeline route, and (ii) identification of threats to each covered pipeline segment using available data and risk assessment. The high consequence areas are defined by different classes of assets in §192.5 and the requirements for their consideration in the PIMS are indicated in §192.903. Table 4 shows the various classes of asset locations defined in 49 CFR, part 192.

The assessment procedure in US DOT's PIMS, even though it is called as a risk-based analysis, does not include the estimation of the threat occurrence probabilities or pipeline failure frequencies. The only hazard area calculated is the "***potential impact radius (R),***"where $R = 0.69\sqrt{pd^2}$, with '*R*' is the radius of a circular area in feet surrounding the point of failure, '*p*' is the maximum allowable operating pressure (MAOP) in psi in the pipeline segment, and '*d*' is the nominal diameter of the pipeline in inches. The procedure, instead, involves the identification of the presence of any high consequence value assets and taking such preventive, mitigative or remedial actions as are necessary (including relocation of the pipeline path). Table 4 shows the definitions used in the regulations for different classes of pipeline locations and high consequence areas.

2.2. European National Standard – EN 1473

The European Standard (EN 1473, 2006) requires that LNG installations be designed to have risk levels at or below the generally accepted levels specified in the Standard (in Annex L, EN 1473). These risks refer to life and property outside and inside the plant boundaries. In order to ensure a high level of safety in the LNG facilities and its surroundings, EN 1473 requires that safety shall be considered throughout all the project development phases: - engineering, construction, start-up, operation and decommissioning. In particular, hazard assessments are required to be carried out to evaluate the dispersion of vapors produced by a LNG release as well as the radiant heat hazard from LNG fires. EN 1473's criteria for hazards are similar to (but not the same as) those in NFPA 59A; both use % of LFL as the criterion for vapor hazard extent and thermal heat flux levels for fire hazard. However, several countries (UK and Ireland) while adopting the EN 1473 procedure in risk analysis use different (dosage) criteria for heat hazards from fires. The risk acceptability criteria used in England are indicated in a HSE publication (HSE, 1989).

The risk analysis procedure required under EN 1473 includes the following steps[2]:

[2] Detailed values of the various criteria in EN 1473 annexes are not provided. This is because, these are similar to the ones incorporated into the Alternative Risk-based Standard NFPA 59A-2009 edition.

Table 4
Pipeline class locations.

Location Class #	Definitions	Remarks
1	(i) An offshore area; or (ii) A class location unit that has 10 or fewer buildings intended for human occupancy.	(1) A "class location unit" is an onshore area that extends 200 m on either side of the centerline of any continuous 1.6 km length of pipeline.
2	More than 10 but fewer than 46 buildings intended for human occupancy.	(2) Each separate dwelling unit in a multiple dwelling unit building is counted as a separate building intended for human occupancy.
3	(i) A class location unit that has 46 or more buildings intended for human occupancy; or (ii) An area where the pipeline lies within 91 m of either a building or a small, well-defined outside area (such as a playground, recreation area, outdoor theater, or other place of public assembly) that is occupied by 20 or more persons on at least 5 days a week for 10 weeks in any 12-month period. (The days and weeks need not be consecutive.)	The length of Class locations 2, 3, and 4 may be adjusted as follows: (1) A Class 4 location ends 200 m from the nearest building with four or more stories above ground. (2) When a cluster of buildings intended for human occupancy requires a Class 2 or 3 location, the class location ends 200 m from the nearest building in the cluster.
4	Any class location unit where buildings with four or more stories above ground are prevalent	

A high consequence area is defined as:	
(i)	A Class 3 location or
(ii)	A Class 4 location or
(iii)	Any area in a Class 1 or Class 2 location where the potential impact radius is greater than 200 m, and the area within a potential impact circle contains 20 or more buildings intended for human occupancy; or
(iv)	Any area in a Class 1 or Class 2 location where the potential impact circle contains an identified site.
	OR
	The area within a potential impact circle containing—
(i)	20 or more buildings intended for human occupancy, or
(ii)	An identified site.

