NAUTICAL AND RISK STUDIES FOR THE DELIMARA LNG TERMINAL IN MARSAXLOKK PORT, MALTA

Item 6: Nautical Quantitative Risk Assessment (QRA) Report

Final report

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LNG terminal in the Marsaxlokk Bay

Nautical Quantitative Risk Assessment (QRA) Report

Malta, December, 2015
Report nº: 02-901-211076-15010. Rev.1

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GLOSSARY

1% lethality distance	The distance to the location where an unprotected person has a 1% probability of dying for a given scenario and weather class
Atmospheric storage tank	Storage tank in which the maximum permitted pressure is less than or equal to 0.5 bar of overpressure Generally the overpressure is a maximum of 70 mbar.
Competent authority	Authority licensing the activity with dangerous substances
BLEVE	Boiling Liquid Expanding Vapour Explosion; results from the sudden failure of a vessel containing liquid at a temperature well above its normal (atmospheric) boiling point. A BLEVE of flammables results in a large fire ball (if ignited)
Flammable (hazardous) substances	Flammable (hazardous) substances are: -inflammable substances (category 0, 1 and 2) -category 3 and 4 substances if the process temperature is higher than the flash point
Dispersion	Mixing and spreading of substances in the air
Domino effect	The effect that Loss of Containment in one installation leads to Loss of Containment in other installations
Dose	A measure of integral exposure; a function of concentration and exposure time
Pressure vessel	Pressurized storage vessel in which the maximum permitted pressure is more than 0.5 bar of overpressure
Operator	Any natural person or corporate entity who operates or holds an establishment or installation or, if provided for by national legislation, has been given decisive economic power in the technical operation thereof
Explosion	A sudden release of energy that causes a blast Fault tree analysis The evaluation of an unwanted event, the top event in the fault tree. Given a top event, a fault tree is drawn up using a deduction method (top-down), which can be used to determine the cause (or causes) of the unwanted event
Jet fire	Combustion of materials emitted from an opening with great force

Flash	Part of a superheated liquid that evaporates rapidly due to a relatively rapid depressurization, until the resulting vapour/liquid mixture has cooled to below boiling point at the end pressure. Superheat is the extra heat of a liquid made available by decreasing the liquid's temperature, for instance, by vaporization, until the vapor pressure equals that of the surroundings
Flash fire	The combustion of a flammable vapor and air mixture in which the flame passes through the mixture at a rate less than sonic velocity so that negligible damaging overpressure is generated
FN curve	Log-log graph: the X-axis represents the number of deaths and the y-axis the cumulative frequency of the accidents, with the number of deaths equal to N or more
Frequency	The number of times an outcome is expected to occur in a given period of time (see also probability)
Vapour cloud explosion	The explosion resulting from ignition of a cloud of flammable vapour, gas or spray mixed with air, in which flames accelerate to significantly high velocities to produce significant overpressure
Event tree	A diagram of success and failure combinations are used to identify event sequences leading to all possible consequences of a given initiating event
Limit value	Measure of the dangerous properties of a substance based on both the physical and the toxic/explosive/flammable properties of the substance
Blocking system	Suppression system to isolate (part of) an installation to prevent (further) outflow
Establishment	The whole area under the control of an operator where dangerous substances are present in one or more installations, including common or related infrastructures or activities
Containment system	One or several devices, any parts of which are permanently in open contact with one another, and which are intended to contain one or multiple substances. A Loss of Containment in one containment system will not lead to the release of significant quantities of hazardous substance from other containment systems
Installation	A technical unit within an establishment where hazardous substances are produced, used, handled or stored

Probability	Measure of the likelihood of an occurrence, expressed as a dimensionless number between 0 and 1 Risk is defined as the probability that within a fixed time period, usually one year, an unwanted effect occurs. Consequently, risk is a dimensionless number. However, risk is often expressed in units of frequency, 'per year'. Since failure frequencies are low, the probability that an unwanted effect will occur within a fixed time period of one year is, practically speaking, equal to the frequency of occurrence per year. In this Reference Manual, frequency is used to denote the risk
LFL	Lower flammability limit; below this concentration too little flammable gas is present in the air to maintain combustion
LOC.	See Loss of Containment event
Loss of Containment	Event resulting in the release of material to the atmosphere
Nominal pumping rate	Normal flow of material through a pump
Explosive substances	Explosive substances are: a. 1°. substances and preparations that present an explosion hazard due to shock, friction, fire or other causes of ignition(risk phrase R2); 2°. pyrotechnic substances. A pyrotechnic substance is understood to be a substance or mixture of substances with the purpose of producing heat, light, sound, gas or smoke or a combination of these phenomena by means of non-explosive, self-propagating exothermic chemical reactions; 3°. explosive or pyrotechnic substances and preparations that are contained in objects; b. substances and preparations that present a serious danger of explosion as a result of shock, friction, fire or other ignition causes (risk phrase R3)
Ignition source	A thing able to ignite a flammable cloud, e.g. due to the presence of sparks, hot surfaces or open flames
Operator	Any individual operating technical equipment
Pasquill class	Classification to qualify the stability of the atmosphere, indicated by a letter ranging from A, for very unstable, to F, for stable
Pool fire	The combustion of material evaporating from a layer of liquid Probit Number directly related to probability by a numerical transformation
Process vessel	Vessel in which a change in the physical properties of the substance occurs, e.g. temperature or phase

QRA	See Quantitative Risk Analysis
Quantitative Risk	Analysis A numerical evaluation of probabilities, effects and consequences of incidents and their combination into measures of risk
Reactivity	Measure for the flame acceleration in a gas/air mixture
Reactor vessel	Vessel in which a chemical change of the substances occurs
Repression system	System to limit the release of substances into the environment given a certain event
Risk	The combination of probability and effect.
Risk contour	Line on a map connecting points having equal risk
Roughness length	Artificial length scale appearing in relationships describing the wind speed over a surface and characterising the roughness of the surface. The roughness length of a pipeline determines the resistance in the pipe, the roughness length of the surroundings determines the wind speed at ground level
Compressed liquefied gas	Gas that is compressed to a pressure that is equal to the saturation vapour pressure at storage temperature, so that the majority is condensed into its liquid phase
Safety Report	Report on the safety of an establishment
Safety valve	Valve (or here also rupture disk) designed to automatically vent excess pressure
Fire ball	A fire, burning rapidly enough for the burning mass to rise into the air as a cloud or ball
Weather class	Combination of Pasquill stability and wind speed. Weather class D5 means Pasquill category D and wind speed 5 m/s

1. INTRODUCTION

1.1. Project background

Enemalta is developing a new gas-fired power station near the existing Delimara Power Station on the north-eastern shore of Marsaxlokk Bay. The gas for the power plant will be imported through a new to build LNG terminal in Marsaxlokk Bay. Figure 1-1 shows the approximate position of the new terminal.

Figure 1-1 Marsaxlokk Port and approximate position of LNG terminal (source: Google Earth)

Enemalta has awarded the contract for design, construction and operation of the new power plant and LNG terminal to Electrogas Malta. The LNG terminal proposed by Electrogas consists of a jetty from the shore south of the power plant to a berth that is positioned where the bay is deeper, so that no or only limited dredging is required. On the jetty a converted LNG carrier will be permanently moored as Floating Storage Unit (FSU), delivering LNG through a cryogenic line over the jetty to the regasification unit onshore. The FSU berth has a conventional layout consisting of a platform, breasting dolphins and mooring dolphins (Figure 1-2). LNG will be imported by LNG carriers (further shortened to LNGCs) that will moor alongside the FSU.

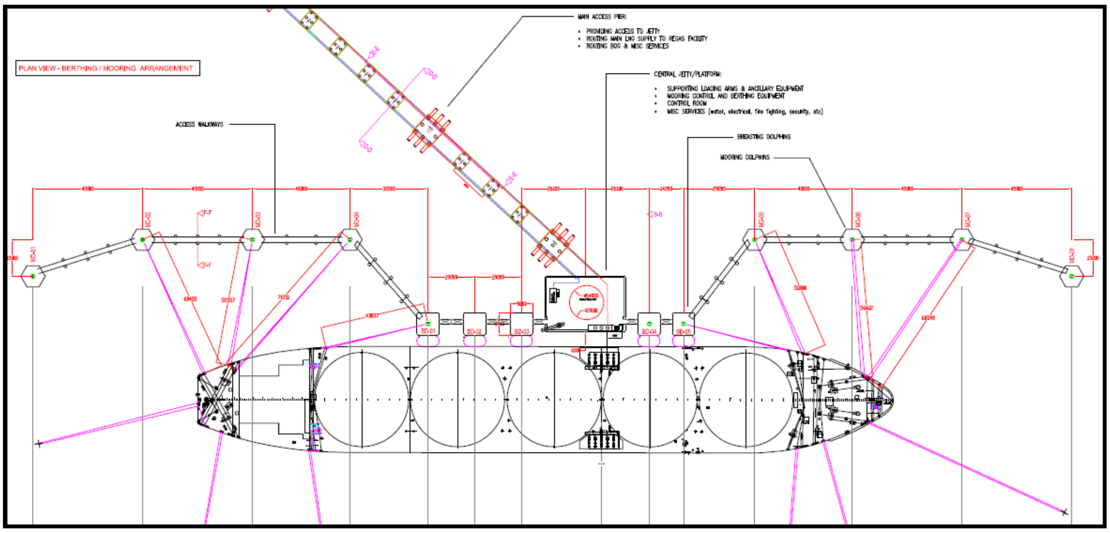


Figure 1-2 Proposed jetty configuration

To verify the design and evaluate safety aspects related to the permanent presence of the FSU in the port and to the regular call of LNGCs to the new LNG terminal, Enemalta has commissioned MARIN to carry out nautical and safety studies for the new LNG terminal. The study addresses a number of items raised by Transport Malta, the authority responsible for the port, who required:

1. Validation of proposed jetty/berth layout
2. Nautical and safety study
    a. Determine the required minimum navigation channel/fairway
    b. Determine the risk involved in the handling of an FSU and LNG carriers when navigating to the terminal
    c. Determine the nautical procedures for the handling of the FSU and LNGC during routine procedures and emergency situations
2. Site specific risk (safety) assessment including
    a. Cargo release
    b. Collision
    c. Fire and explosion
    d. Grounding

The contract for the study (Ref: DPS-GEN-1190) was signed on 25 August 2014 and is based on MARIN's proposal of 24 March 2014.

1.2. Objective, approach and scope of work

1.2.1. Objective

The objective of the proposed study is to make a nautical evaluation of the proposed LNG facility in Malta. This evaluation includes:

- An evaluation of the proposed layout (channel width and berthing area);
- Determine the operational envelope for ship manoeuvres;
- Determine the operational conditions for safe offloading and the maximum conditions for staying safely at the berth;
- Determine the risk involved in the operations, in terms of collisions and groundings and in terms of individual and societal risk.

1.2.2. Approach

The above mentioned items are evaluated using numerical simulations of moored ship response (validation of jetty/berth layout), real-time manoeuvring simulations (dimensions of fairway, operational limits for sailing with LNG carriers) and a quantitative risk assessment (risk of grounding and collisions). MARIN has carried out such studies for many LNG terminals worldwide. A wave study provides input required for the moored ship response study and the manoeuvring simulations.

The study thus consists of the following items:

1. Wave climate study to determine the normal and extreme wave climate outside Marsaxlokk port (frequency of occurrence of directions and wave heights)
2. Wave penetration calculations to determine the wave conditions at the terminal
3. Numerical moored ship response simulations;
4. Real-time manoeuvring simulations;
5. Nautical risk study
6. Quantitative Risk Assessment

The wave studies (items 1 and 2), which serve as input for the nautical studies (items 3 and 4) were carried out by ARCADIS. Items 3 and 5 were carried out by MARIN. Item 4 was carried out by MARIN in cooperation with MMRTC (Malta Maritime Research and Training Centre). SGS Tecnos SA carried out the Nautical QRA in item 6.

1.2.3. Reports

The total study is presented in a series of reports, each one treating one of the above mentioned study items. Table 1-1 gives an overview of the reports presenting the results of the study.

Table 1-1 Overview of reports

Volume	Title	Main author
27689-1-MSCN	Item 1: Wave climate study	ARCADIS
27689-2-MSCN	Item 2: Wave penetration study	ARCADIS
27689-3-MSCN	Item 3: Moored ship response study	MARIN
27689-4-MSCN	Item 4: Real-time manoeuvring simulations	MARIN
27689-5-MSCN	Item 5: Nautical risk study	MARIN
27689-6-MSCN	**Item 6: Nautical Quantitative Risk Assessment**	**SGS Tecnos**

To support the design of the modifications to the FSU and the storm mooring for the FSU, some additional analysis was carried out for ElectroGas Malta on the data from the wave climate and wave penetration studies. This has been reported directly to EGM.

This report

This report (marked in bold in Table 1-1) presents the Nautical Quantitative Risk Assessment Report by SGS Tecnos. The study identifies the possible hazards, addresses the causes and assesses the consequences of the credible major accident scenario which can lead to a spillage of LNG and/or to the dispersion of a natural gas cloud. Hence the ultimate purpose is:

- To calculate the individual risk contour on the site map
- To calculate the societal risk graph
- To compare the results with the acceptability criteria.

This is the final report in which the results have been updated based on a total of 12 calls of LNGCs to the terminal.

2. GENERAL

2.1. Scope

The scope of this study includes any offshore activity associated to the LNG terminal. The terminal requires regular visits of an LNG carrier (LNGC) for the transportation of the LNG from the exporting countries and includes unloading facilities to the FSU tanks and continuous pumping and transfer activities to the onshore regasification unit for the purpose of feeding the natural gas supplied combined cycle power plants. Therefore, the mentioned offshore activities shall be understood as LNGC approach, maneuvering, mooring, unloading and onboard operations; FSU permanent presence, onboard operation and feeding to onshore; jetty presence with permanent operations. In simple words, under the scope of this report shall fall all the possible new hazards directly or indirectly related to the presence of the new players in the Marsaxlokk bay water area. Any other onshore hazards related to the same project have already been addressed in a first approach in the Preliminary QRA and must be addressed in details in the Safety Report of the establishment. Likewise, any other hazards due to the already existing nautical activity in the port must be considered out of scope.

2.2. Limitations

This study uses frequencies, risk assessment method and risk acceptance criteria (based on individual risk) with cut off values adopted by HSE UK (PADHI system [1]), HSA Ireland [2], the Dutch authorities [3], [4] and other relevant QRA references [5], [6]. A different conclusion may be drawn in the future if more restrictive criteria and cut off values are applied to the same calculation.

A part from these, another indirect limitation of the study is the result itself of the cited nautical risk assessment [7] provided by MARIN, which in turn is based on the acceptance of several limitations as specified in the reference. Additionally, MARIN report shall be considered as part of this report in order to fully understand the nautical scenarios, their limitations, the manoeuvring considered, the type of vessels considered, etc.

The Loss of Containment (LOC) of the vessels and pipeline are considered in association with general frequencies of failure, defined on statistical basis for average installations considered in each case. For this reason, the details of Safety Shut Down Systems, Fire & Gas Systems and other preventive measures, which can lead to an additional reduction of risk, are not considered in a QRA.

Aside, the aforementioned scope may be interpreted as a limitation of the study. In fact the overall risk perceived by the population is due to multiple activities in the port area, some of them due to the handling activity of hazardous substances in the onshore terminal, while others due to the navigation, approach, maneuvering, mooring and loading / unloading activities of dangerous cargo vessels. Theoretically, in a first step the overall risk must be calculated for the entire port area based on the existing hazards, in a second step the risk included under the scope of this document should be added to the existing one and, in a third step, any remarkable increase in the risk must be highlighted and compared with the acceptability criteria. Although this approach is strictly required in areas with a high density of population and high traffic statistic, i.e. inland water channels with continuous traffic of barges on the same route and very close to residential areas; it is out of discussion that in an open port with multiple navigation routes and wide spaces between terminal, the risk perceived in a single point is influenced only by a few hazards. Accordingly, the calculation of the existing overall risk and the cumulative effect will not add outstanding details to the study and will not vary the final results.

2.3. Area of concern

The proposed new LNG terminal will be located offshore in the Marsaxlokk Bay, southern of the existing ENEMALTA facilities in the Delimara peninsula. The area of concern to be considered in the study is the entire Bay area, including the approaching route of the LNGC and focusing specifically on the location of the FSU.

2.3.1. Meteorology

Within a QRA, adopted weather conditions are described as a combination of a letter and number. The letter denotes the Pasquill stability class and the number gives the wind speed in metres per second. The Pasquill stability classes describe the amount of turbulence present in the atmosphere and range from A to F. Stability class A corresponds to ‘unstable’ weather, with a high degree of atmospheric turbulence, as would be found on a bright sunny day. Stability class D describes ‘neutral’ conditions, corresponding to an overcast sky with moderate wind. A clear night with little wind would be considered to represent ‘stable’ conditions, denoted by stability class F.

Accurate and reliable stability class statistic is recommended to complete this meteorological information. Unfortunately, this statistic is complete and available only for a few locations in Europe. For the remaining locations, estimation on the basis of similar weather conditions is the best approach. The stability class is related to the insulation, cloud cover, winds, and other climatic variable. For locations at the same latitude and with similar weather conditions, the stability is similar, while moving North, the stability would vary according to decreasing insulation, increasing cloud cover, etc.

Air Temperature and Humidity

The presence of the surrounding water mass significantly shapes the climate of the Maltese Islands. The general weather is often cooler and more humid than what is experienced in inland areas of larger land masses. The high thermal capacity of the sea also reduces large fluctuations in the ambient temperature of the islands. But the presence of surrounding warm waters during the end of the summer season is a source of major weather instability when colder air migrates into the Central Mediterranean, thus creating areas with heavy thunderstorms and intense precipitation [8].

The average temperature considered for the calculations is 19 ºC and the average humidity considered for the calculation is 75%.