Source: 49 CFR, part 192, §192.5 & §192.903.

1 Listing of potential hazards of external and internal origin;
2 Determination of the consequences of each hazard and their allocation into the Standard specified classes of consequence (Annex K);
3 Collection/input of failure rate data;
4 Determination of the probability or frequency of each hazard;
5 Summation of frequency for all hazards within any one allotted consequence class and classification by the frequency range for that consequence class (Annex J);
6 Classification of hazards in accordance with their consequences class and frequency range, in order to determine the level of risk (Annex L).

In this Standard, detailed assessments of individual or societal risks and the plotting of their contours (or the F vs. N curve) are required directly, as in the case of UK and Irish regulations.

A comparison of the important current requirements related to safety in NFPA 59A (prescriptive part of the standard) and EN 1473 is indicated in Table 5.

3. Details of alternative risk-based standard in NFPA 59A (2009)

The NFPA 59A Committee voted to include an alternative risk assessment-based standard in a mandatory annex in the 2009 edition of the LNG facility siting standard. The preamble to this risk-based standard states that "LNG plants shall be designed and located in such areas as to not pose unacceptable risks to the surrounding populations, installations or property." In addition, it states that reassessment of the risk to the surrounding population is required to be performed once in three years, or as required by the AJH or if the plant is modified or other conditions change, to ensure that the risk to the people does not exceed an acceptable level.

In the NFPA 59A (2009), the risk assessment procedure and criteria for acceptability for siting a LNG plant are based on "Societal Risk" considerations. That is, the annual frequency with which a certain level of hazard (in this case injury from exposure to radiant heat and vapor concentrations higher than LFL) may occur to a specified number (or less) of persons. Obviously, the risk result (based on such criteria) depends upon the local population density, among other variables. It is entirely possible that in future editions, other criteria based on "risk to a typical individual" would be included.

The principal requirements and features of the "Societal Risk-based" Risk Assessment protocol included in NFPA 59A, 2009 edition Annex are:

1 Consideration of a spectrum of LNG release scenarios obtained from systematic (ex, HAZOP type) analyses and including the release scenarios currently in prescriptive section.
2 Evaluation of the annual probabilities of occurrence of release scenarios, including the conditional probabilities of different types of LNG behavior, in different weather conditions.
3 Characterization of an event (taking into consideration the occurrence of conditional probability sub-events) into a probability class based on published class listings (Table 6)
4 Determination of the consequence categories according to the number of injuries (see Table 7). The criteria for injury, whether exposed to a fire or to a flammable vapor cloud concentration are the same as in the current Standard.
5 Mapping the frequency-consequence pair for each release scenario event into an acceptability matrix, indicated as Table 8.

If the risk (denoted by the annual probability of occurrence and the corresponding magnitude of consequence) is in the region denoted by "***A***" in Table 8, then the risk is deemed to be acceptable and no further review is needed of the facility design. In the case that the risk falls in the "**AR**" region then appropriate design changes (including provision of mitigating technologies and operational changes) need to be made, in consultation with and approval of the AHJ, to minimize the calculated risk. Should the risk fall in the "*NA*" region the design would not be acceptable.

The NFPA 59A risk approach is "Societal" in nature. It does not require the evaluation of individual risks. This is because, the Standard is more focused on the society and the location where the plant will be built (and hence the geographical and the demographical details are important).

Table 5
Comparison of prescriptive requirements for siting and operating LNG facilities In NFPA 59A and risk-based requirements in EN 1473- the European Standard.