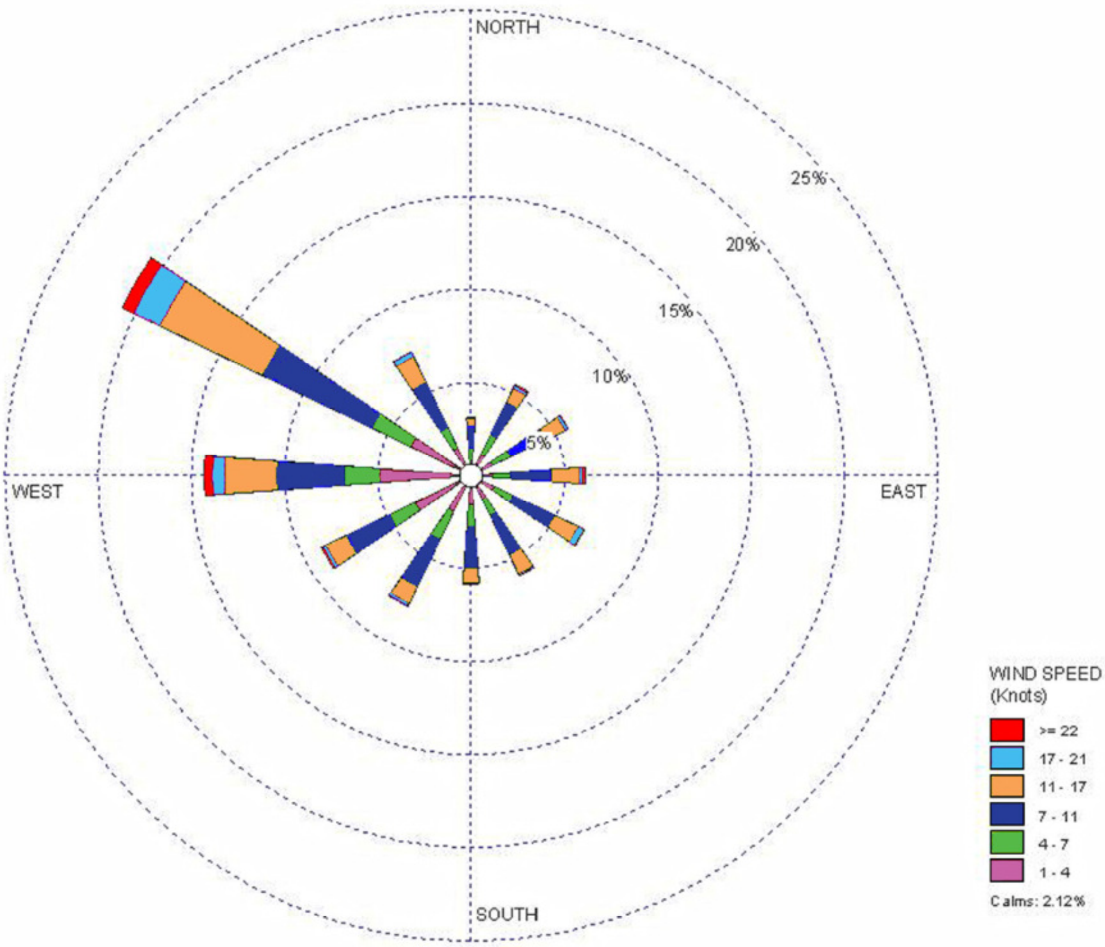
Atmospheric Pressure

Atmospheric pressure differences are fairly limited, and generally fall in the range from 1004 to 1017 mbar.

Wind

The prevailing wind is from the northwest, and approximately 20% of annual average recorded winds come from this direction.

In the following figure, the wind rose is shown.

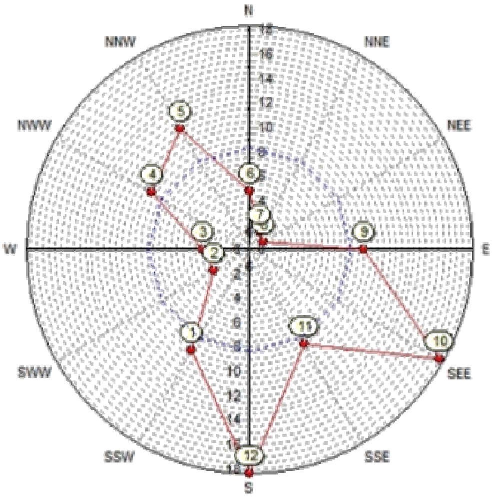


Several wind velocity shall be considered in the calculation in order to represent the possible wind conditions together with the correspondent weather stability wind direction, as explained in the next paragraph.

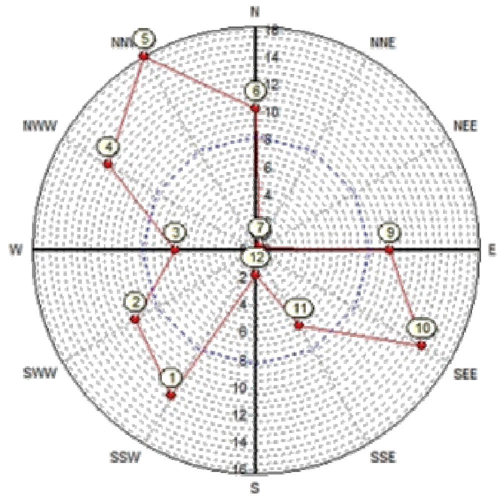
Windrose

Windroses have been obtained from the Charles Galdies Report [8].

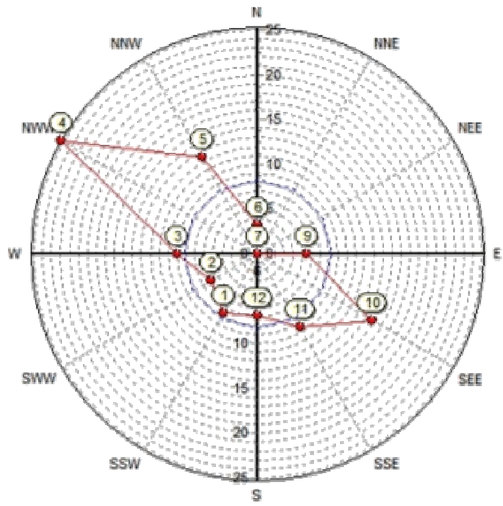
In the following page they have been grouped according to the wind velocity and the weather stability.



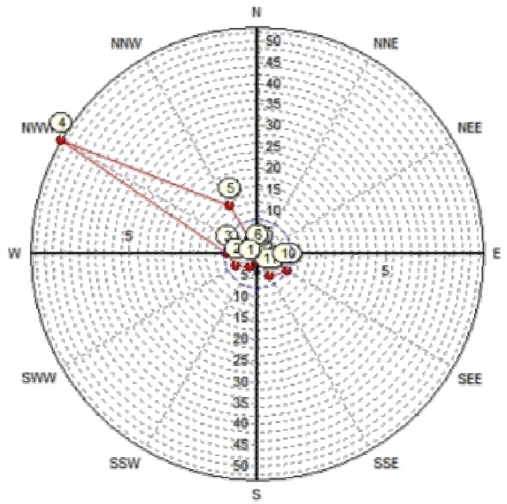
Wind velocity = 3.1 m/s (stability B)



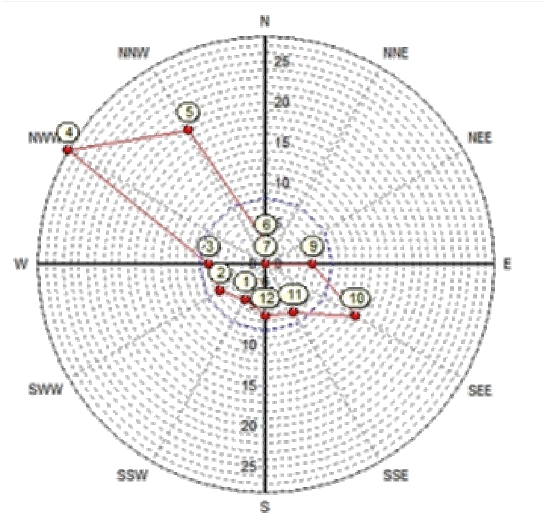
Wind velocity = 3.6 m/s (stability D)



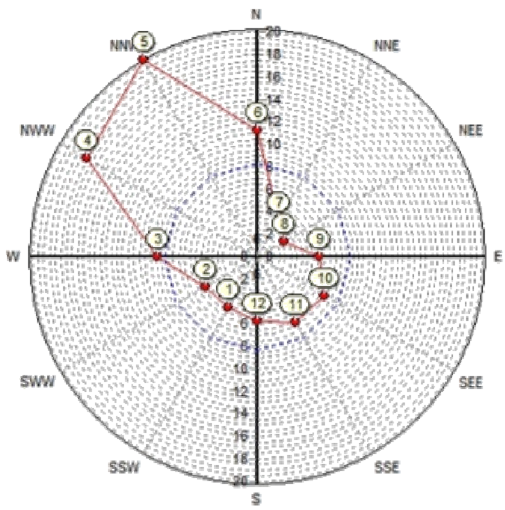
Wind velocity = 7.2 m/s (stability D)



Wind velocity = 7.4 m/s (stability D)



Wind velocity = 3.2 m/s (stability E)



Wind velocity = 0.9 m/s (stability F)

Weather stability

Weather stability data are required to perform the simulation of the atmospheric dispersion of natural gas. Atmospheric stability is defined in terms of the tendency of a parcel of air to move upward or downward after it has been displaced vertically by a small amount. Essentially, unstable atmospheres tend to develop vertical updrafts which increase boundary-layer turbulence intensity. Stable atmospheres tend to suppress vertical updrafts and reduce turbulence intensity.

Since it is difficult to measure turbulence intensity directly, correlations are sought to indicate stability class as a function of readily measurable variables. The earliest stability classification scheme, attributed to Pasquill (1961), is summarized in the table below:

Surface wind(at 10 m) m/s	Day incoming Solar radiation** Strong	Day incoming Solar radiation** Moderate	Day incoming Solar radiation** Slight	Night* (thin overlat or >= 4/8 cloudiness	Night* (<= 3/8 cloudiness
<2	A	A-B	B	F	F
2-3	A-B	B	C	E	F
3-5	B	B-C	C	D	E
5-6	C	C-D	D	D	D
6	C	D	D	D	D

* Night is defined as the period from 1 hour before sunset to 1 hour after sunrise.

** Appropriate insolation categories have been determined through the use of sky cover and solar elevation information according to the following matrix.

Sky Cover (opaque or total)	Solar Elevation Angle > 60º	Solar Elevation Angle < 60º and >35º	Solar Elevation Angle < 35º and > 15º
4/8 or less or any amount of high thin clouds	Strong	Moderate	Slight
5/8 to 7/8 Middle Clouds (700 ft. – 16000 ft. base)	Moderate	Slight	Slight
5/8 to 7/8 Low Clouds (less than 700 ft. base)	Slight	Slight	Slight

The Pasquill stability classes describe the amount of turbulence Meteorological data present in the atmosphere and range from “A” to “F” class. Stability class “A” corresponds to ‘unstable’ weather, with a high degree of atmospheric turbulence, as would be found on a bright sunny day. Stability class “D” describes ‘neutral’ conditions, corresponding to an overcast sky with moderate wind. A clear night with little wind would be considered to represent ‘stable’ conditions, denoted by stability class “F”.

As agreed during the meetings helds with independent experts participating in the Land Use Permit and to the windroses already presented in the previous paragraph, the obtained average frequency distributions of weather classes are presented in the following table for 12 wind directions and 6 weather classes.

STABILITY CLASS	WIND (m/s)	DAY	NIGHT	SSW	SWW	W	WWN	WNN	N	NNE	NEE	E	EES	ESS	S	TOTAL (%)
B MEDIUM	**3,1**	**25,99**	**0,00**	9,58	3,44	3,83	9,31	11,44	4,79	1,65	1,27	9,33	18,00	9,00	18,35	**100,00**
D LOW	**3,6**	**2,37**	**0,00**	12,24	10,13	5,91	12,46	16,26	10,34	0,46	0,42	9,71	13,93	6,33	1,79	**100,00**
D MEDIUM	**7,2**	**14,71**	**7,80**	7,69	5,93	8,93	25,29	12,42	3,18	0,00	0,00	5,44	14,76	9,47	6,89	**100,00**
D HIGH	**7,4**	**6,93**	**4,09**	3,77	5,81	6,95	53,15	12,89	0,32	0,00	0,00	0,82	8,03	6,17	2,09	**100,00**
E MEDIUM	**3,2**	**0,00**	**8,51**	5,00	6,47	7,00	28,04	19,11	2,59	0,00	0,06	5,76	12,70	6,94	6,35	**100,00**
F LOW	**0,9**	**0**	**29,62**	5,22	5,39	8,90	17,56	20,26	11,31	3,73	2,74	5,49	6,92	6,75	5,74	**100,00**
TOTAL	**---**	**50,00**	**50,00**	**7,25**	**6,20**	**6,92**	**24,30**	**15,40**	**5,42**	**0,97**	**0,75**	**6,09**	**12,39**	**7,44**	**6,87**	**100,00**
		100,00														

2.3.2. Facilities description

All the calculation supporting this QRA have been performed on the basis of the following description, based on the Preliminary Quantitative Risk Assessment [9] issued in 2013 and MARIN [7]. The facilities within the scope of the study include the following details:

<u>LNG tanker</u>

The LNGC will visit the terminal 12 times per year (12 calls), following a specific route (shown in the drawing no. 2), maneuvering near the terminal 0.75 hours for each mooring or de-mooring operation, staying 24 hours moored for each unloading operation.

LNGCs of various capacities may visit the FSU. Carriers are normally classified as follows:

Standard class: 125-180,000 m^3
Q-Flex class: 210-217,000 m^3 [10] [11]
Q-Max class: 250,000 m^3 [12] [13] [14]

According to Maltese consumption and technical and commercial availability of tankers, the parameters proposed for LNG carriers are as follows:

- The LNGC for which the analysis is carried out has a length overall of 290 m, a beam of 46 m and a draught of 11-12 m when fully laden. capacity: max. 140,000 m^3
- boil-off rate : 0.25 % per day
- vapour return temperature : -151 °C
- LNG discharge pressure : 4 barg at ship manifold (The LNG is pumped from the FSU storage tanks by primary or low pressure pumps located in several wells inside the tanks and submerged in the liquid)
- The visiting LNG carrier would be moored to the FSU.

<u>Ship to ship unloading by arms</u>

The LNG transfer from the visiting tanker to the FSU would be carried out through:

- two un-loading arms each capable of unloading 4,000 m^3/hr of LNG.
- A 3rd hose which is the vapour return

LNG is discharged by the visiting ship pumps to either one or several of the FSU storage tanks. The tanks boil-off is sent back to the ship via the return gas hose for displacement gas supply during unloading and to the boil-off compressors where it is compressed for re-condensation in the liquefier, as described below.

Floating storage unit (FSU)

The FSU will be based on the reconversion of the Moss spherical carrier Wakaba Maru with a capacity of 123,780 m^3. This ship has a length overall of 283 m, a beam of 44.8 m and a draught of about 11 m. According to Maltese requirements, the FSU storage capacity initially required was a quantity of 180,000 m^3, the vessel would be permanently moored to the jetty and the connection to onshore pipelines would be through common unloading arms for liquid and vapour phase on each side for LNG unloading from LNG carrier to FSU and from FSU to onshore regasification units.

Jetty

The jetty is expected to allow mooring of the FSU and to provide permanent services to the ship. Mooring facilities should admit ships of up to 140,000 m^3 capacity (more than 300m long). The jetty will be located in Marsaxlokk Bay, south of the existing ENEMALTA facilities in the Delimara peninsula.

2.3.3. Substances hazards and behaviours

LNG terminals have exhibited an exceptionally high safety record when compared to refineries and other (petro) chemical plants. Small LNG vapour releases, and minor fires and explosions have been reported, but their effect was limited to the plant itself and the hazard was promptly handled by plant personnel. During the past sixty years of LNG operations, not a single general public fatality has occurred anywhere in the world because of LNG operations.

Also, LNG tankers are among the safest transportation mode. In the last three decades, after more than 40,000 voyages by sea worldwide, there has not been a single reported LNG release from a ship’s cargo tank. LNG tankers have experienced groundings and collisions during this period, but none has resulted in a major spill. This is partly due to the double-hulled design of LNG tankers which offers significant protection to the double walled LNG containers along with the state-of-the-art technology and highly qualified human resources.

However, LNG and methane hazards must be seriously considered in the QRA, due to the nature of the substance and its behaviour.

Liquefied natural gas (LNG) is a liquid fluid, colourless, composed primarily of methane. LNG may contain small amounts of low molecular weight hydrocarbons held at cryogenic temperatures (ethane, propane, nitrogen and others). Physical properties for methane, ethane and propane (the principal constituents of LNG) are provided in the following table. [5]

Substance	Methane	Ethane	Propane
Chemical Name	Methane	Ethane	Propane
Chemical Formula	CH4	C2H6	C3H8
CAS Number	74-82-8	74-84-0	74-98-6
Appearance at 20ºC	Colourless Gas	Colourless Gas	Colourless Gas
Atmospheric Boiling Point (ºC)	-161.5	-88.6	-42.1
Melting Point (ºC)	-182.5	-183.3	-187.7
Liquid Specific gravity	0.422	0.546	0.59
Vapour Density (Air=1)	0.55	1.1	1.5
Lower flammable limit (vol%)	5	2.9	2.1
Upper flammable limit (vol %)	15	13	9.5
Flash Point (ºC)	-188	-135	-104
Auto Ignition Temperature (ºC)	595	504	450
Long term exposure limit	N/A	N/A	N/A
LD50	N/A	N/A	N/A
Eco-toxicity	Unlikely to cause adverse effects	Unlikely to cause adverse effects	Unlikely to cause adverse effects
Degradability	Disperses rapidly	Disperses rapidly	Disperses rapidly

LNG is produced by cooling natural gas (NG) till approximately – 161 ºC. At this temperature the natural gas condenses into a liquid. The volume decreases by approximately a factor 600 as a result of the condensation. The main goal of liquefying is to make it possible to transport and store the natural gas.

Flammability

LNG is not flammable until it is vaporized, mixed in the right proportions with air, and then ignited. The measured minimum ignition energy of LNG vapours is 0.29 mJ (milli-Joules). Flammable LNG vapours are easily ignited by machinery, cigarettes, and static electricity.

Its fire-related properties are comparable to other light hydrocarbon fuels. Depending on leakage pressure and conditions, the fire can be associated with a spreading pool of LNG, a spray of mix-phase or a cloud of vapour phase.

Cryogenic burns

As a cryogenic liquid, LNG can cause burns to personnel if it comes in contact with the skin. A second cryogenic hazard is associated with LNG vapours; breathing cold vapours from LNG evaporation or boiling can damage the lungs. Whilst methane does not chemically react with the lungs, the cold vapour can cause 'frosting of the lungs'. The severity of damage is directly related to the severity of exposure.

Typically process equipment in LNG duty is thermally insulated to reduce heat 'in leak' and to prevent injury to personnel during normal operation.

Embrittlement

Also, as a cryogenic liquid, LNG can cause fragile fracture of common materials, if it comes to contact with them. This can happen in case of leakages or spillages over carbon steel or common concrete.

Asphyxiation

Methane, or natural gas, is odourless and colourless. It's neither toxic nor carcinogenic, being a simple asphyxiant gas. The danger of asphyxiation is normally increased in LNG facilities due to the absence of an odourant in the gas. However, asphyxiation requires a relatively high concentration of gas in air and such effects are only important close to a release of LNG.

Pools vaporisation

If LNG is accidentally released, it vaporises rapidly when exposed to ambient heat sources such as water, producing approximately 600 standard cubic meters of natural gas for each cubic meter of liquid. When spilled on the ground or water, LNG will initially produce a cold vapour cloud that is denser than air and will stay close to the surface or ground. As this cloud mixes with air, it will warm up and cause dispersion into the atmosphere. The downwind distance that flammable vapours might reach is a function of the LNG spill rate/volume, the evaporation rate, and the prevailing weather conditions. In order to disperse to significant downwind distances, a vapour cloud must avoid ignition.

This behaviour is most common for low pressure and cryogenic leakages, and would normally be chosen as the calculation option for QRA purposes. However, other phenomena are important, such as liquid jets and sprays (for high pressure leakages), and LNG boiling or Rapid Phase Transition (for high thermal transfer). These special effects can only be taken into account when included in models.

Pool Fires

A pool fire is the combustion of a substance in a liquid phase, while accumulated in a basin or spreading on the ground or water. A pool fire can be a continuous effect if the released quantity is enough and can burn over a very large period of time, until all the quantity is gone or the pool is properly covered with fire fighting foam.

Jet-fires

A jet-fire is the direct combustion of a substance leaking from a pressurized vessel. The leakage can be in vapour or in a liquid phase. In this last case, the liquid is spread at high pressure forming fine drops which can be ignited.

Flash-fire

Following an LNG release, a large proportion of the liquid will evaporate immediately to form a cloud of natural gas, initially located around the release point. If this cloud is not ignited immediately, it will drift with the wind and be diluted as a result of air entrainment.

A flash-fire is a phenomenon which occurs when an ignition point ignites a flammable cloud. It's a transient phenomenon with an immediate effect on the population or plant personnel exposed. Depending on the combustion velocity, a flash-fire may create an expansive wave and present an explosive effect, as described in the following definition.

Flammable Gas Cloud

A gas cloud is the dispersion of a pure or concentrated flammable gas in the air, in a condition which keeps the gas concentration higher than the lower flammability limit. In case of no direct ignition, a gas cloud is formed over a spillage of LNG, due to the high thermal gradient. A gas cloud is not directly dangerous for the population or environment, unless an ignition point provokes a flash-fire.

UVCE

An Unconfined Vapour Cloud Explosion (UVCE) is the ignition of a flammable cloud in open space in a condition which ensures expansive effect, due to the increase in the volume of the combustion gases versus the volume of the explosive mixture. This can happen depending on substance behaviour, accumulated quantity in the cloud, etc. In general, a cloud of natural gas in an open space such as the proposed plant is scarcely explosive, even for a large amount of gas in the cloud.

Explosion and BLEVE of LNG

Liquid LNG does not explode, so that a very large spill of LNG cannot release its entire energy content in a very short time, as explosives do. Also, refrigerated LNG is stored at an approximately atmospheric pressure, so that no BLEVE (boiling liquid expanding vapour explosion) is expected. The explosion scenarios sometimes observed when spilled LNG contacts the sea water are in fact the already described RPTs.

Roll-over in tanks (onshore or offshore)

A "roll-over" [15], [16] is a phenomenon that can happen in LNG tanks following a stratification in the liquid content, due, for example, to the filling with LNG presenting a different composition and density. In this case, the liquid at the bottom becomes lighter than that at the top, and rapidly rises to the surface. The liquid that moves to the top of the container experiences a drop in pressure equal, to a first approximation, to the head of liquid. It may therefore create a large amount of vapour, and increase the pressure rapidly in the vapour phase.

The resulting pressure peak might overwhelm the design pressure and opens the pressure relief valves. Such accidents have been known to happen, but they are not taken into account in QRA, considering that any emission coming from safety instruments should be delivered to safe place.

Water entering the LNG tanker

In case of collision between a passing ship and the LNG tanker or the LNG FSU/FSRU, the first one can open a hole below the water line. In this case, the leaking LNG emerges up to water surface and boils over it and the water is allowed to enter the tank, helping the LNG to leak due to the difference in densities and to vaporize due to heat transfer from the water to the LNG. This will lead to the generation of vapour from within the containment and the potential for a rapid pressure rise. This secondary effect forces further leakage of LNG form the tank, due to pressure.

Rapid Phase Transitions

The effect called Rapid Phase Transitions (RPT) [16] happens when spilled LNG is heated so rapidly that the expansion of the fluid on vaporisation is so fast that it produces a significant pressure wave, even though the pressure wave itself is not strong in comparison with common chemical explosions, so this effect is usually not considered in QRA.

2.3.4. Water and Land Use

The location proposed for the new LNG terminal may have health effects both onshore and offshore.

The area onshore is mainly dedicated to agricultural use, with a few isolated buildings: the scattered houses include some cottages, a horse farm, an historic fort and a farm in the extreme South of the Delimara peninsula. Heading north, the village of Marsaxlokk (with a total population of more than 3,000) is located at a distance of less than 1,000 m from the jetty. On the other side of Birzebbuga Bay, the biggest centre of population is Birzebbuga (population 8,800), which is located approximately 1.8 km west of the jetty. The population distribution considered on land is described in the Preliminary QRA [9].

The area offshore covers the entire water layer inside the port, for which the presence of vulnerable people is considered as a total population of 100 persons. Additionally, in the Freeport, located at more than 1,000 m from the jetty, a maximum density of 100 persons has been considered.

2.4. Metodology

2.4.1. Quantitative Risk Assessment

A Quantitative Risk Assessment is used to make decisions about the acceptability of risk in relation to developments for a company or in the area surrounding an establishment or transport route. The criteria for assessing the acceptability of risks for a large number of categories of establishments are set in internationally recognised guidelines and regulations.

In order to be able to use the results of a QRA for decisions, they must be verifiable, reproducible and comparable. Consequently, QRAs must be completed based upon the same assumptions, models and basic information.

The general Health and Safety Executive (HSE) [2], [17], [18], [19], [20] or BEVI [3] [4] calculation method can be followed to carry out QRA calculations. This calculation method can in principle be used in all situations that present themselves within the scope of the project.

A number of choices have been made in the development of the project. In so doing in each case, an evaluation was made between making the calculation method as clear as possible, for which parameters need to be set, and enabling location-specific modelling, for which some freedom of choice needs to be given to the user. The result of this evaluation is that, within the available framework of the calculation method, the user always has the option to modify specific information. For this the precondition applies that all QRA calculations must be worked out using properly substantiated and fully documented evaluations and choices.

The general approach of a QRA is illustrated in the flowchart below. This scope definition (internal, external, domino-effects) will have an influence on the selection of the relevant installations.

Modelling of liquid releases resulting in vapour cloud is largely dependent upon the modelling method employed. Limitations in modelling methods traditionally used for these behaviours produce unrealistic estimates of cloud travel offsite. In general there is a perception of consequences modelling as dramatically conservative in comparison with real spillages and major accidents reconstructions.

For this QRA, all consequences models are incorporated into the software EFFECTS 8.1.8. This software calculates and clearly presents in tables, graphs and on geographical maps, the physical effects of any accident scenario with toxic and/or flammable chemicals.

EFFECTS examines the progress of a potential incident from the initial release to far-field dispersion including modelling of pool spreading and evaporation, and flammable and toxic effects. The mathematical models introduced in the EFFECTS software fulfil the Yellow Book [21].

EFFECTS contains several models:

- Release (Gas, liquefied gas, liquid): discharge from a vessel or a pipe of gas, liquid or pressurized liquefied gas: vapour, liquid, two-phases and spray release.
- Pool evaporation: from land or water surfaces of a boiling or a non-boiling liquid.
- Atmospheric dispersion: neutral gas, heavy gas and turbulent free jet.
- Heat Radiation and combustion: Jet fire, pool fire, BLEVE
- Explosion
- Damage models

EFFECTS can link different models in order to organize the information in a structure to simplify the calculations.

Final risk calculation would be prepared with Risk Curves 7.6. While EFFECTS calculates the physical effects of a single accident with a dangerous substance, RISKCURVES takes multiple accident scenarios with multiple equipments into account and quantifies the total risk it has to human life. The calculated risks are expressed in terms of Individual- and Societal Risks.

Both are copyright of the Dutch organization TNO. [22]

2.4.2. Specific assumptions

Additional to the general criteria for loss of containment and effects calculations, the following specific assumptions should be taken into account:

Meteorological conditions

Within a QRA, adopted weather conditions are described as a combination of a letter and number. The letter denotes the Pasquill stability class and the number gives the wind speed in metres per second.

Using the data provided in previous chapters, the calculation will be done at the stability class and wind speed defined by HSE, grouping together the percentages for the different combinations of wind and stability.

It’s important to explain the relevance of this data, and to highlight the weight of the stability classes distribution within the study. In further steps of the calculation, any flammable gas cloud dispersion would be calculated for each stability class condition and corresponding wind velocity. The reason is due to the dependence of the dispersion phenomenon from the weather conditions. Then, all the proposed calculations are pieced together, each one according to its weight in the general statistic.

Release Duration

Release duration is a variable that depends on the organizational and technology structure of the equipment installed on site.

For pipelines, the estimated release duration is based on judgments of the closing time of emergency and operational valves. The detection systems to be provided at the facility would enable leaks to be detected rapidly.

The release duration time is [2] [21] [4]:

2 minutes when an automatic detection and acting system are installed.
30 minutes when an automatic detection and acting system are not installed.
These duration release times can be modified if an advanced technological system is installed (i.e. SIL, suppressors)

For tanks and vessels, the duration of a release from tanks or vessels (atmospheric) have been assumed to be equal to the time taken to empty the tank/vessel contents.

Releases on the Jetty

The unloading arm and the pipeline from the ship to the storage tank are partially located on the FSRU or the LNGC. All the leaks from the unloading arms are assumed to fall onto the water. All the leaks in the pipelines are assumed to fall onto the ship deck and from here to the sea.

Releases on water

Releases on water (proceeding from leakages in unloading arms or impacts on the LNG tanker) cannot be limited, unless a breakwater or other technical solution is put in place. However, the unlimited extension of a spillage on water is in general not credible. The layer of the released product cannot be thinner than a minimum amount, depending on the substance. And the effect of the waves, currents, winds, etc, must be considered.

Subsoil Length Descriptions

The roughness length is an artificial length-scale appearing in relations describing the wind speed over a surface, and which characterizes the roughness of the surface. Note that the sizes of the elements causing the roughness can be more than ten times larger than the roughness length [21].

Description	Roughness length
Open water, at least 5 km	0.0002 m
Mud flats, snow, no vegetation	0.005 m
Open flat terrain, grass, few isolated objects	0.03 m
Low crops, occasional large obstacles, x/h > 20	0.1 m
High crops, scattered large objects, 15 < x/h < 20	0.25 m
Parkland, bushes, numerous obstacles, x/h < 15	0.5 m
Regular large obstacles coverage (suburb, forest)	1.0 m
City centre with high- and low rising buildings	3.0 m

Surface Roughness Parameters

The surface roughness parameters are related to the type of soil on which the pool is spreading. Several different classes are supplied here where the type determines the heat transfer rate.

In practical situations the pool will spread until it reaches some minimum thickness which is related to the surface roughness. As typical values a lower limit of 5 millimetres for smooth surfaces, and for very rough surfaces several centimetres are used [21].

The classification provided here is based on table 3.1 from the Yellow Book [21]:

Subsoil	Average Roughness
flat sandy soil, concrete, tiles, plant-yard	0.005 m
relatively flat sandy soil, gravel	0.010 m
rough sandy soil, arable land, meadows	0.020 m
very rough overgrown sandy soil with holes	0.250 m

Averaging time

EFFECTS consider that the averaging time is a description of the time over which gas concentration is averaged. The default value is 18.75 s for flammable substances [21].

Thermal Radiation

The probit most commonly used to determine the risk from thermal radiation is the Eisenberg et al (1975) probit. [4] [23]

$$\text{Probit} = -14.9 + 2.56 \ln (I^{1.33t}) \text{ with I in kW/m}^2 \text{ and t in seconds.}$$

This relationship applies to people exposed outdoors. Consequently, this relationship can be used for most exposed population indoors and outdoors.

The value t is related to the exposure time. The value proposed in the Yellow Book [21] is 18.75 s.

It is sometimes necessary to make some further refinement and assumptions for people indoors, based on Crosthwaite et al (1988) [24]. The 12.7 kW/m^2 criterion is based on the figure used in the Building Regulations of 2006 Technical Guidance Document B on Building Fire Safety [25] and takes into account that the people are fully clothed.

Estimation of likelihood

There are two reference manuals [2] [3] used in the definition of the scenario. Each scenario type considers the failures on demand of the equipment and a proposed likelihood value.

In case of special protection measures are implemented, a fault tree analysis can be applied to determine the occurrence frequency of each event.

The event failure frequency is determined by [3] and [26]. To determine the final frequency of occurrence of the event defined as scenario, it is necessary to calculate the using hours per year of the installation and apply a correction factor to obtain the final occurrence.

Individual Risk

The Individual Risk represents the frequency of an individual dying due to loss of containment events (LOCs). The individual is assumed to be unprotected and to be present during the total exposure time. The Individual Risk is presented as contour lines on a topographic map.

Societal Risk

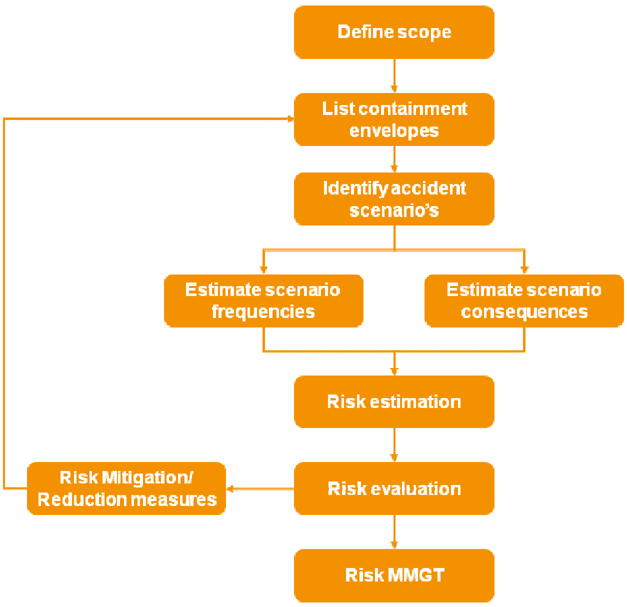
The Societal Risk represents the frequency of having an accident with N or more people being killed simultaneously. The people involved are assumed to have some means of protection. The Societal Risk is presented as an FN curve, where N is the number of deaths and F the cumulative frequency of accidents with N or more deaths. [27]

As the HSA conditions [2], the methodology for calculating the Societal Risk Index (SRI) is described by Carter (1995) [28] and Hirst and Carter (2000) [29] as follows:

$$SRI = P \times R \times T/A$$

Where

- P = population factor, defined as (n + n2)/2
- n = number of persons at the development
- R = average estimated level of individual risk in cpm
- T = proportion of time development is occupied by n persons
- A = area of the development in hectares



All relevant equipment will be listed and studied in the next steps. A first step is to determine the accident scenario's related to the equipment using i.e. Purple book [4], Handbook failure frequencies [30], PERD, HSE FRED [26],…. This step exists out of LOC-scenario's and event trees to determine the possible outcomes.

Generic LOC-scenario's will be used together with the published generic failure frequencies and escalation probabilities.

Risk calculation will be performed based on the scenarios with all relevant consequences (lethality), for the existing situation, using specialised software.

Individual risk (expressed per year) is the multiplication of the number of times that a major accident per year occurs, with the adverse effect (death) that a person experiences as a result of exposure to the disturbance (toxic effect, heat, pressure wave). This can be defined as follows:

$$IR_{(x,y)} = \sum F_i \cdot p_{f,i}$$

Where:

$IR_{(x,y)}$ =	total individual risk of fatality at location x,y (per year)
F_i =	Frequency of incident outcome case i with outcome case I
$p_{f,i}$ =	Probability that incident outcome case i results in a fatality at location (x,y)

To ensure full representation on safety, the calculation of the Group risk is required. The group risk is the risk that at one time a group of persons are victims of the same adverse event. This Group risk is shown in the form of a cumulative frequency curve (called FN curve). The damage is shown on the x-axis while the cumulative frequency of occurrence is in ordinate. The calculation of the Group risk is based on the existing population. In a final step the results will be assessed using criteria developed and agreed.

2.4.3. Risk acceptance criteria

Several similar risk acceptance criteria are accepted around the world for land use planning purposes (refer to Annex B for details). Most of them are based on an acceptable Individual Risk plus a combination of acceptable damages. In some cases, the Societal Risk is also used. Specifically for Malta, MEPA [31] have agreed on a set of risk acceptance criteria, to be followed for the preparation of the QRA. They are reported below:

Acceptable Heat radiation:

- Inner Zone: 13.4 kW/m^2 for 50% fatalities in a normal population
- Middle Zone: 9.3 kW/m^2 for 1 to 50% fatalities in a normal population
- Outer Zone: 7,3 kW/m^2 for 1 to 5% fatalities in a vulnerable population
- Industrial buildings: < 15 kW/m2

Acceptable Overpressure:

- 350 mbar for 50% fatalities
- 140 mbar for 1% fatalities

Acceptable Individual Risk (IR):

- Development in Inner Zone: IR < 10^{-5}/y
- Development in Middle Zone: IR < 10^{-6}/y
- Development in Inner Zone: IR < 10^{-7}/y

Additionally, another internationally recognized criterion is the societal risk (SR). The combination of 10 or more fatalities at an interval of 10,000 years is used to establish the F-N anchor point of (10, 10^{-4})10 which is used as acceptance criteria.

According to the purpose of this report, only the IR and SR will be considered in the calculation.

3. HAZARD IDENTIFICATION

In this chapter, a list of major accident scenarios is presented. The identification of the scenarios is carried out on the basis of the list of generic scenarios shown in the recommended guidelines.

This list is compared with the list of principal equipment and pipelines expected for the plant, in order to build a credible list of scenarios specifically designed for the plant. Proceeding in this way, the main risk factors in the facilities are primarily focused on possible leakages in pipes, pumps, storage tanks and vessels, as well as failures in loading / unloading arms and connections.

In other words, the plant has been broken down into a set of sections that could be isolated in the event of an accident, typically by the closure of emergency shutdown valves. For each inventory, at least one scenario is postulated and presented.

Other scenarios may be identified, using Process Hazard Analysis (PHA) techniques, such as HAZID, HAZOP, etc. [32]. These scenarios are generally related to the control of the process itself, so that any possible failure in the control system and/or human error is considered to be a cause for a pipe or vessel failure. Experience teaches us that for highly automated and controlled processes, these techniques add no additional credible scenarios.

3.1. Development of final events

Any Loss of Containment (LOC) scenario can result in a number of different final consequences which may affect the people, the environment and the facilities. The developing of one or other effect depends in great measure on environmental conditions, such as the wind velocity, the weather stability, the temperature, the released quantity or the presence of ignition points.

In general, the most common effects are well known, typified and modelled. More than one effect corresponds to one loss of containment, depending on the duration and evolution. For a liquid release of LNG, the following effects are considered:

- Pool Fire
- Pool evaporation and flammable gas cloud generation
- Flash-fire
- UVCE

For a release in gas phase, the effects are as follows:

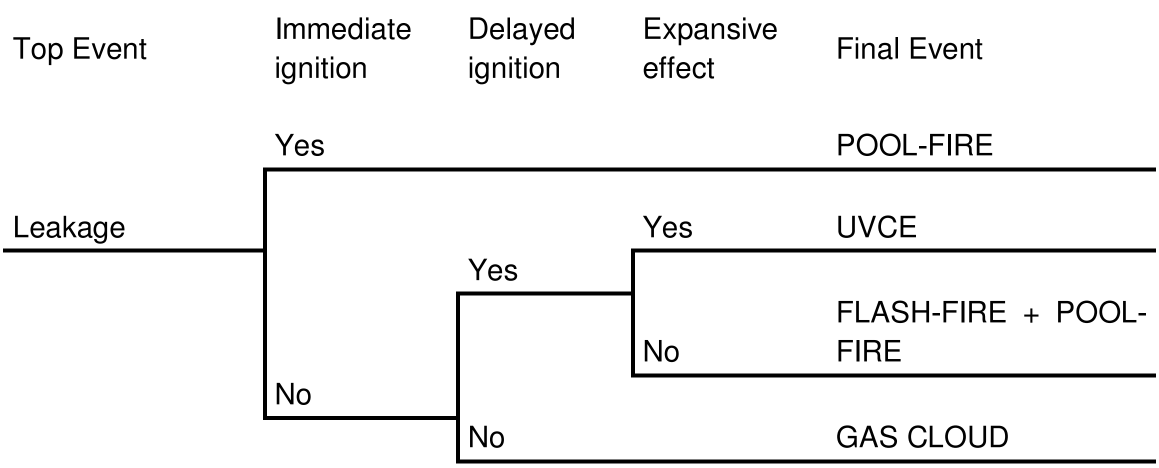
- Jet-fire
- Flash-fire
- UVCE

A brief description of these effects is provided at the end of the chapter.