Item #	Topic	NFPA 59A (prescriptive requirements)	EN 1473:2006
1	General philosophy	Siting criteria are based only on consequences from deterministic events. Specified types and magnitude of releases are required to be evaluated. No consideration is given to how often the specified releases may occur. No flexibility is allowed in considering any other types, sizes or frequency of releases.	Provides the option to consider the siting hazard assessment based on the hazardous effects of "credible" releases, or using risk analysis which considers an entire spectrum of events, their frequency of occurrence and their consequences.
2	Siting acceptability criteria	Based only on specific consequence metrics (for fire radiant heat hazard and vapor cloud concentration, see items 6 and 7 below). These consequence criteria shall not be exceeded for specified target classes within the exclusion zone.	Acceptability of a site is based on the calculated 'societal risk' from the plant being within acceptable range. This range is expressed in a matrix of class of event frequencies and magnitude class of events. EN 1473 defines a set of seven ranges of cumulative plant accident (all) frequencies and five classes of consequences (with three sub classes, namely fatalities, injuries and hydrocarbon quantity released). In the matrix certain regions are termed Risk Magnitude 1 region (low frequency –low consequence "cells"), Risk Magnitude 3 (high frequency- high consequence "cells") which is unacceptable and a Risk Magnitude 2 which is acceptable only with additional safety systems and procedures.
3	Types of LNG tanks allowed	Single containment, full or double containment types allowed. Bottom penetration tanks allowed.	Single containment cylindrical metal tank; double containment cylindrical metal inner tank and metal or concrete outer tank; full containment cylindrical metal inner tank and metal or concrete outer tank; pre-stressed cylindrical concrete tank with an internal metal membrane are acceptable. In addition, other types, such as cryogenic cylindrical concrete tank: internal concrete tank and pre-stressed concrete outer tank; spherical tank, is also acceptable if the tank meets the functional requirements specified in EN 1473. No penetrations of the primary and secondary container base or walls of tanks are allowed.
4	Impoundment sizing	For leaks from tanks the impoundment volume should be at least 110% of the largest tank's maximum capacity. For spills from transfer piping and in process areas, the impoundment volume is 100% of the volume spilled at the highest flow rate from the largest size equipment/ piping for 10 min or shorter time if the surveillance and shut off system is approved.	The spill collection system or impounding basin capacity for process areas are required to be at least 110% of the total liquid inventory of the largest equipment item and related piping and other equipment that can drain through this item. For transfer areas and in the interconnecting pipe-work the impounding basin capacity can be determined by risk analysis considering potential leak sources, flow rates, detection systems, manning levels and response times.
5	Spacing of containers and other exposures	Spacing requirements for containers and exposures are specified based on the size of the containers.. Inter-tank distance can also be calculated on the basis of specified allowable heat flux values on adjacent tank roofs from a fire on a tank. Consideration of the mitigative effects of active water spray or deluge systems are allowed.	The spacing between two adjacent tanks is to be obtained by a detailed hazard assessment. The minimum separation distance cannot be less than half the diameter of the secondary container of the larger tank.
		For large tanks the spacing between tanks is not less than 1/4th of the sum of the diameters of the tanks.	Other hazard area separation distances are to be based on an assessment of the vulnerability of equipment to fire or blast effects due to release from a neighboring equipment. Specific thermal flux levels are specified. It is the responsibility of the designer to justify the maximum thermal radiation flux level used by calculating the surface temperature consistent with the expected duration of the fire and show that it is sufficiently low to maintain the integrity of the structure. The heat flux level can be reduced to the required limit by means of separation distance, water sprays, fire proofing, radiation screens or similar systems.
6	Design spills	Design spill volumes are based on 10 min (or less time if the surveillance and shutoff systems are approved) spill at full flow rate from the largest size line from tanks with top penetration only. For bottom penetration tanks no time limit for spill indicated.	A spectrum of LNG release scenarios developed from HAZOP or other techniques are to be considered in performing a risk assessment. For the analysis based only on hazard considerations, "credible" spills are to be considered.
7	Hazard limit for exposure to fire radiant heat effects	Two radiant heat flux values are specified for the radiant heat (limit) fluxes for exposure at the property line or at a point used by assembly of 50 or more people. (See Table 2)	Allowed radiant heat levels (in kW/m^2) are Concrete outer surface of adjacent storage tanks = 32 Metal outer surface of adjacent storage tanks, = 15 outer surfaces of adjacent pressure storage vessels, etc. Control rooms, workshops, laboratories, warehouses, etc. = 8 Administrative buildings = 5 Area only infrequently occupied by few persons = 8 (ex, farmland, desert, etc.) Critical areas (occupied by persons with no protective = 1.5 Clothing, or population density $> 20/km^2$ Other areas (industrial, LNG operator facilities, etc) = 5
8	Vapor concentration limit for hazard from the dispersion of vapor cloud	Hazard distance arising from the dispersion of vapor is to be determined by using the criterion that a this distance the average vapor concentration is equal to 50% of the lower flammability limit (LFL)	Hazard distance arising from the dispersion of vapor is to be determined by using the criterion that a this distance the average vapor concentration is equal to 100% of the lower flammability limit (LFL)
9	Consideration of the effects of passive mitigation systems	Passive mitigation allowed only for minimizing vapor dispersion hazards, when approved by the AHJ	Passive systems and other systems can be considered in the risk assessment, especially if the overall risk falls in the ALARP region