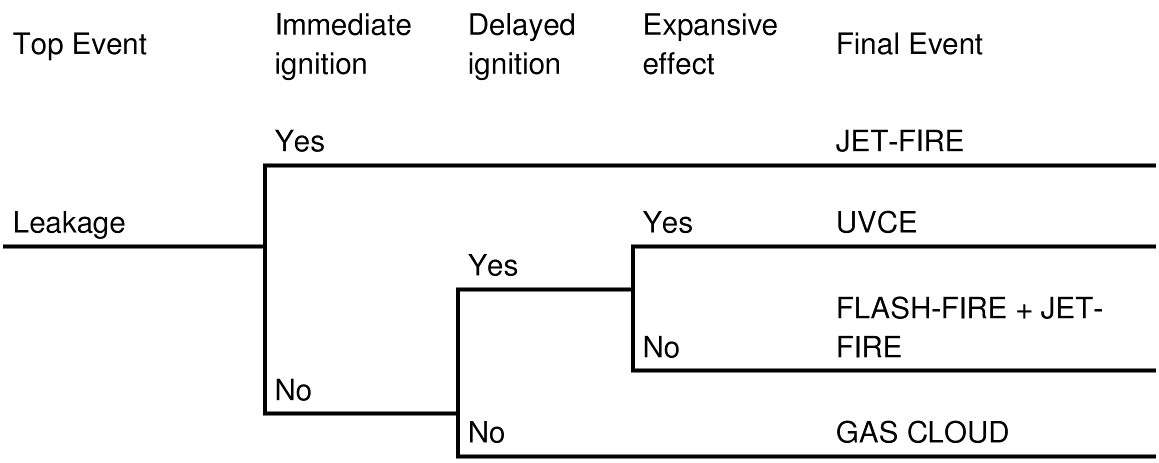
The final effects described in the previous chapter are related to the LOC event by the so-called Event Trees. An event tree is a graphical representation which helps the study of chronological and subsequent events or consequences.

The consequences of the event are followed through a series of possible paths, generally known as "minimum cut-set". Each path is assigned a probability of occurrence and the probability of the various possible outcomes can be calculated. The event trees for the release scenarios considered in the QRA are shown below.

Event tree for liquid release (LNG)



Event tree for gas release (GAS PHASE)



Pool Fire

A pool fire is the combustion of a substance in a liquid phase, while accumulated in a basin or spreading on the ground or water. A pool fire can be a continuous effect if the released quantity is enough and can burn over a very large period of time, until all the quantity is gone or the pool is properly covered with fire fighting foam.

Flammable Gas Cloud

A gas cloud is the dispersion of a pure or concentrated flammable gas in the air, in a condition which keeps the gas concentration higher than the lower flammability limit. In case of no direct ignition, a gas cloud is formed over a spillage of LNG, due to the high thermal gradient. A gas cloud is not directly dangerous for the population or environment, unless an ignition point provokes a flash-fire.

Flash-fire

A flash-fire is a phenomenon which occurs when an ignition point ignites a flammable cloud. It’s a transient phenomenon with an immediate effect on the population or plant personnel exposed. Depending on the combustion velocity, a flash-fire may create an expansive wave and present an explosive effect, as described in the following definition.

UVCE

An Unconfined Vapour Cloud Explosion (UVCE) is the ignition of a flammable cloud in open space in a condition which ensures expansive effect, due to the increase in the volume of the combustion gases versus the volume of the explosive mixture. This can happen depending on substance behaviour, accumulated quantity in the cloud, etc. In general, a cloud of natural gas in an open space such as the proposed plant is scarcely explosive, even for a large amount of gas in the cloud.

Jet-fire

A jet-fire is the direct combustion of a substance leaking from a pressurized vessel. The leakage can be in vapour or in a liquid phase. In this last case, the liquid is spread at high pressure forming fine drops which can be ignited.

3.2. List of credible scenarios

In this chapter, a list of major accident scenarios is presented. The identification of the scenarios is carried out on the basis of the HAZID study (issued in attachment of the Preliminary QRA [9]) plus the list of generic scenarios shown in the recommended guidelines.

This list is compared with the list of principal equipment and pipelines expected for the LNGC and FSU, in order to build a credible list of scenarios specifically designed for the offshore side of the LNG terminal. Proceeding in this way, the main hazards have been identified 1) in the ship to ship collision [7] including a third ship collision to the sailing LNGC or the moored FSU and the collision between the LNGC and the FSU during the maneuvering; and 2) in the on deck equipment, primarily focused on possible leakages in pipes, compressors and vessels, as well as failures in loading / unloading arms and connections during the ship to ship transfer of LNG.

In other words, the project has been broken down into a set of sections that could be isolated in the event of an accident, typically by the closure of emergency shutdown valves. For each inventory, at least one scenario is postulated and presented.

Regarding the collision scenarios, it is important to emphasize that several additional scenarios have been previously set and assessed by MARIN in the NAUTICAL AND RISK STUDIES FOR THE DELIMARA LNG TERMINAL IN MARSAXLOKK PORT, MALTA [7]. Only the relevant scenarios for an LNG spillage have been included in this report after a screening has been performed by SGS. Details regarding the scenarios considered by MARIN can be found in the cited report.

Detailed scenarios may be identified, using Process Hazard Analysis (PHA) techniques, such as HAZID, HAZOP, etc. [32]. These scenarios are generally related to the control of the process itself, so that any possible failure in the control system and/or human error is considered to be a cause for a pipe or vessel failure. Experience teaches us that for highly automated and controlled processes, these techniques add no additional credible scenarios.

In the following table, the complete list of scenarios considered in the QRA is presented.

ITEM	COD	DESCRIPTION	SUBSTANCE	NOTES	COORDINATE X	COORDINATE Y
S1	LNGC/LNG_TNK/G2	Major failure of the cargo tank (0,72 m2)	LNG	Membrane cargo tank	459661	3964841
					459631	3964819
					459604	3964817
					459560	3964820
					459511	3964813
					459472	3964770
					459421	3964666
					459368	3964564
					459334	3964476
					459304	3964403
					459285	3964348
					459366	3964246
					459568	3964032
					459736	3963754
					459929	3963452
					460190	3963170
					460443	3962887
					460720	3962621
S2	LMGC/LNG_TNK/G3	Minor failure of the tank (0,42 m2)	LNG	Membrane cargo tank	459661	3964841
					459631	3964819
					459604	3964817
					459560	3964820
					459511	3964813

ITEM	COD	DESCRIPTION	SUBSTANCE	NOTES	COORDINATE X	COORDINATE Y
					459472	3964770
					459421	3964666
					459368	3964564
					459334	3964476
					459304	3964403
					459285	3964348
					459366	3964246
					459568	3964032
					459736	3963754
					459929	3963452
					460190	3963170
					460443	3962887
					460720	3962621
S4	LNGC/BOG COMPRESSOR/G1	Rupture	NG	DN600	459661	3964841
					459631	3964819
					459604	3964817
					459560	3964820
					459511	3964813
					459472	3964770
					459421	3964666
					459368	3964564
					459334	3964476
					459304	3964403
					459285	3964348

ITEM	COD	DESCRIPTION	SUBSTANCE	NOTES	COORDINATE X	COORDINATE Y
					459366	3964246
					459568	3964032
					459736	3963754
					459929	3963452
					460190	3963170
					460443	3962887
					460720	3962621
S5	LNGC/BOG COMPRESSOR/G2	Large hole (1/3 diameter) on pipework	NG	DN600	459661	3964841
					459631	3964819
					459604	3964817
					459560	3964820
					459511	3964813
					459472	3964770
					459421	3964666
					459368	3964564
					459334	3964476
					459304	3964403
					459285	3964348
					459366	3964246
					459568	3964032
					459736	3963754
					459929	3963452
					460190	3963170

ITEM	COD	DESCRIPTION	SUBSTANCE	NOTES	COORDINATE X	COORDINATE Y
					460443	3962887
					460720	3962621
S6	LNGC/BOG COMPRESSOR/G3	Small hole (4mm) on pipework	NG	DN600	459661	3964841
					459631	3964819
					459604	3964817
					459560	3964820
					459511	3964813
					459472	3964770
					459421	3964666
					459368	3964564
					459334	3964476
					459304	3964403
					459285	3964348
					459366	3964246
					459568	3964032
					459736	3963754
					459929	3963452
					460190	3963170
					460443	3962887
					460720	3962621
S7	LNGC/BOG COMPRESSOR/G4	Pin hole	NG	DN600	459661	3964841
					459631	3964819
					459604	3964817

ITEM	COD	DESCRIPTION	SUBSTANCE	NOTES	COORDINATE X	COORDINATE Y
					459560	3964820
					459511	3964813
					459472	3964770
					459421	3964666
					459368	3964564
					459334	3964476
					459304	3964403
					459285	3964348
					459366	3964246
					459568	3964032
					459736	3963754
					459929	3963452
					460190	3963170
					460443	3962887
					460720	3962621
S8	LNGC/LINE BOC TO RECONDENSER/G1	Small hole (4mm) on pipework	NG	DN200	459661	3964841
					459631	3964819
					459604	3964817
					459560	3964820
					459511	3964813
					459472	3964770
					459421	3964666
					459368	3964564

ITEM	COD	DESCRIPTION	SUBSTANCE	NOTES	COORDINATE X	COORDINATE Y
					459334	3964476
					459304	3964403
					459285	3964348
					459366	3964246
					459568	3964032
					459736	3963754
					459929	3963452
					460190	3963170
					460443	3962887
					460720	3962621
					459661	3964841
S9	LNGC/LINE BOC TO RECONDENSER/G1	Medium hole (25mm) on pipework	NG	DN200	459661	3964841
					459631	3964819
					459604	3964817
					459560	3964820
					459511	3964813
					459472	3964770
					459421	3964666
					459368	3964564
					459334	3964476
					459304	3964403
					459285	3964348
					459366	3964246

ITEM	COD	DESCRIPTION	SUBSTANCE	NOTES	COORDINATE X	COORDINATE Y
					459568	3964032
					459736	3963754
					459929	3963452
					460190	3963170
					460443	3962887
					460720	3962621
S10	LNGC/LINE BOC TO RECONDENSER/G1	Large hole (1/3 diameter) on pipework	NG	DN200	459661	3964841
					459631	3964819
					459604	3964817
					459560	3964820
					459511	3964813
					459472	3964770
					459421	3964666
					459368	3964564
					459334	3964476
					459304	3964403
					459285	3964348
					459366	3964246
					459568	3964032
					459736	3963754
					459929	3963452
					460190	3963170
					460443	3962887

ITEM	COD	DESCRIPTION	SUBSTANCE	NOTES	COORDINATE X	COORDINATE Y
					460720	3962621
S11	LNGC/LINE BOC TO RECONDENSER/G1	Guillotine break on pipework	NG	DN200	459661	3964841
					459631	3964819
					459604	3964817
					459560	3964820
					459511	3964813
					459472	3964770
					459421	3964666
					459368	3964564
					459334	3964476
					459304	3964403
					459285	3964348
					459366	3964246
					459568	3964032
					459736	3963754
					459929	3963452
					460190	3963170
					460443	3962887
					460720	3962621
S12	LNGC/RECONDENSER/G1	Instantaneous release of the entire contents of the process vessel (30% LNG)	LNG	Process vessel	459661	3964841
					459631	3964819
					459604	3964817
					459560	3964820

ITEM	COD	DESCRIPTION	SUBSTANCE	NOTES	COORDINATE X	COORDINATE Y
					459511	3964813
					459472	3964770
					459421	3964666
					459368	3964564
					459334	3964476
					459304	3964403
					459285	3964348
					459366	3964246
					459568	3964032
					459736	3963754
					459929	3963452
					460190	3963170
					460443	3962887
					460720	3962621
S13	LNGC/RECONDENSER/G2	Release of entire contents in 10 min in a continous stream (30% LNG)	LNG	Process vessel	459661	3964841
					459631	3964819
					459604	3964817
					459560	3964820
					459511	3964813
					459472	3964770
					459421	3964666
					459368	3964564
					459334	3964476

ITEM	COD	DESCRIPTION	SUBSTANCE	NOTES	COORDINATE X	COORDINATE Y
					459304	3964403
					459285	3964348
					459366	3964246
					459568	3964032
					459736	3963754
					459929	3963452
					460190	3963170
					460443	3962887
					460720	3962621
S14	LNGC/RECONDENSER/G3	Continuous release from a hole with an effective diameter of 10 mm (30% LNG)	LNG	Process vessel	459661	3964841
					459631	3964819
					459604	3964817
					459560	3964820
					459511	3964813
					459472	3964770
					459421	3964666
					459368	3964564
					459334	3964476
					459304	3964403
					459285	3964348
					459366	3964246
					459568	3964032
					459736	3963754

ITEM	COD	DESCRIPTION	SUBSTANCE	NOTES	COORDINATE X	COORDINATE Y
					459929 460190 460443 460720	3963452 3963170 3962887 3962621
S15	LNGC/LNG_TNK/G2	Major failure of the cargo tank (0,72 m2)	LNG	Membrane cargo tank	459652	3964838
S16	LMGC/LNG_TNK/G3	Minor failure of the tank (0,42 m2)	LNG	Membrane cargo tank	459652	3964838
S17	LNGC/BOG COMPRESSOR/G1	Rupture	NG	DN600	459652	3964838
S18	LNGC/BOG COMPRESSOR/G2	Large hole (1/3 diameter) on pipework	NG	DN600	459652	3964838
S19	LNGC/BOG COMPRESSOR/G3	Small hole (4mm) on pipework	NG	DN600	459652	3964838
S20	LNGC/BOG COMPRESSOR/G4	Pin hole	NG	DN600	459652	3964838
S21	LNGC/LINE BOC TO RECONDENSER/G1	Small hole (4mm) on pipework	NG	DN200	459652	3964838
S22	LNGC/LINE BOC TO RECONDENSER/G1	Medium hole (25mm) on pipework	NG	DN200	459652	3964838
S23	LNGC/LINE BOC TO RECONDENSER/G1	Large hole (1/3 diameter) on pipework	NG	DN200	459652	3964838
S24	LNGC/LINE BOC TO RECONDENSER/G1	Guillotine break on pipework	NG	DN200	459652	3964838
S25	LNGC/RECONDENSER/G1	Instantaneous release of the entire contents of the process vessel (30% LNG)	LNG	Process vessel	459652	3964838
S26	LNGC/RECONDENSER/G2	Release of entire contents in 10 min in a continous stream (30% LNG)	LNG	Process vessel	459652	3964838

ITEM	COD	DESCRIPTION	SUBSTANCE	NOTES	COORDINATE X	COORDINATE Y
S27	LNGC/RECONDENSER/G3	Continuous release from a hole with an effective diameter of 10 mm (30% LNG)	LNG	Process vessel	459652	3964838
S28	FSU/GAS TANKER UNLOADING ARM/G1	Total failure rate when three arms (hoses) used	LNG	Unloading hose	459689	3964808
S29	FSU/GAS TANKER UNLOADING ARM/G2	Hole = 0.1 cross sectional area of pipe	LNG	Unloading hose	459689	3964808
S30	FSU/FSU UNLOADING ARM/G1	GUILLOTINE BREAK Total failure rate when one arm used	LNG	Unloading arm	459961	3964807
S31	FSU/FSU UNLOADING ARM/G2	Hole = 0.1 cross sectional area of pipe	LNG	Unloading arm	459961	3964807
S32	FSU/GAS TANKER GAS RETURN ARM/G1	Release limited according to ERC max content – total	NG	Gas arm	459689	3964808
S33	FSU/GAS TANKER GAS RETURN ARM/G2	Release limited according to ERC max content – partial	NG	Gas arm	459689	3964808
S34	FSU/PIPE TANK TO SECONDARY PUMP/G1	Total rupture in the pipeline	LNG	DN100	459717 459718 459759 459857 459944 459959	3964821 3964807 3964808 3964911 3965006 3965008

ITEM	COD	DESCRIPTION	SUBSTANCE	NOTES	COORDINATE X	COORDINATE Y
S35	FSU/PIPE FSU TANK TO COMPRESSOR/G1	Total rupture in the pipeline	NG	DN150	459718 459718 459758 459953 459953 459975	3964832 3964808 3964809 3965016 3965037 3965036

4. RISK ASSESSMENT

4.1. Frequency analysis

This chapter aims to quantify the frequency of the accident initiators or loss of containment scenarios using bibliographic data.

The frequencies of each accident scenario were obtained from tabulated standard frequencies from referenced guidelines [26] [3] and have been adapted to the period of use of the facilities, especially in the case of the presence of the LNG Carrier and the LNG unloading facilities.

4.1.1. Ignition probability

For each top scenario, depending on substance behaviours, state and quantity, a list of final events can be prepared, according to the explanation given in previous chapter. In the case of natural gas, the probability of each final event scenario depends on the ignition frequency.

In this QRA, specific ignition probabilities have been proposed, considering the heterogeneous set of activities in the neighbouring areas. They have been developed on the basis of the main renowned sources on the subject.

Cox, Lees and Ang, cited in Lees [33], present ignition probabilities for flammable gases and liquids based on the review of published values and on historical experience. The ignition probability varies with the size of the release and should be intended for overall probability of ignition, combining both immediate and delayed cases, but differentiating between gases and liquids, as shown below.

Failure Type	Ignition Probability – Gases	Ignition Probability – Liquids	Release Rate (kg/s)
Minor	0.01	0.01	<1
Major	0.07	0.03	1-50
Massive	0.3	0.8	>50

On the other hand, the Purple Book distinguishes between gases of different reactivity, classifying the methane as low reactivity:

Release Rate for Continuous Source (kg/s)	Mass released for Instantaneous Source	Ignition Probability for Low Reactivity Gas
<10	<1,000	0.02
10-100	1,000-10,000	0.04
>100	>10,000	0.09

Additionally, the HSE's PCAG [34] document indicates that immediate ignition probability values should vary between 0.1 and 0.9 for flammable liquids.

The analysis of this information suggests that the probability of immediate ignition can be as low as 0.01, specifically for methane, which presents a low reactivity and increases as a function of the size of the release.

SGS conclusion is to propose a set of probabilities slightly more conservative than those specified by the 'Purple Book', considerably more conservative than HSE for small leakages and consistent with the HSE for larger leakages, and also consistent with the overall ignition probabilities reported by Cox, Lees and Ang.

The final ignition frequency is considered to be variable depending on the release rate for delayed ignition, as shown in the following table:

Failure type	Release rate	Frequency
Minor	<10 kg/s	0.01
Small	10-100 kg/s	0.02
Large	>100 kg/s	0.1
Storage tank	n.a.	0.5

4.1.2. Event trees

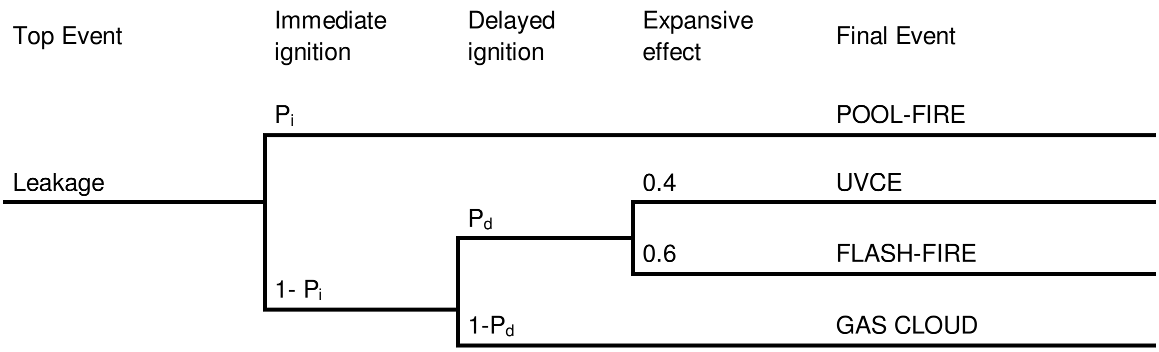
Starting from the literature, the goal is to quantify the probability of events that determine the evolution from the initial event and end up causing damage. This can be done by using the event tree technique.

The event tree is an inductive method that describes in a qualitative and quantitative mode, the evaluation from an initial event up to the final accident depending on the characteristics of the initiator, the environmental and the protection systems, where known.

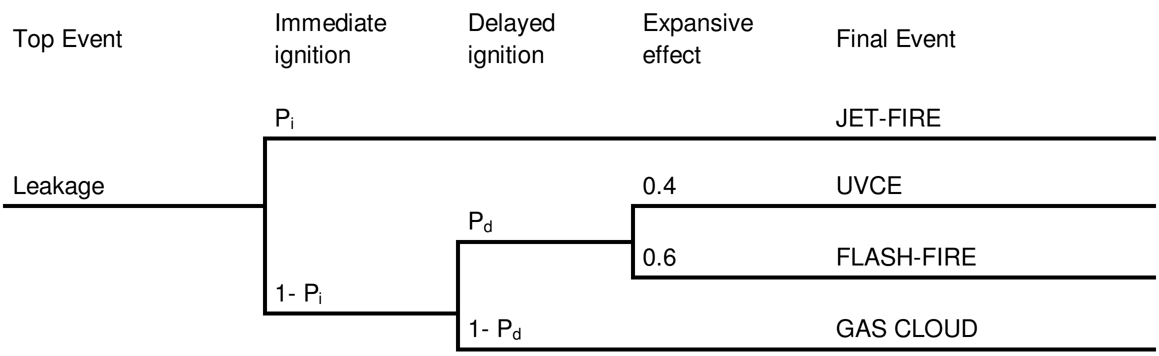
From the initial failure or initiator and considering the conditioning factors involved, the tree describes the accident sequences leading to possible events. The construction and evaluation of the tree begins by identifying the conditions and their probabilities of occurrence of each of them.

Each starting point, based on the initial event, is identified in the tree as N. The tree has to be systematically raised in two branches: the one at the top reflecting success or the occurrence of the event (with probability P) and the one below representing the failure or non-occurrence of the event (probability 1-P). The resulting event trees are shown below for a couple of examples.

Event tree for liquid release (LNG)



Event tree for gas release (GAS PHASE)



4.1.3. List of frequencies

In the following table, the calculation of the final frequency per each scenario is shown.

ITEM	COD	EQUIPMENT	DESCRIPTION	SUBSTANCE	NOTES	BASE FREQUENCY	UNITS	OBS.	SCENARIO FREQUENCY y^{-1}	OPERATION TIME (FRACTION)	SCENARIO FREQUENCY y^{-1}
S1	LNGC/ LNG_ TNK/G 2	LNG REFRIGERATED VESSEL	Major failure of the cargo tank (0.72 m2)	LNG	Membrane cargo tank	1.633E-14	y-1·m-1	N_{TANKS} = 1 Route L= 3900 m	6.37E-11	1.00	6.37E-11
S2	LMGC/ LNG_ TNK/G 3	LNG REFRIGERATED VESSEL	Minor failure of cargo tank (0.42 m2)	LNG	Membrane cargo tank	1.633E-14	y-1·m-1	N_{TANKS} = 1 Route L= 3900 m	6.37E-11	1.00	6.37E-11
S4	LNGC/ BOG COMPRESSOR/G1	BOIL-OFF GAS COMPRESSOR	Rupture	NG	DN600	2.9E-06	compressor-1 y-1	$N_{COMPRESSORS}$=1	2.90E-06	2.05E-03	5.96E-09
S5	LNGC/ BOG COMPRESSOR/G2	BOIL-OFF GAS COMPRESSOR	Large hole (1/3 diameter) on pipework	NG	DN600	2.9E-06	compressor-1 y-1	$N_{COMPRESSORS}$=1	2.90E-06	2.05E-03	5.96E-09
S6	LNGC/ BOG COMPRESSOR/G3	BOIL-OFF GAS COMPRESSOR	Small hole (4mm) on pipework	NG	DN600	2.7E-04	compressor-1 y-1	$N_{COMPRESSORS}$=1	2.70E-04	2.05E-03	5.55E-07
S7	LNGC/ BOG COMPRESSOR/G4	BOIL-OFF GAS COMPRESSOR	Pin hole	NG	DN600	1.2E-02	compressor-1 y-1	$N_{COMPRESSORS}$=1	1.20E-02	2.05E-03	2.47E-05
S8	LNGC/ LINE BOC TO RECONDENSER/G 1	NG PIPELINE FROM BOG COMPRESSOR TO RECONDENSER	Small hole (4mm) on pipework	NG	DN200	1.0E-06	m-1 y-1	L = 190m	1.90E-04	2.05E-03	3.90E-07

ITEM	COD	EQUIPMENT	DESCRIPTION	SUBSTANCE	NOTES	BASE FREQUENCY	UNITS	OBS.	SCENARIO FREQUENCY y^{-1}	OPERATION TIME (FRACTION)	SCENARIO FREQUENCY y^{-1}
S9	LNGC/ LINE BOC TO RECONDENSER/G 1	NG PIPELINE FROM BOG COMPRESSOR TO RECONDENSER	Medium hole (25mm) on pipework	NG	DN200	7.00E-7	m-1 y-1	L = 190m	1.33E-04	2.05E-03	2.73E-07
S10	LNGC/ LINE BOC TO RECONDENSER/G 1	NG PIPELINE FROM BOG COMPRESSOR TO RECONDENSER	Large hole (1/3 diameter) on pipework	NG	DN200	4.0E-07	m-1 y-1	L = 190m	7.60E-05	2.05E-03	1.56E-07
S11	LNGC/ LINE BOC TO RECONDENSER/G 1	NG PIPELINE FROM BOG COMPRESSOR TO RECONDENSER	Guillotine break on pipework	NG	DN200	2.0E-07	m-1 y-1	L = 190m	3.80E-05	2.05E-03	7.81E-08
S12	LNGC/ RECONDENSER/G 1	RECONDENSER	Instantaneous release of the entire contents of the process vessel (30% LNG)	LNG	Process vessel	5.00E-06	y-1	$N_{RECONDENSERS}$ = 1	5.00E-06	2.05E-03	1.03E-08
S13	LNGC/ RECONDENSER/G 2	RECONDENSER	Release of entire contents in 10 min in a continous stream (30% LNG)	LNG	Process vessel	5.00E-06	y-1	$N_{RECONDENSERS}$ = 1	5.00E-06	2.05E-03	1.03E-08

ITEM	COD	EQUIPMENT	DESCRIPTION	SUBSTANCE	NOTES	BASE FREQUENCY	UNITS	OBS.	SCENARIO FREQUENCY y^{-1}	OPERATION TIME (FRACTION)	SCENARIO FREQUENCY y^{-1}
S14	LNGC/ RECO NDEN SER/G 3	RECONDENS ER	Continuous release from a hole with an effective diameter of 10 mm (30% LNG)	LNG	Process vessel	1.00E-04	y-1	$N_{RECONDENSERS}$ = 1	1.00E-04	2.05E-03	2,05E-07
S15	LNGC/ LNG_ TNK/G 2	LNG REFRIGERAT ED VESSEL	Major failure of the cargo tank (0.72 m2)	LNG	Membrane cargo tank	1.63E-14	y-1·m-1	N_{TANKS} = 1 Route L= 3900 m	6.37E-11	1.00	6.37E-11
S16	LMGC/ LNG_ TNK/G 3	LNG REFRIGERAT ED VESSEL	Minor failure of the tank (0.42 m2)	LNG	Membrane cargo tank	1.63E-14	y-1·m-1	N_{TANKS} = 1 Route L= 3900 m	6.37E-11	1.00	6.37E-11
S17	LNGC/ BOG COMP RESS OR/G1	BOIL-OFF GAS COMPRESSO R	Rupture	NG	DN600	2,90E-06	compr essor-1 y-1	$N_{COMPRESSORS}$=1	2,90E-06	3,35E-02	9,71E-08
S18	LNGC/ BOG COMP RESS OR/G2	BOIL-OFF GAS COMPRESSO R	Large hole (1/3 diameter) on pipework	NG	DN600	2,90E-06	compr essor-1 y-1	$N_{COMPRESSORS}$=1	2,90E-06	3,35E-02	9,71E-08
S19	LNGC/ BOG COMP RESS OR/G3	BOIL-OFF GAS COMPRESSO R	Small hole (4mm) on pipework	NG	DN600	2,70E-04	compr essor-1 y-1	$N_{COMPRESSORS}$=1	2,70E-04	3,35E-02	9,04E-06
S20	LNGC/ BOG COMP RESS OR/G4	BOIL-OFF GAS COMPRESSO R	Pin hole	NG	DN600	1,20E-02	compr essor-1 y-1	$N_{COMPRESSORS}$=1	1,20E-02	3,35E-02	4,02E-04

ITEM	COD	EQUIPMENT	DESCRIPTION	SUBSTANCE	NOTES	BASE FREQUENCY	UNITS	OBS.	SCENARIO FREQUENCY y^{-1}	OPERATION TIME (FRACTION)	SCENARIO FREQUENCY y^{-1}
S21	LNGC/ LINE BOC TO RECONDENSER/G 1	NG PIPELINE FROM BOG COMPRESSOR TO RECONDENSER	Small hole (4mm) on pipework	NG	DN200	1,00E-06	m-1 y-1	L = 190m	1,90E-04	3,35E-02	6,36E-06
S22	LNGC/ LINE BOC TO RECONDENSER/G 1	NG PIPELINE FROM BOG COMPRESSOR TO RECONDENSER	Medium hole (25mm) on pipework	NG	DN200	7,00E-07	m-1 y-1	L = 190m	1,33E-04	3,35E-02	4,45E-06
S23	LNGC/ LINE BOC TO RECONDENSER/G 1	NG PIPELINE FROM BOG COMPRESSOR TO RECONDENSER	Large hole (1/3 diameter) on pipework	NG	DN200	4,00E-07	m-1 y-1	L = 190m	7,60E-05	3,35E-02	2,55E-06
S24	LNGC/ LINE BOC TO RECONDENSER/G 1	NG PIPELINE FROM BOG COMPRESSOR TO RECONDENSER	Guillotine break on pipework	NG	DN200	2,00E-07	m-1 y-1	L = 190m	3,80E-05	3,35E-02	1,27E-06
S25	LNGC/ RECONDENSER/G 1	RECONDENSER	Instantaneous release of the entire contents of the process vessel (30% LNG)	LNG	Process vessel	5,00E-06	y-1	$N_{RECONDENSERS}$ = 1	5,00E-06	3,35E-02	1,67E-07

ITEM	COD	EQUIPMENT	DESCRIPTION	SUBSTANCE	NOTES	BASE FREQUENCY	UNITS	OBS.	SCENARIO FREQUENCY y^{-1}	OPERATION TIME (FRACTION)	SCENARIO FREQUENCY y^{-1}
S26	LNGC/RECONDENSER/G2	RECONDENSER	Release of entire contents in 10 min in a continous stream (30% LNG)	LNG	Process vessel	5,00E-06	y-1	$N_{RECONDENSERS}$ = 1	5,00E-06	3,35E-02	1,67E-07
S27	LNGC/RECONDENSER/G3	RECONDENSER	Continuous release from a hole with an effective diameter of 10 mm (30% LNG)	LNG	Process vessel	1,00E-04	y-1	$N_{RECONDENSERS}$ = 1	1,00E-04	3,35E-02	3,35E-06
S28	FSU/GAS TANKER UNLOADING ARM/G1	UNLOADING ARM	Total failure rate when three arms (hoses) used	LNG	Unloading hose	1,90E-06	transf-1	12 operations	2,28E-05	1,00E+00	2,28E-05
S29	FSU/GAS TANKER UNLOADING ARM/G2	UNLOADING ARM	Hole = 0.1 cross sectional area of pipe	LNG	Unloading hose	2,40E-05	transf-1	12 operations	2,88E-04	1,00	2,88E-04
S30	FSU/FSU UNLOADING ARM/G1	UNLOADING ARM	GUILLOTINE BREAK Total failure rate when one arm used	LNG	Unloading arm	7,00E-06	transf-1	Continuous operation while frequency is referred to 12 hour operation. Frequency adapted considered a 0.1 reduction	1,68E-05	1,00	1,68E-05

ITEM	COD	EQUIPMENT	DESCRIPTION	SUBSTANCE	NOTES	BASE FREQUENCY	UNITS	OBS.	SCENARIO FREQUENCY y^{-1}	OPERATION TIME (FRACTION)	SCENARIO FREQUENCY y^{-1}
S31	FSU/FSU UNLOADING ARM/ G2	UNLOADING ARM	Hole = 0.1 cross sectional area of pipe	LNG	Unloading arm	7,00E-07	transf-1	Continuous operation while frequency is referred to 12 hour operation. Frequency adapted considered a 0.1 reduction	1,68E-06	1,00	1,68E-06
S32	FSU/GAS TANKER GAS RETURN ARM/ G1	UNLOADING ARM	Release limited according to ERC max content – total	NG	Gas arm	7,00E-06	transf-1	Continuous operation while frequency is referred to 12 hour operation. Frequency adapted considered a 0.1 reduction	1,68E-05	1,00	1,68E-05
S33	FSU/GAS TANKER GAS RETURN ARM/ G2	UNLOADING ARM	Release limited according to ERC max content – partial	NG	Gas arm	8,00E-06	transf-1	Continuous operation while frequency is referred to 12 hour operation. Frequency adapted considered a 0.1 reduction	1,92E-05	1,00	1,92E-05

ITEM	COD	EQUIPMENT	DESCRIPTION	SUBSTANCE	NOTES	BASE FREQUENCY	UNITS	OBS.	SCENARIO FREQUENCY y^{-1}	OPERATION TIME (FRACTION)	SCENARIO FREQUENCY y^{-1}
S34	FSU/PIPE TANK TO SECONDARY PUMP/G1	PIPELINE FROM TANK TO RECONDENSER	Total rupture in the pipeline	LNG	DN100	6,50E-09	m·y-1		1,98E-06	3,35E-02	6,64E-08
S35	FSU/PIPE FSU TANK TO COMPRESSOR/G1	PIPELINE FROM FSU TANK TO COMPRESSOR	Total rupture in the pipeline	NG	DN150	6,50E-09	m·y-1		5,53E-06	3,35E-02	1,85E-07

In the following table, the complete list of the final events frequencies is presented.

ITEM	COD	EQUIPMENT	DESCRIPTION	SUBSTANCE	NOTES	DIRECT IGNITION PROB.	DELAYED IGNITION PROB.	POOL FIRE / JET FIRE FREQUENCY	FLASHF + EXPLOSION FREQUENCY	NO EFFECTS FREQUENCY
S1	LNGC/LNG_TNK/G2	LNG REFRIGERATED VESSEL	Major failure of the cargo tank (0.72 m2)	LNG	Membrane cargo tank	0.50	0.50	1.59E-11	7.96E-12	7.96E-12
S2	LNGC/LNG_TNK/G3	LNG REFRIGERATED VESSEL	Minor failure of the tank (0.42 m2)	LNG	Membrane cargo tank	0.50	0.50	2.28E-10	1.14E-10	1.14E-10

ITEM	COD	EQUIPMENT	DESCRIPTION	SUBSTANCE	NOTES	DIRECT IGNITION PROB.	DELAYED IGNITION PROB.	POOL FIRE / JET FIRE FREQUENCY	FLASHF + EXPLOSION FREQUENCY	NO EFFECTS FREQUENCY
S4	LNGC/ BOG COMPRESSOR/G1	BOIL-OFF GAS COMPRESSOR	Rupture	NG	DN600	0.01	0.50	5.96E-11	2.95E-09	2.95E-09
S5	LNGC/ BOG COMPRESSOR/G2	BOIL-OFF GAS COMPRESSOR	Large hole (1/3 diameter) on pipework	NG	DN600	0.01	0.50	5.96E-11	2.95E-09	2.95E-09
S6	LNGC/ BOG COMPRESSOR/G3	BOIL-OFF GAS COMPRESSOR	Small hole (4mm) on pipework	NG	DN600	0.01	0.50	5.55E-09	2.75E-07	2.75E-07
S7	LNGC/ BOG COMPRESSOR/G4	BOIL-OFF GAS COMPRESSOR	Pin hole	NG	DN600	0.01	0.50	2.47E-07	1.22E-05	1.22E-05
S8	LNGC/ LINE BOC TO RECONDENSER/G1	NG PIPELINE FROM BOG COMPRESSOR TO RECONDENSER	Small hole (4mm) on pipework	NG	DN200	0.50	0.50	1.95E-07	9.76E-08	9.76E-08
S9	LNGC/ LINE BOC TO RECONDENSER/G1	NG PIPELINE FROM BOG COMPRESSOR TO RECONDENSER	Medium hole (25mm) on pipework	NG	DN200	0.50	0.50	1.37E-07	6.83E-08	6.83E-08