Table 9
Calculation of individual risk for a person at distance "S" from plant center.

Release scenario	Annual probability of release	Compass direction (10° sector)	Probability of wind in the compass direction	Total annual probability of hazard extending to hazard distance	Hazard distance in the specified direction ("X")	Individual risk from accidents for which X>=S
Impoundment fire	P1	E	Pd1	P1 × Pd1	X1	P1 × Pd1
Impoundment vapor source	P2	E	Pd1	P2 × Pd1	X2	P2 × Pd1
Transfer pipe break	P3	E	Pd1	P3 × Pd1	X3	0
				Total annual risk to an individual at "S"		Sum numbers in this column

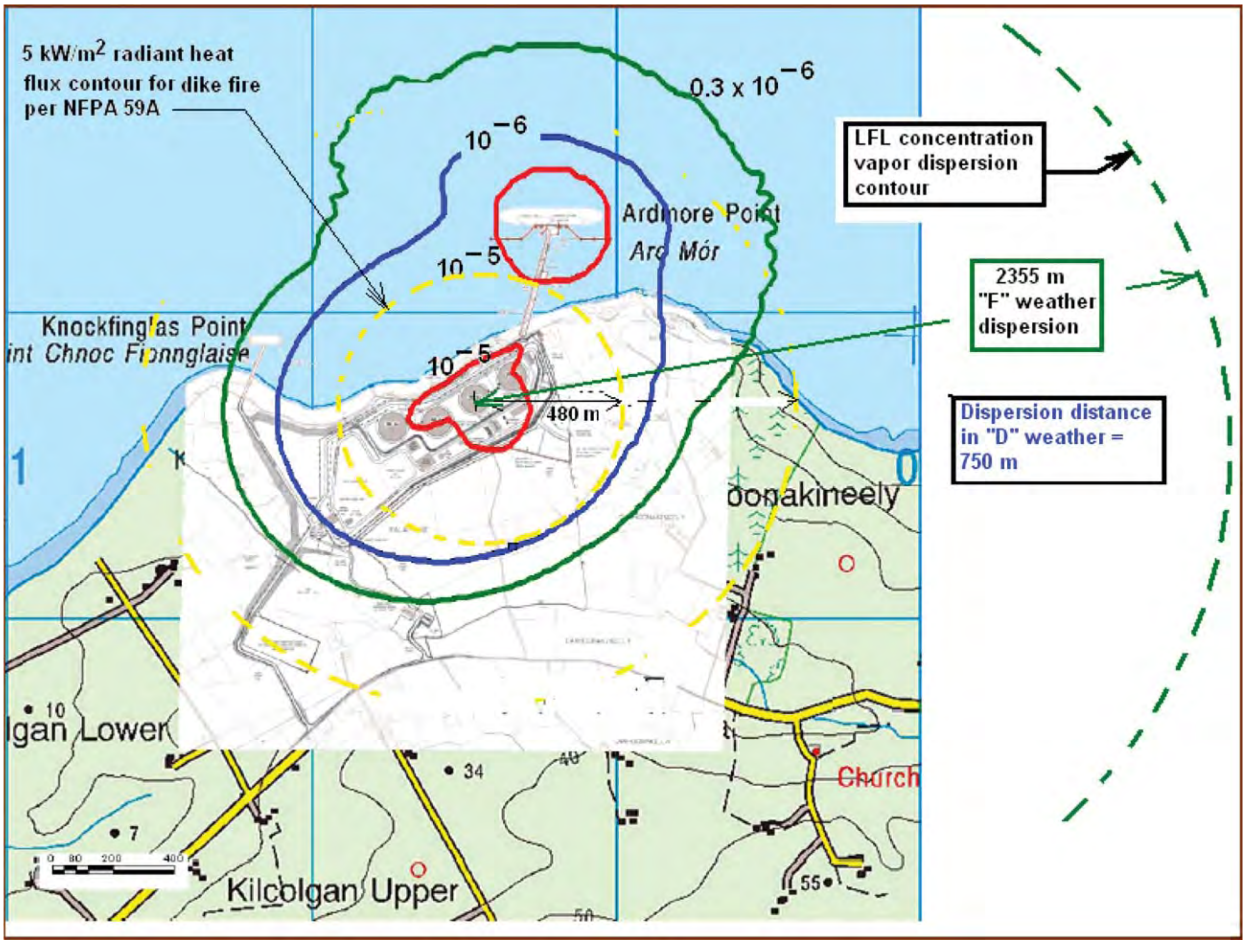

Fig. 3. Comparison of the results for an outdoor person's individual risk and NFPA 59A calculations for a LNG import terminal (Ireland) Source : Franks (2007).

4.2. Comparison of the risk results with application of NFPA requirements

NFPA 59A requires the calculation of pool fire radiant heat hazard distance as well as the dispersion distance of vapor generated by the "credible" spill to a mean concentration of 50% LFL. It is difficult to compare, on a par basis, risk results and definitive hazard distances. However, also shown in Fig. 3 are the exclusion zone distances from (the prescriptive requirements in) the NFPA 59A Standard with (1) the largest credible pool fire radiant heat hazard, and (2) the dispersion of vapor to 100% LFL concentration arising from the release of LNG from a 1000 mm diameter ship-to-shore tank transfer pipeline[3] It is seen that these distances, respectively, are 480 m (pool fire radiant heat effect) and about 2355 m (vapor dispersion in stable atmosphere). The maximum distance for the acceptable individual risk contour on land is about 800 m from the center of the storage tank. It is clearly seen that the above facility would not meet the vapor dispersion or the radiant thermal hazard distance requirements of NFPA 59A since the property line that can be built upon is within the respective contours for heat and vapor concentration.

5. Discussions & conclusions