ITEM	COD	EQUIPMENT	DESCRIPTION	SUBSTANCE	NOTES	DIRECT IGNITION PROB.	DELAYED IGNITION PROB.	POOL FIRE / JET FIRE FREQUENCY	FLASHF + EXPLOSION FREQUENCY	NO EFFECTS FREQUENCY
S10	LNGC/ LINE BOC TO RECONDENSER/G1	NG PIPELINE FROM BOG COMPRESSOR TO RECONDENSER	Large hole (1/3 diameter) on pipework	NG	DN200	0.50	0.50	7.81E-08	3.90E-08	3.90E-08
S11	LNGC/ LINE BOC TO RECONDENSER/G1	NG PIPELINE FROM BOG COMPRESSOR TO RECONDENSER	Guillotine break on pipework	NG	DN200	0.50	0.50	3.90E-08	1.95E-08	1.95E-08
S12	LNGC/ RECONDENSER/G1	RECONDENSER	Instantaneous release of the entire contents of the process vessel (30% LNG)	LNG	Process vessel	0.50	0.50	5.14E-09	2.57E-09	2.57E-09
S13	LNGC/ RECONDENSER/G2	RECONDENSER	Release of entire contents in 10 min in a continous stream (30% LNG)	LNG	Process vessel	0.50	0.50	5.14E-09	2.57E-09	2.57E-09
S14	LNGC/ RECONDENSER/G3	RECONDENSER	Continuous release from a hole with an effective diameter of 10 mm (30% LNG)	LNG	Process vessel	0.01	0.50	2.05E-09	1.02E-07	1.02E-07
S15	LNGC/ LNG_TNK/G2	LNG REFRIGERATED VESSEL	Major failure of the cargo tank (0.72 m2)	LNG	Membrane cargo tank	0.50	0.50	3.18E-11	1.59E-11	1.59E-11
S16	LMGC/ LNG_TNK/G3	LNG REFRIGERATED VESSEL	Minor failure of the tank (0.42 m2)	LNG	Membrane cargo tank	0.50	0.50	3.18E-11	1.59E-11	1.59E-11

ITEM	COD	EQUIPMENT	DESCRIPTION	SUBSTANCE	NOTES	DIRECT IGNITION PROB.	DELAYED IGNITION PROB.	POOL FIRE / JET FIRE FREQUENCY	FLASHF + EXPLOSION FREQUENCY	NO EFFECTS FREQUENCY
S17	LNGC/ BOG COMP RESSO R/G1	BOIL-OFF GAS COMPRESSOR	Rupture	NG	DN600	0.02	0.50	1,94E-09	4,76E-08	4,76E-08
S18	LNGC/ BOG COMP RESSO R/G2	BOIL-OFF GAS COMPRESSOR	Large hole (1/3 diameter) on pipework	NG	DN600	0.01	0.50	9,71E-10	4,81E-08	4,81E-08
S19	LNGC/ BOG COMP RESSO R/G3	BOIL-OFF GAS COMPRESSOR	Small hole (4mm) on pipework	NG	DN600	0.01	0.50	9,04E-08	4,48E-06	4,48E-06
S20	LNGC/ BOG COMP RESSO R/G4	BOIL-OFF GAS COMPRESSOR	Pin hole	NG	DN600	0.01	0.50	4,02E-06	1,99E-04	1,99E-04
S21	LNGC/ LINE BOC TO RECO NDENS ER/G1	NG PIPELINE FROM BOG COMPRESSOR TO RECONDENSE R	Small hole (4mm) on pipework	NG	DN200	0.50	0.50	3,18E-06	1,59E-06	1,59E-06
S22	LNGC/ LINE BOC TO RECO NDENS ER/G1	NG PIPELINE FROM BOG COMPRESSOR TO RECONDENSE R	Medium hole (25mm) on pipework	NG	DN200	0.50	0.50	2,23E-06	1,11E-06	1,11E-06

ITEM	COD	EQUIPMENT	DESCRIPTION	SUBSTANCE	NOTES	DIRECT IGNITION PROB.	DELAYED IGNITION PROB.	POOL FIRE / JET FIRE FREQUENCY	FLASHF + EXPLOSION FREQUENCY	NO EFFECTS FREQUENCY
S23	LNGC/ LINE BOC TO RECONDENSER/G1	NG PIPELINE FROM BOG COMPRESSOR TO RECONDENSER	Large hole (1/3 diameter) on pipework	NG	DN200	0.50	0.50	1,27E-06	6,36E-07	6,36E-07
S24	LNGC/ LINE BOC TO RECONDENSER/G1	NG PIPELINE FROM BOG COMPRESSOR TO RECONDENSER	Guillotine break on pipework	NG	DN200	0.50	0.50	6,36E-07	3,18E-07	3,18E-07
S25	LNGC/ RECONDENSER/G1	RECONDENSER	Instantaneous release of the entire contents of the process vessel (30% LNG)	LNG	Process vessel	0.50	0.50	8,37E-08	4,19E-08	4,19E-08
S26	LNGC/ RECONDENSER/G2	RECONDENSER	Release of entire contents in 10 min in a continuous stream (30% LNG)	LNG	Process vessel	0.50	0.50	8,37E-08	4,19E-08	4,19E-08
S27	LNGC/ RECONDENSER/G3	RECONDENSER	Continuous release from a hole with an effective diameter of 10 mm (30% LNG)	LNG	Process vessel	0.01	0.50	3,35E-08	1,66E-06	1,66E-06

ITEM	COD	EQUIPMENT	DESCRIPTION	SUBSTANCE	NOTES	DIRECT IGNITION PROB.	DELAYED IGNITION PROB.	POOL FIRE / JET FIRE FREQUENCY	FLASHF + EXPLOSION FREQUENCY	NO EFFECTS FREQUENCY
S28	FSU/GAS TANKER UNLOADING ARM/G1	UNLOADING ARM	Total failure rate when three arms (hoses) used	LNG	Unloading hose	0.50	0.50	1,14E-05	5,70E-06	5,70E-06
S29	FSU/GAS TANKER UNLOADING ARM/G2	UNLOADING ARM	Hole = 0.1 cross sectional area of pipe	LNG	Unloading hose	0.50	0.50	1,44E-04	7,20E-05	7,20E-05
S30	FSU/FSU UNLOADING ARM/G1	UNLOADING ARM	GUILLOTINE BREAK Total failure rate when one arm used	LNG	Unloading arm	0.50	0.50	8,40E-06	4,20E-06	4,20E-06
S31	FSU/FSU UNLOADING ARM/G2	UNLOADING ARM	Hole = 0.1 cross sectional area of pipe	LNG	Unloading arm	0.50	0.50	8,40E-07	4,20E-07	4,20E-07

ITEM	COD	EQUIPMENT	DESCRIPTION	SUBSTANCE	NOTES	DIRECT IGNITION PROB.	DELAYED IGNITION PROB.	POOL FIRE / JET FIRE FREQUENCY	FLASHF + EXPLOSION FREQUENCY	NO EFFECTS FREQUENCY
S32	FSU/GAS TANKER GAS RETURN ARM/G1	UNLOADING ARM	Release limited according to ERC max content – total	NG	Gas arm	0.50	0.50	8,40E-06	4,20E-06	4,20E-06
S33	FSU/GAS TANKER GAS RETURN ARM/G2	UNLOADING ARM	Release limited according to ERC max content – partial	NG	Gas arm	0.50	0.50	9,60E-06	4,80E-06	4,80E-06
S34	FSU/PIPE TANK TO SECONDARY PUMP/G1	PIPELINE FROM TANK TO RECONDENSER	Total rupture in the pipeline	LNG	DN100	0.50	0.50	3,32E-08	1,66E-08	1,66E-08
S35	FSU/PIPE FSU TANK TO COMPRESSOR/G1	PIPELINE FROM FSU TANK TO COMPRESSOR	Total rupture in the pipeline	NG	DN150	0.50	0.50	9,25E-08	4,63E-08	4,63E-08

4.2. Isorisk and societal risk

The risk contour for the population, based on the scenario's consequences and frequencies listed in the previous tables is the result of the risk calculation, performed implementing the criteria and methodology already described. The risk contour is shown in drawing attached in Annex A.

The risk contours must be drawn in accordance with the adopted criteria for the boundaries of the following zones:

- 10^{-3} / year: boundary of the individual risk of fatality for operators.
- 10^{-4} / year: boundary of the individual risk of fatality for personnel of the neighboring terminals.
- 10^{-6} / year: boundary of the individual risk of fatality for the public.

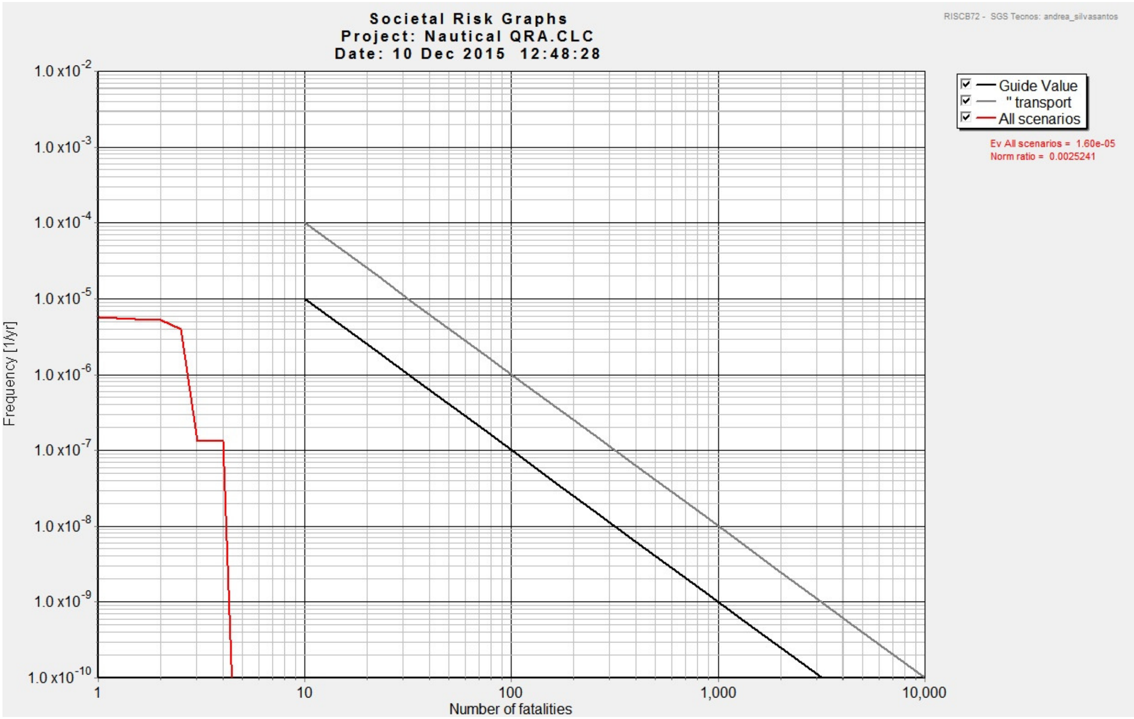
Also, the societal risk calculation has been performed, considering the permanent presence of operators in the terminals, plus the presence of people in the passing road.

Societal risk is defined [6] [35] as the relationship between frequency and the number of people suffering from a specified level of harm in a given population from the realization of specified hazards [36]. Societal risk evaluation is concerned with estimation of the chances of more than one individual being harmed simultaneously by an incident. The likelihood of the primary event (an accident at a major hazard plant) is still a factor, but the consequences are assessed in terms of level of harm and the numbers affected (severity), to provide an idea of the scale of an accident in terms of numbers killed or harmed.

Societal risk is dependent on the risks from the substances and processes located on a major hazard installation. A key factor in estimating societal risk is the population around the site, in particular its location and density.

Societal risk can be represented by FN curves [4], which are plots of the cumulative frequency (F) of various accident scenarios against the number (N) of casualties associated with the modelled incidents. The plot is cumulative in the sense that, for each frequency, N is the number of casualties that could be equalled or exceeded. Often 'casualties' are defined in a risk assessment as fatal injuries, in which case N is the number of people that could be killed by the incidents.

The resultant F-N curve is shown in the following figure.



As can be easily understood, the red curve is well below the black lines, thus the number of fatalities per each frequency considering all the scenarios is acceptable.

5. CONCLUSIONS

A comprehensive Nautical Quantitative Risk Assessment (QRA) of the LNG Terminal located in the Marsaxlokk Bay has been carried out, on the basis of a specific nautical risk assessment published by MARIN as NAUTICAL AND RISK STUDIES FOR THE DELIMARA LNG TERMINAL IN MARSAXLOKK PORT, MALTA [7]. Clear, detailed and definitive results for the offshore side of the project have been calculated, in accordance with the set of criteria established on the basis of renowned international sources and a site-specific ship to ship collision assessment.

The following results have been obtained: individual risk contours and societal risk FN curve.

Regarding the individual risk contour, the acceptability value of 10^{-6}/y remains at a high distance from any leisure activity or residential area and remains in any case contained by the safety zone to be established around any moored or navigating dangerous goods vessel, according to the international ship standards and to the Maltese regulation for dangerous goods in port areas. In the specific case of the navigating LNG Carrier, the frequency of a major accident is highly unlikely being the 10^{-9}/y the only representative individual risk contour perceived.

Regarding the societal risk, in the unlikely event of an accident, the number of fatalities is acceptable, if compared with the acceptance criteria used in other European Countries with a large tradition of quantitative risk assessment.

The main conclusion is that the presence of the LNG terminal, from a nautical point of view, is fully compatible with the acceptability criteria proposed, in agreement with the set of criteria adopted in the calculation, provided that procedures, maintenance, safety measures, safeguards and leakage prevention considered in the calculations are set in place.

In other words, the presence of a permanently moored FSU, a visiting LNG Carrier and the jetty is compatible with the presence of other activities in the vicinity, i.e. fishing or sailing boats as well as with the presence of people in the surrounding area.

Despite the positive conclusion, the consultant recalls the importance of completing the safety documentation before the commissioning of the project, with the implementation of a complete Safety Report, Safety Management System and an Emergency Response Planning, in order to demonstrate that:

- The safety measures (preventing, controlling, and mitigation) are appropriately implemented;
- The major accident risks are kept as low as reasonably possible;
- The non-ignition zone, area classification, security zone and marine exclusion zone are set in place as already recommended by the Preliminary QRA.

- The emergency response measures are sufficient and effective to handle all major accident hazards.

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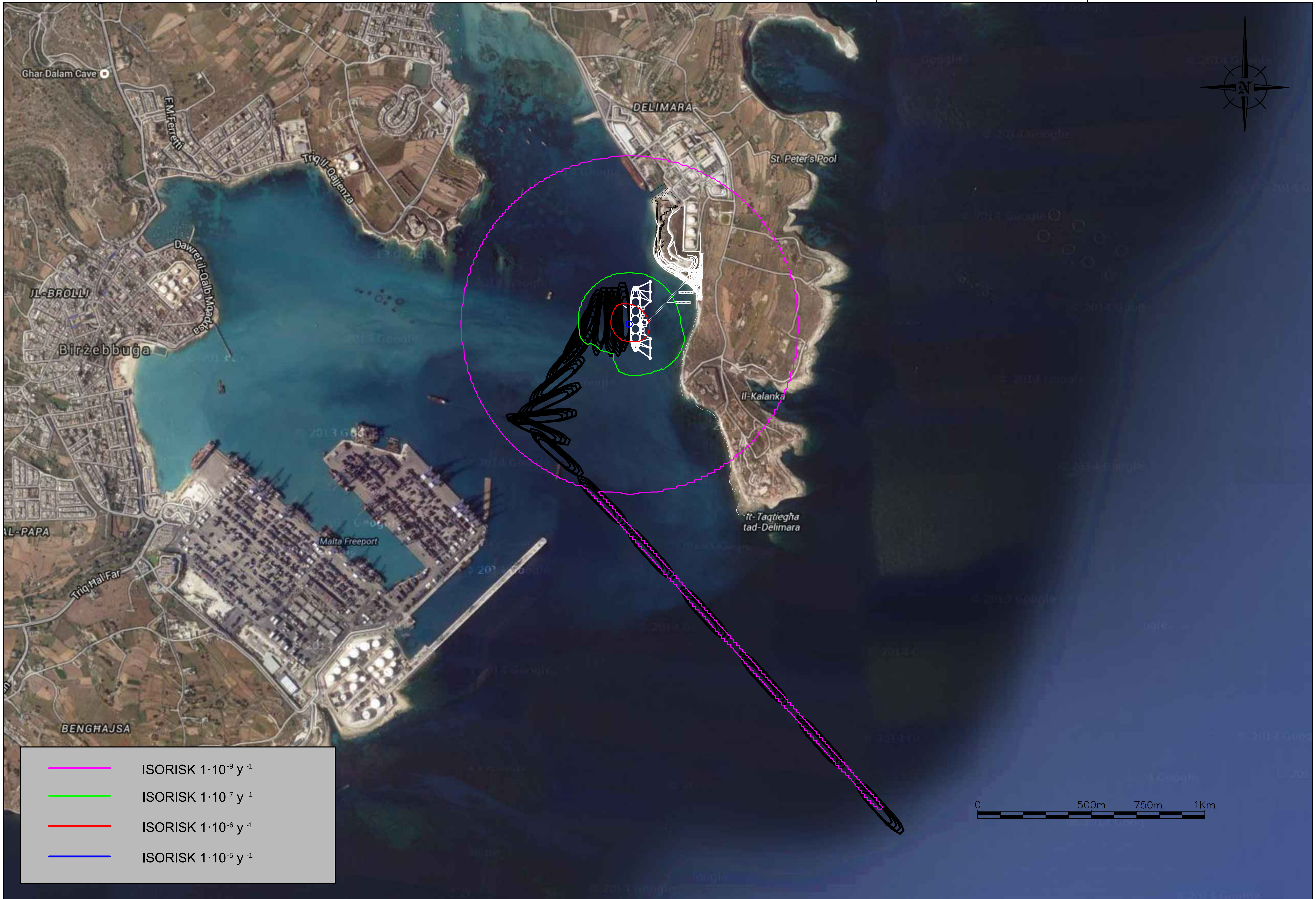
ANNEX A. DRAWINGS

The following drawings are attached in the present Annex:

Drawing 1: Area of concern
Drawing 2: Plot plan
Drawing 3: Individual risk curves
Drawing 4: Individual risk curves – FSU Area Detail

SGS	PROJECT: LNG TERMINAL IN THE MARSAXLOKK BAY	SCALE: A3 : 1/10000	DRAWING NAME: AREA OF CONCERN	DATE: April 2015	DRAWING: 1

	SGS	PROJECT: LNG TERMINAL IN THE MARSAXLOKK BAY	SCALE: A3 : 1/20000 A3 : 1/10000	DRAWING NAME: PLOT PLAN	DATE: December 2015	DRAWING: 2



	PROJECT:	SCALE:	DRAWING NAME:	DATE:	DRAWING:
SGS	LNG TERMINAL IN THE MARSAXLOKK BAY	A3 : 1/15000	INDIVIDUAL RISK CURVE	December 2015	3

SGS	PROJECT: LNG TERMINAL IN THE MARSAXLOKK BAY	SCALE: A3 : 1/10000	DRAWING NAME: INDIVIDUAL RISK CURVE - FSU AREA DETAIL	DATE: DECEMBER 2015	DRAWING: 4

ANNEX B. COMPARISON OF RISK CRITERIA ACCEPTANCE IN SOME EU COUNTRIES AND OTHERS

COMPARISON OF RISK CRITERIA ACCEPTANCE IN SOME EU COUNTRIES AND OTHERS

Barcelona, February, 23th, 2013

1 QUANTITATIVE RISK CRITERIA

1.1 INDIVIDUAL RISK

Individual Risk expresses the risk to a simple person exposed to a hazard; in other words, an individual in the potential effect zone of an incident or set of incidents. The scale of any incident, in terms of the number of people impacted by a single event, does not affect individual risk. Individual risk measures can be single numbers, tables of numbers, or various graphical summaries. Commonly used individual risk measures include [1]:

1. Individual risk contours show the geographical distribution of individual risk. The risk contours are calculated from the expected frequency of an event capable of causing the specified level of harm at a specified location, regardless of whether or not anyone is present at that location to suffer that harm. Thus, individual risk contour maps are generated by calculating individual risk at every geographic location assuming that somebody will be present, unprotected (e.g., outdoors), and subject to the risk 100% of the time (i.e., annual exposure of 8,760 hours per year). In contrast, the other risk measures described below consider the fraction of the time that the individual is exposed to the risk. See Figure 1 for an example of an individual risk contour. An individual risk profile, as illustrated in Figure 2, is a plot of individual risk as a function of distance from the risk source and is a simplification of a risk contour. The risk depicted in these figures is associated with a particular location rather than a particular person. For this reason, this risk measure is sometimes referred to as location risk or geographical risk.

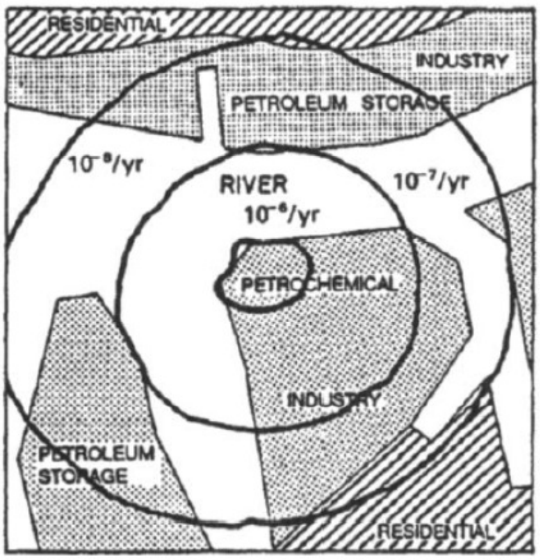


Figure 1.- Example Individual Risk Contour [1]

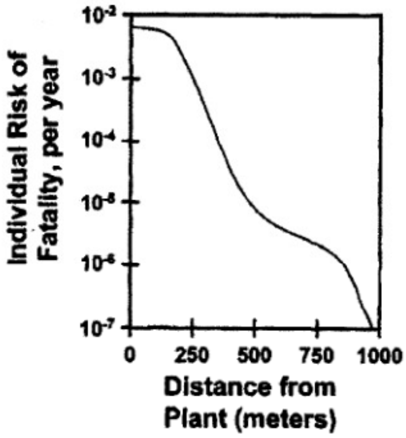


Figure 2.- Example Individual Risk Profile [1]

2. Maximum individual risk is the individual risk to the person exposed to the highest risk in an exposed population. For example, this might be the operator working at the unit being analyzed or, for a normally unstaffed location; it might be the person in the general population living at the location of highest risk. Maximum individual risk can be determined by calculating individual risk at every geographical location where people are present and searching the results for the maximum value. Alternatively, this calculation may seek the greatest risk considering individual working patterns (i.e., time spent on different activities, in different locations).
3. Average individual risk (exposed population) is the individual risk averaged over the population that is exposed to risk from the specified scenarios (e.g., all of the operators in a building, or those people within the largest incident effect zone). This risk measure is useful only if the risk is relatively uniformly distributed over the population, and can be extremely misleading if risk is not evenly distributed. For example, a few individuals may be exposed to a very high risk, but this fact may not be apparent when their risk is averaged with a large number of people at lower risk.
4. Average individual risk (total population) is the individual risk averaged over a predetermined population, without regard to whether or not all people in that population are actually exposed to the risk. This average risk measure is potentially extremely misleading. If the population selected encompasses many individuals who are exposed to little or no risk, the average individual risk will obscure the risk to those at greatest risk.
5. Average individual risk (exposed hours/worked hours) is the individual risk for an activity that is calculated for the duration of the activity or that is averaged over the working day. For example, if an operator spends 1 hour per shift sampling a reactor and 7 hours per shift in the control room, the individual risk while sampling would be 8 times the average individual risk for the entire work day, assuming no risk for the time in the control room.

The calculation of individual risk is made with the understanding that the contributions of all incident outcome cases (i.e., event sequences) are additive. For example, the total individual risk to an individual working at a facility is the sum of the risks from all potentially harmful incidents considered separately, in other words, the sum of all risks due to fires, explosions, toxic chemical exposures, and so forth, to which the individual might be exposed.

1.2 SOCIETAL RISK

Some major incidents have the potential to affect large numbers of people; societal risk expresses the cumulative risk to groups of people who might be affected by such events. In other words, societal risk measures the potential for impacts to a group of people located in the effect zone of an incident or set of incidents.

Thus, societal risk estimates include a measure of incident scale in terms of the number of people impacted. Some societal risk measures are designed to reflect the observation that society tends to be more concerned about the risk of large (multi-fatality) incidents than small (fewer fatality) incidents, and may assign greater significance to large incidents. This potential risk aversion will be discussed further when addressing risk criteria formulation.

Societal risk measures can be expressed as single number measures, tabular sets of numbers, or graphical summaries, with the most common graphical representation being the Frequency-Number (F-N) curve. An F-N curve is a plot of the frequency distribution of multiple-casualty events, where F is the cumulative frequency of all events leading to N or more casualties (typically expressed as the number of fatalities). F-N curves typically use loglog plots since the frequency and number of fatalities often range over several orders of magnitude. Figure 3 shows examples of three F-N curves.

The calculation of societal risk requires the same frequency and consequence information as individual risk. Whereas individual risk requires details of an individual's occupancy within hazard zones, societal risk estimation requires a definition of the number of exposed population within hazard zones. This definition can include factors such as (1) the number and geographical distribution of the population, (2) the population type (e.g., residential, school, industrial), and (3) the likelihood of people being present (i.e., including the number of hours a day people are present).

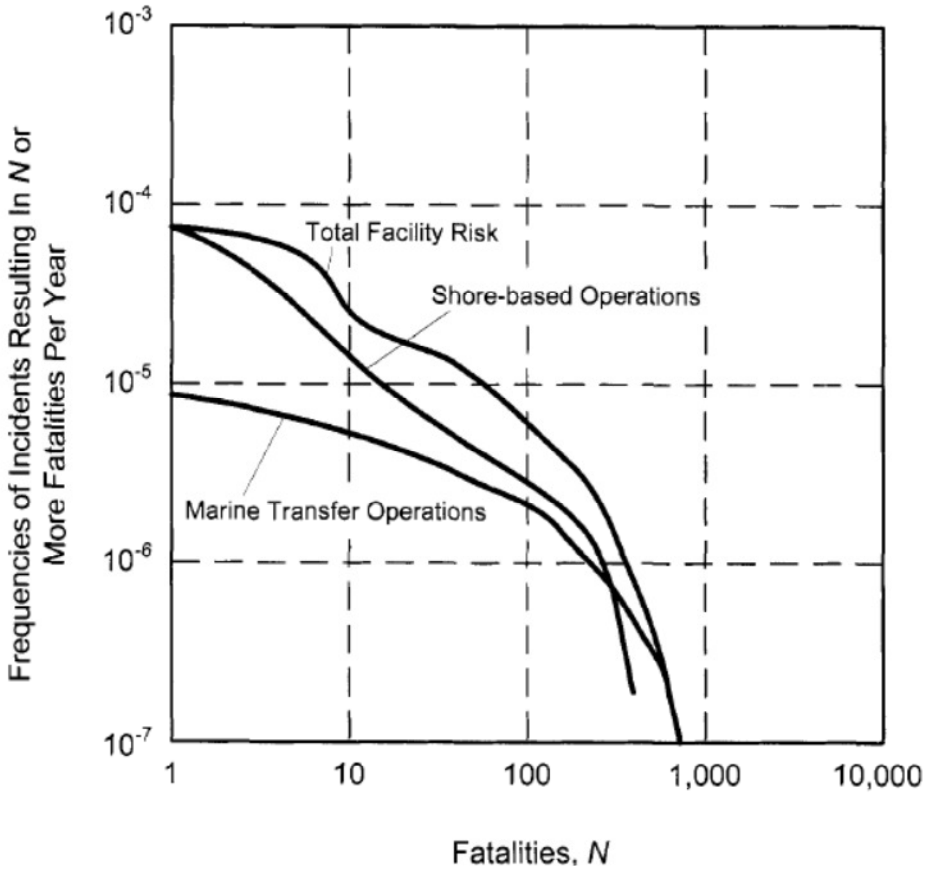


Figure 3.- Example F-N Curve [1]

2 EVOLUTION OF LAND USE PLANNING CRITERIA IN THE UK

The UK has more than four decades of experience in developing criteria for evaluating technological risks. The following sections, discussed chronologically, highlight some of the more significant milestones in the UK's continually evolving approach to risk management.

2.1 UK Atomic Energy Authority - 1967

F. R. Farmer first proposed an incident scale/frequency criterion for nuclear power reactors in 1967. His proposal is not a true societal risk F-N curve per se, since the frequency scale is not expressed as a cumulative frequency of 'N or greater' consequences.

However, the Farmer curve quantitatively expressed the expectation that, as the magnitude of the incident consequences increases, the likelihood should decrease.

2.2 Health and Safety Commission/ Advisory Committee on Major Hazards – 1976

The Advisory Committee on Major Hazards (ACMH) was formed by the UK Health and Safety Commission (HSC) in 1974, largely in response to the vapour cloud explosion in Flixborough, UK. In its first report, the ACMH addressed societal risk by suggesting that, for any one major nonnuclear plant, the maximum tolerable annual frequency for an undefined 'serious accident' might be **10^{-4}/year**. [2]

> "If…in a particular plant a serious accident was unlikely to occur more often than once in 10,000 years… this might perhaps be regarded as just on the borderline of acceptability, bearing in mind the known background of risks faced every day by the general public. The distribution of casualties…after a major accident…may range from less than 10 to over 1,000,…the upper part of this range is improbable as it requires the unlikely combination of many independent factors."

While the range of consequences was broadly defined, many experts interpret the report to imply that this 'serious accident' could involve 10 or more fatalities. In a subsequent publication, HSE quoted ACMH and noted [3]:

> "[ACMH]… which, for any one major non-nuclear plant, suggested (one in ten thousand) as the maximum tolerable annual frequency for a "serious accident" - one undefined, but from the context, with the potential of killing 10 or more people, on or off site. For the 1500 or so Notified Installations in the UK, this implies a national frequency of such events of about 1 in 10 years. This is not inconsistent with UK experience."

The combination of 10 or more fatalities at an interval of 10,000 years has been used to establish the F-N anchor point of (10, 10^{-4})[1] which is still used in some risk criteria (e.g., Hong Kong; Sao Paulo, Brazil; and Victoria and New South Wales, Australia).

2.3 ROYAL SOCIETY - 1983

Royal Society Study Group (RSSG), in 1983, defined concepts that the HSE would later integrate into its Tolerability of Risk (TOR) framework, proposed individual risk criteria that the HSE applies to this day, and discussed the concept of as far as reasonably practicable with respect to risk management.

The RSSG proposed upper and lower bounds for risk to workers of 10^{-3} fatality/year and 10^{-6} fatality/year, respectively. The HSE subsequently adopted the RSSG's proposals and substantiations.

2.4 HEALTH AND SAFETY EXECUTIVE – 1988

In its report, *The Tolerability of Risk from Nuclear Power Stations*, the HSE reaffirmed and elaborated upon the guidance contained in the RSSG report, extending the discussion to address societal risk. Even though this document focused primarily on the risk from nuclear reactors, it established the basis for discussion of risk in the UK for the next two decades and formalized the tenets upon which these Guidelines are premised. The TOR framework defined three basic tests that are applicable to the management of risk: [4]

1. Is the given risk so great or the outcome so unacceptable that it must be refused altogether?
2. Is the risk so small, or has it been made so small, that no further precaution is necessary?
3. If the risk falls between these two extremes, has it been reduced to the lowest level that is reasonably practicable?

In addressing the third test, HSE detailed the concept of ALARP – as low as reasonably practicable - , noting that the 'higher or more unacceptable a risk is, the more, proportionately, that an employer is expected to spend to reduce it.' The TOR framework was depicted in Figure 4.

[1] As a shorthand convenience, anchor points for F-N curves will be expressed in the unit less form (N, F), where N is the number of fatalities on the X axis of the diagram and F is the corresponding frequency on the Y axis, in events/year, at which N or more fatalities are expected to occur. The entire F-N curve (assuming the curve has no inflection points; i.e., has a single slope along its entire length) will be expressed as (F, N, S), where S (a negative number) is the slope of the curve on a log-log graph.

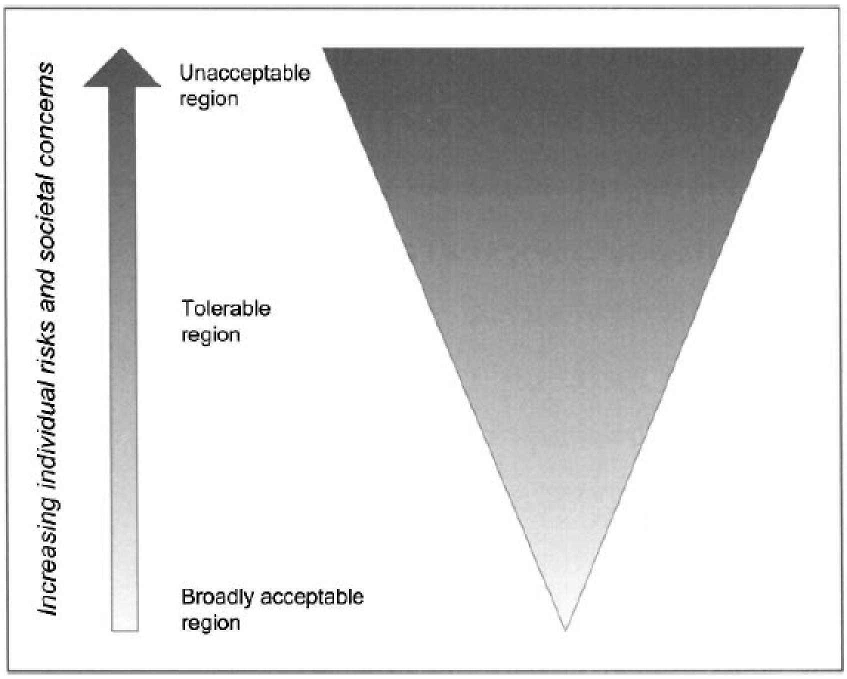


Figure 4.- HSE Tolerability of Risk Diagram [5]

For individual risk, HSE suggested:

> "Broadly, a risk of death of 1 in 1000 per annum is about the most that is ordinarily accepted under modern conditions for workers in the UK ... and it seems reasonable to adopt it as the dividing line between what is just tolerable and what is intolerable."

As for the public, HSE recommended,

> "[If the above is established for worker risk] ... it seems to suggest that the maximum level that we should be prepared to tolerate for any individual member of the public from any large-scale industrial hazard should be not less than ten times lower, i.e., 1 in 10,000…"

Finally, having proposed upper bounds for tolerable risk, HSE proposed for 'broadly acceptable risk':

> "This level might be taken to be 1 in a million (1 in 10^6) per annum bearing in mind the very small addition that this would involve to the ordinary risks of life … [this is] not altogether negligible … [but it] is a level of risk which, provided there is a benefit to be gained, and proper precautions are taken, does not worry us or cause us to alter our ordinary behaviour in any way."

The HSE did not propose explicit societal risk criteria in this document, but did speculate on tolerable event frequencies, stating that:

> "… a figure that might be accepted as tolerable for a considerable uncontrolled release [from a nuclear reactor] anywhere in the UK might be about 1 in 10,000 per annum…"

Note that the above frequency was a cumulative frequency for all nuclear reactors operating in the UK. HSE also projected that an event of this magnitude might result in 100 latent cancer deaths from radiation exposure.

2.5 HEALTH AND SAFETY EXECUTIVE (HSE) - 1989

The HSE issued the document *Risk Criteria for Land-use Planning in the Vicinity of Major Industrial Hazards in 1989* [6]. The guidance was directed solely at decisions related to proposed new land use developments around existing major hazards. Issues related to the suitability of existing land uses or proposed new major hazards were explicitly excluded from the scope of the document. In making this distinction, HSE noted that valid reasons exist for taking a different approach to decisions about new major hazards as compared to new developments around existing major hazards. HSE observed that, generally, "...there may well be more scope for sitting new developments a considerable distance from major hazards, than there is for sitting new major hazards a considerable distance from any existing populations."

In establishing criteria for land use planning decisions, HSE acknowledged that the process of making decisions about the significance of risk is "fraught with subjective perceptions." Consequently, HSE sought to incorporate societal values into the criteria:

> " ... HSE has attempted to incorporate its understanding of the prevailing consensus based upon published views, decided cases, etc., and also leave a certain amount of flexibility."

In the implementation of land use planning in the UK, the HSE's role has traditionally been an advisory role to local planning authorities. After looking at the particulars of a situation referred to it, HSE would decide whether or not to recommend against the development. However, final authority for approving or denying the application rested with the planning authority.

HSE's approach to land use planning criteria is built upon its tolerability of risk (TOR) framework [5] and addresses both individual risk and societal risk considerations, but is less straightforward than the UK precedents outlined before.

For the HSE, land use planning decisions require an evaluation to determine the "risk that a typical user of the development will be exposed to a dangerous dose or worse" In identifying the typical user, HSE described two basic types of developments:

1. those used on a daily basis by the same people (e.g., homes, schools, and workplaces) and

2. those that might be used intermittently or only once by a particular individual (e.g., supermarkets, hotels).

The first type of development would require consideration of both individual risk and societal risk, while the second type posed primarily societal risk issues.

Individual Risk Criteria For individual risk criteria, HSE proposed that the lower bound (broadly acceptable) risk level should be a risk of 1 in a million (**1×10^{-6}**) per year of receiving a dangerous dose or more. For developments with a high proportion of highly susceptible people, HSE proposed a lower risk of 1/3 in a million (**0.33×10^{-6}**) per year of receiving a dangerous dose or more. For an upper bound (intolerable) risk level, HSE proposed a risk of 10 in a million (**10×10^{-6}**) per year of receiving a dangerous dose or more.

HSE estimated that a risk of **10^{-6}/year** of receiving a dangerous dose or more would correspond to an individual risk of fatality/year for the most vulnerable members of the population, and **$0{,}33 \times 10^{-6}$ fatality/year** for the majority of the population. Similarly, a risk of **10^{-5}/year** of receiving a dangerous dose or more would correspond to an individual risk of fatality/year for the most vulnerable.

2.6 HEALTH AND SAFETY EXECUTIVE (HSE) - 2008[2]

Beginning in about 2003, the HSE undertook a fundamental review of its approach to land use planning, resulting in new guidance that was further updated in 2008 under the title *PADHI - HSE's land use planning methodology* [7] . The updated methodology is similar to, but more detailed than, that described above. In addition, the scope has been expanded to include consideration of hazardous material pipelines, explosives sites, and nuclear facilities.