In this paper the risk analysis process as practiced in other countries and those recently included in the NFPA 59A (2009) edition have been discussed. An example risk calculation, based on a consideration of the individual risk, has been presented for a real LNG import facility. This result has been compared with the exclusion zone result from the application of the currently applicable NFPA 59A (prescriptive) Standard's requirements. The results are significantly different simply because the parameters included in the Individual Risk (IR) calculations are different from those that are in the NFPA 59A requirements.

[3] It is noted that NFPA 59A requires the calculation of vapor dispersion hazard distance to 50% of LFL vapor concentration.

No attempt was made to compare the IFR result with that from the newly approved "societal risk-based requirements" included in the NFPA 59A, 2009 edition. This is because there are significant difficulties in comparing the IFR results with the societal risk results.

Acceptability of risk as the basis of permitting LNG facility siting depends very importantly on the criteria for acceptability. A first step has been made in the 2009 edition of NFPA 59A to include certain injury based risk criteria and risk acceptability in terms of the location of the calculated results on a risk acceptability matrix. The criteria in the NFPA 59A should be evaluated very carefully to ensure that these are acceptable to Authorities Having Jurisdiction (AHJs). If not other risk acceptability criteria should be developed. Also, consideration should be given to developing thermal dosage criteria for hazard from radiant heat and their dependence on classes of people exposed. In addition, the criteria should be developed based on potential fatalities and specified relationships between fatalities and levels of injury. Further research is also needed to incorporate the effects of emergency preparedness (on risk reduction), effects of at-event emergency action. Also, procedures should be developed to quantify them for consideration in a risk analysis based decision-making for siting LNG facilities.

References

49 CFR, part 192, Subpart O. *Pipeline integrity management* (1 October 2007 ed.). Washington, DC: Government Printing Office.

49 CFR, part 193. (10-01-2007). *Liquefied natural gas facilities: Federal safety standards* (2007 ed.). Washington, DC: Government Printing Office.

Ball, D.J, & Floyd, P. J. (1998). Societal risks, Report to the Risk Assessment Policy Unit, Health and Safety Executive. Crown Copyright..

Bottelberghs, P. H. (2000). Risk analysis and safety policy developments in the Netherlands. *Journal of Hazardous Materials, 71*, 59–84.

Breyer, S. (1993). *Breaking the vicious circle – Toward effective risk regulation*. Cambridge, MA: Harvard University Press.

Ccps. (October 1999). *Guidelines for chemical process quantitative risk analysis* (2nd Edition).. New York: Center for Process Safety, AIChE, Wiley Press.

EN 1473. (2006). *Installation and equipment for liquefied natural gas – Design of onshore installations*. prEN 1473. rue de Stassart, 36 B-1050 Brussels: European National Standard, European Committee on Standardizations, Management Centre.

Franks, A. (September 2007). Land use planning QRA studies of the proposed shannon LNG terminal, Report # 02, Environmental resources management, Ltd., Report submitted to the Health & safety authority of Ireland.

Glickman, T. S., & Gough, M. (Eds.). (1990). *Readings in risk*. Washington, DC: Resources for the Future.

HSA (2006). *Land-use planning advice for Kilkenny County Council in relation to Grassland Fertilisers (Kilkenny) Ltd at Palmerstown*. Dublin: Health & Safety Authority, Government of Ireland.

HSE. (1989). *Risk criteria for land-use planning in the vicinity of major industrial hazards*. London, England: Her Majesty's Stationery Office, ISBN 011-8854917.

HSE. (2001). *Reducing risks, protecting people – HSE's decision-making process*. Crown Copyright.

HSE. (2003). Failure rate and event data for use within risk assessments, Chapter 6k, Planning Case Assessment Guide.

Lemoff, T. LNG Incident – Cleveland, October 20, 1944, Paper presented at the Gastech 2008 Conference, Bangkok, March 2008.

Morgan, M. G. (July 1993). Risk analysis and management. *Scientific American* 32–38.

Naruc. (2008). Resolution encouraging the use of risk assessment approach to provide comprehensive information on LNG facility safety," by the Committee on Gas and adopted by NARUC Board, Winter meeting, Washington, DC, 20 February 2008. http://www.naruc.org/resolutions.cfm?action=doit&AdoptedDate=2008-02-20&committeeID=&criteria.

Nasfm. (February 2, 2009). Risk assessment approach to LNG facility safety, Resolutions adopted by the Board of Directors, National Association of State Fire Marshals.

NFPA 59A. (2009). *Standard for the production, storage, and handling of liquefied natural gas (LNG)* (Edition). Quincy, MA: National Fire Protection Association.

NFPA 59A (2001). *Standard for the production, storage, and handling of liquefied natural gas (LNG)* (2001 ed.). Quincy, MA: National Fire Protection Association.

Glossary

AHJ: Authority having jurisdiction
CFR: Code of Federal Regulations (of the US)
DOT: Department of Transportation (of the US)
FERC: Federal Energy Regulatory Commission (of the US)
HSE: Health and Safety Executive (of the UK Government)
IFR: Individual Fatality Risk
LFL: Lower flammability limit (concentration)
LNG: Liquefied natural gas
NFPA: National Fire Protection Association
PHMSA: Pipeline and Hazardous Materials Safety Administration (of US DOT)
PIMS: Pipeline Integrity Management System
UK: The United Kingdom
US: The United States (of America)