Under the new guidance, the HSE establishes a consultation distance around major hazard sites and pipelines, based upon its modeling of the risks associated with the activity. The consultation distance is divided into an inner zone (**IZ**), middle zone (**MZ**), and outer zone (**OZ**). These zones and the consultation distance are illustrated in Figure 5. The boundaries of these zones can be established based upon either a risk or consequence approach. For some facilities, the zones are established by iso-risk curves corresponding to the risks of receiving or exceeding a dangerous dose of **10×10^{-6}**/year, **1×10^{-6}**/year, and **$0{,}3 \times 10^{-6}$**/years, respectively [8]. For other facilities handling large amounts of flammable hydrocarbons, the zones values, without considering the likelihood of a release occurring. [9] A database of consultation distance information is maintained for use by the planning authority.

[2] The UK HSE released new land use planning guidance as these *Guidelines* were being finalized [3]. This guidance, issued in response to the Buncefield fuel terminal explosion [4], addresses concerns about the adequacy of prior methods of determining consultation distances in the vicinity of facilities storing large quantities of flammable liquids.

New criteria have been established for categorizing developments by sensitivity levels that, similar to the precedent set in [10], are determined based upon consideration of the number and vulnerability of the exposed population and other characteristics of the proposed development.

- Broadly, the four categories can be summarized as:
- People at work, parking
- Developments for use by the general public
- Developments for use by vulnerable people
- Very large and sensitive developments

HSE provides explicit definitions for a number of subcategories under each of these main classifications. [7]

Knowing the category of a particular proposed development, along with its location within any consultation distance surrounding an adjacent major hazard, allows the determination of HSE's recommendation based upon the decision matrix shown in Table 1. HSE's recommendation will be either Advise Against (AA) or Don't Advise Against (DAA).

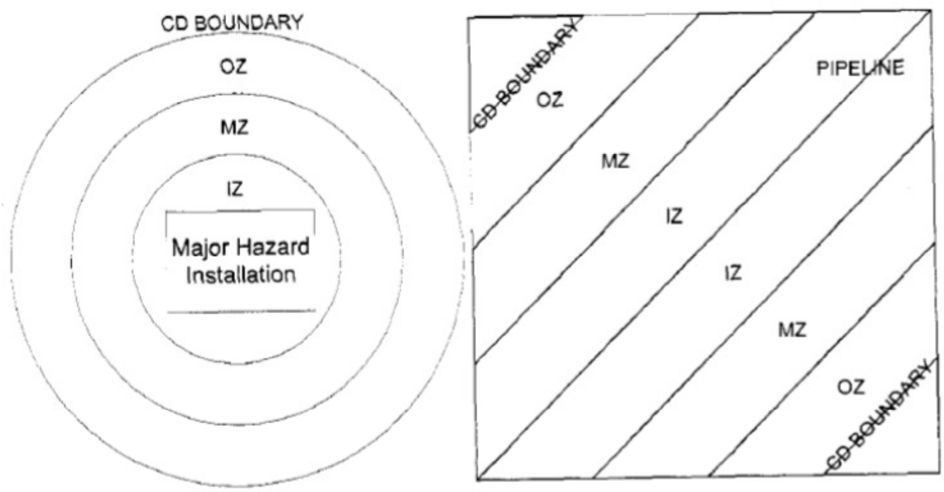


Figure 5.- Illustration of HSE's Consultation Distance Around Fixed Facilities and Pipelines [3]

Level of Sensitivity	Development in Inner Zone	Development in Middle Zone	Development in Outer Zone
1	DAA	DAA	DAA
2	AA	DAA	DAA
3	AA	AA	DAA
4	AA	AA	AA

Table 1.- HSE's PAHDI Decision Matrix [7]

Detailed rules in the guidance address situations such as:

- The development straddles a zone boundary (i.e., is located in more than one zone)
- The development is exposed to more than one hazardous installation
- The proposal contains more than one development type
- An existing permitted use of the land is in place[3]

Under PADHI, the HSE maintains its advisory role, but automates the planning decision process via a website from which the planning authority can obtain information on consultation distances and, after inputting information on the proposed development, obtain the land use planning recommendation determined by the prescribed methodology.

[3] The HSE has modified its guidance with regard to the existing use rule in the PADHI guidance (Rule 4c). Details are been provided in an interpretation letter from the Hazardous Installations Directorate. [24]

3 LAND USE PLANNING CRITERIA IN THE NETHERLANDS

The situation in the Netherlands is more straightforward than in the UK, in that the same basic risk criteria are used for evaluating risk from both the perspective of the risk source and the risk receptor. In the Netherlands, under the *External Safety (Establishments) Decree* [11], these considerations are addressed through the environmental permitting process (which reviews applications for new or modified industrial activities) and the spatial planning process (which reviews applications for new off-site developments). Local planning authorities, charged with the responsibility for implementing both processes, apply the current risk criteria in the conduct of both types of reviews.

The spatial planning process distinguishes between certain specified categories of establishments for which a standardized approach can be taken (e.g., liquefied petroleum gas [LPG] fuelling stations, ammonia refrigeration installations, and facilities storing dangerous chemicals) and establishments where operations, and risk perspectives, are more complex (e.g., refineries and chemical processing plants). For the former establishments, safety distances have been defined in the regulations, based on the fatality/year individual risk criterion, and development may not be permitted within these zones.

Furthermore, to ensure that the societal risk F-N criterion is not exceeded, maximum population densities have been established for the region between the fatality/year individual risk contour and a maximum impact distance, defined by the 1% probability that an exposed individual would be fatally injured.

A quantitative risk assessment (QRA) is required for more complex establishments. A new risk source may not be permitted if this would cause the risk to existing residential populations to exceed the $\mathbf{10^{-6}}$ fatality/year individual risk criteria for vulnerable populations, and new housing may not be permitted in an area if the risk from an existing industrial facility exceeds fatality/year .

However, only the criterion for individual risk to vulnerable objects is binding; in other words, societal risk criteria and individual risk criteria for less vulnerable objects may be waived by the planning authority. A number of sources have pointed out that adherence to the established risk criteria has been problematic in the Netherlands (e.g., [12], [13], [14]) with some noting that, of the two processes, compliance with the requirements of the environmental permitting requirements is the more rigorous.

4 LAND USE PLANNING CRITERIA IN HONGKONG

Hong Kong, concerned with high density residential developments located close to hazardous installations, mainly for bulk LPG storage, on Tsing Yi Island, commissioned a major hazards study in 1981. [15] This and subsequent studies prompted the government to formulate preliminary risk criteria in the mid 1980s. [12] The Coordinating Committee on Land-Use Planning and Control Relating to Potentially Hazardous Installations (CCPHI) was formed in 1986 to coordinate the government's risk management policy, and interim risk criteria were produced in 1988. [12] and [13]. The risk criteria were formalized and added to the *Hong Kong Planning Standards and Guidelines* [18] in 1993.

The individual risk and societal risk criteria are presented in Table 2 and Figure 6. The individual risk is a 'personal risk' and not a 'location risk'; in other words, the duration of exposure can be considered when calculating the individual risk. Hong Kong does not specify a broadly acceptable risk criterion for individual risk, nor does it specify the application of the As Low As Reasonably Practicable (ALARP) principle to individual risk. While some early risk studies proposed risk criteria for dangerous goods transport, no risk criteria currently exist for transportation risks.

QRA in Hong Kong is required by two different departments, the Planning Department and the Environmental Protection Department (EPD). The same risk criteria are used for both facility licensing and land use planning applications.

From a land use planning perspective, the Planning Department monitors compliance with the requirements for Potentially Hazardous Installations (PHIs), as documented in Chapter 12 of the *Hong Kong Planning Standards and Guidelines*. PHI's are defined as facilities that store hazardous materials in quantities equal to or in excess of established threshold quantities (TQs). These TQs were originally based upon the 1982 UK *Notification of Installations Handling Hazardous Substances Regulations*; however, some TQs have been revised to reflect considerations unique to Hong Kong.

Examples of common PHIs and the associated substances and TQs are:

- LPG storage facilities, 25 tonnes
- Town gas installations, 15 tonnes
- Chlorine storage, 10 tonnes, or any storage in one tonne drums
- Gasoline (petrol) or naphtha storage, 10,000 tonnes
- Liquid oxygen storage, 500 tonnes
- Explosives factories/government storage depots, any quantity

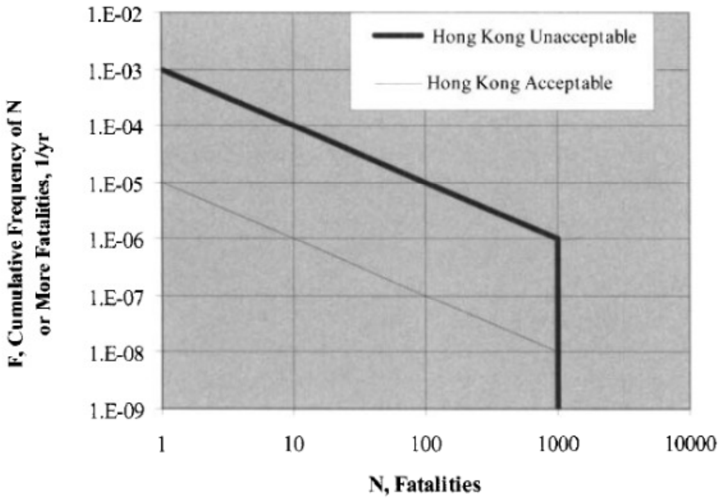


Figure 6.- Hong Kong Societal Risk Criteria

Individual Risk Criteria, fatality/year	
Maximum tolerable risk to workers	N/A
Maximum tolerable risk to the public Existing situations New situations	 10^{-5} (see note 1) 10^{-5}
Broadly acceptable risk	N/A
Note 1: The risk criteria apply to both new and existing situations. However, more flexibility is apparent in the application of risk criteria to existing situations.	

Table 2.- Hong Kong Individual Risk Criteria

Each identified PHI has a surrounding control zone, within which land use planning is required. Each PHI requires a QRA, which Hong Kong terms a hazards assessment. Based upon the results of the hazards assessment, a planning study is conducted to examine present and future land use and development proposals to identify appropriate planning considerations and development controls within the control zone. The risks to proposed developments are assessed against the risk criteria, as part of the application review.

From a facility licensing perspective, the EPD monitors compliance with the *Environmental Impact Assessment Ordinance* (EIAO). [19] As outlined in a technical memorandum explaining the EIAO requirements, hazards assessments must be conducted for facilities that manufacture, store, use, or transport dangerous goods, if impacts from facility operation “may cause adverse public health effects...or pose an unacceptable risk to life.” [20]

Examples of facilities that require environmental permits, and are therefore subject to requiring an environmental impact assessment, include but are not limited to: [20]

- A chemical or biochemical plant with a storage capacity of more than 500 tonnes and in which substances are processed or produced
- An oil refinery
- A petrochemical plant with an annual production capacity of more than 70,000 tonnes
- A bulk chemical storage facility with a storage capacity of more than 80,000 tonnes

Ball reports that Hong Kong followed UK precedents in developing its risk criteria [16], which is not surprising considering its past history as a British colony. The societal risk F-N curve for maximum tolerable risk (**10**, **10^{-4}**, **-1**) draws its anchor point from the Advisory Committee on Major Hazards (ACMH) report. [2] The curve for acceptable risk is two orders of magnitude lower. Both curves defining the societal risk criteria terminate at an N value of 1,000.

Full documentation of the rationale underlying the individual risk and societal risk criteria was not available. However, considering the low threshold quantities illustrated above for classification as a PHI, these risk criteria may prove to be hard to achieve for larger scale facilities. No discussion was found in the literature of the relative ease or difficulty experienced in applying these risk criteria to new, larger-scale facilities requiring Environmental Impact Assessments (EIAs). However, the planning process in Hong Kong appears to be effective in diverting new high-risk industrial developments to remote locations where meeting the societal risk criteria may be more readily achievable. In fact, the *Planning Standards and Guidelines* provide for proactively identifying and preserving remote areas as potential sites for future PHIs. [21]

While the risk criteria do not explicitly provide a distinction between new and existing facilities, the *Planning Standards and Guidelines* contain an implication of some flexibility in the land use planning application of the risk criteria with regard to existing facilities: [18]

> "Where the risk guidelines cannot be met, for existing PHIs, CCPHI will consider the necessary risk mitigation to bring the risk level down."

Discussion of the application of the ALARP principle is limited to societal risk, with the stated intent to "ensure that all practicable and cost effective measures which can reduce risks will be considered." However, no mention is made of a gross disproportion test in the ALARP review. A less rigorous ALARP process would tend to offset the additional conservatism in the societal risk criteria.

Hong Kong has also proposed the use of QRA to evaluate the adequacy of controls to mitigate landslide risks. The Civil Engineering and Development Department has proposed risk criteria specific to this evaluation. [22]

5 LAND USE PLANNING CRITERIA IN STATES OF SAO PAULO, RIO DE JANEIRO, AND RIO GRANDE DO SUL, BRAZIL

Three states in Brazil have implemented risk criteria: Sao Paulo, Rio de Janeiro, and Rio Grande do Sul[4]. The individual risk and societal risk criteria for the three states are provided in Table 3 and Figure 7. Omitted from Figure 7, for clarity, are the F-N curves for broadly acceptable risk, which are two orders of magnitude lower than the curve for maximum tolerable risk for Sao Paulo and one order of magnitude lower for the Rio de Janeiro and Rio Grande do Sul curves.

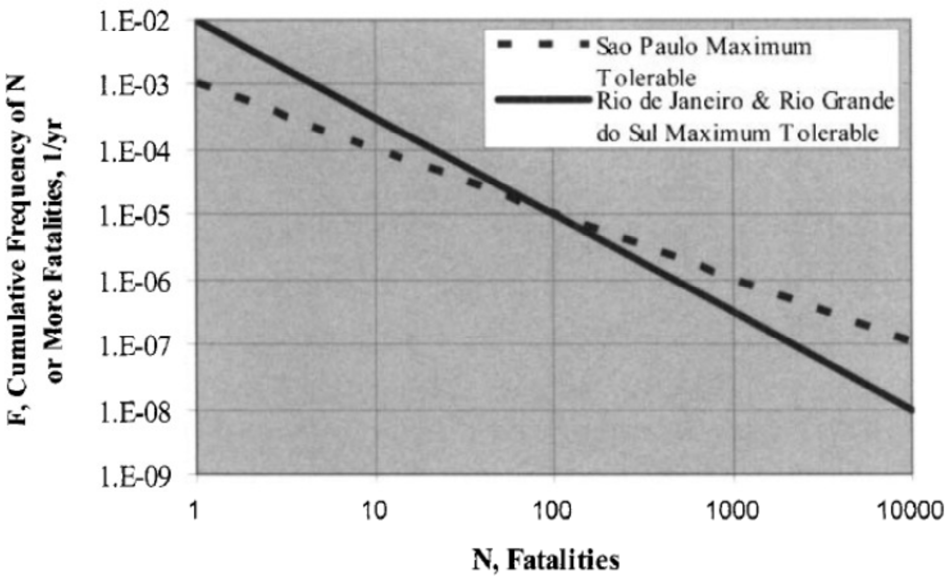


Figure 7.- Societal Risk Criteria for Three States in Brazil

As Table 3 indicates, all three states also have individual risk criteria for pipeline transportation risks. Sao Paulo and Rio Grande do Sul have set these criteria one order of magnitude higher than the corresponding individual risks for facilities, while Rio de Janeiro has set its individual risk criterion for pipelines equal to the criterion for fixed facilities.

Rio de Janeiro is the only one of the three states that requires evaluation of societal risks for pipelines, again setting the criterion for pipelines equal to the criterion for fixed facilities.

Individual Risk Criteria for Three States in Brazil , fatality/year		
	Sao Paulo, Rio Grande do Sul	**Rio de Janeiro**
Maximum tolerable risk to workers	N/A	N/A

[4] A federal regulatory agency, the Brazilian Institute of Environment and Renewable Natural Resources (IBAMA), requires QRA for environmental operating licenses. Reports indicate that IBAMA generally applies the Sao Paulo risk criteria.

Individual Risk Criteria for Three States in Brazil , fatality/year		
	Sao Paulo, Rio Grande do Sul	**Rio de Janeiro**
Maximum tolerable risk to the public Existing situations New situations	Plants: 10^{-6} Pipelines: 10^{-4} Plants: 10^{-6} Pipelines: 10^{-5}	Plants: 10^{-5} Pipelines: 10^{-5} Plants: 10^{-6} Pipelines: 10^{-6}
Broadly acceptable risk	Plants: 10^{-6} Pipelines: 10^{-5}	N/A
Note 1: Sao Paulo: Risk criteria are applicable to new projects and significant modifications, and are applied to existing plants upon renewal of the operating license (the review frequency is generally 5 years, but varies with the type of activity being evaluated). Rio Grande do Sul: Risk criteria are not currently applicable to existing plants. Operating license renewal (every 4 years) is contingent on the update of the Risk Management Program of the company.		

Table 3.- Individual Risk Criteria for Three States in Brazil

All three states require a preliminary consequence analysis to determine if a full QRA is required.

Sao Paulo

The QRA guidelines indicate the CETESB[5] [23] may, for fixed facilities, allow individual risk to exceed **10^{-5}** fatality/year provided that the societal risk criterion is satisfied. QRA requirements, previously applicable to new projects and significant modifications to existing facilities, are now also being applied to existing facilities for routine renewal of operating licenses.

Rio de Janeiro [24]

The state environmental agency, FEEMA[6] has not issued a standard QRA requirements document. However, requirements commonly imposed by FEEMA can be determined from terms of reference issued to companies preparing to conduct individual EIAs.

Rio Grande do Sul [25]

QRA guidelines, including risk tolerance criteria, have been issued by the state environmental licensing agency, FEPAM.27[7]

The QRA guidelines indicate the FEPAM may, for fixed facilities, allow individual risk to exceed **10^{-5}** fatality/year (to a maximum of 10^{-4} fatality/year) for surrounding industrial populations.

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[5] Companhia de Tecnologia de Saneamento Ambiental

[6] Fundação Estadual de Engenharia do Meio Ambiente

[7] Fundação Estadual de Proteção ambiental

6 LAND USE PLANNING CRITERIA IN FRANCE

The French approach to major hazards risk has traditionally been deterministic; in other words, consequence based. However, in response to lessons learned from the Toulouse explosion, France enacted new legislation in July 2003 that addresses general principles of risk assessment, land use planning, risk communication, and compensation for the damages caused by accidents. This new law required, among other things, the conduct of risk assessments for industrial facilities and a renewed emphasis on land use planning [26]. The land use planning requirements introduced a new tool - the technological risks prevention plan (in French: PPRT) that requires the identification of three risk zones around an industrial facility:

- Expropriation zone - in which the risk posed by the facility is so high that it warrants mandatory removal of residences
- Renunciation zone - a lower risk zone in which inhabitants have the right to request and receive compensation for voluntarily abandoning their residences
- Preemption zone - a zone in which the risk, while lower, is still significant and the community may wish to further reduce the risk by offering to buy out the inhabitants

A subsequent decree, issued in September 2005, defined the required structure and content for risk assessments, based upon a semi-quantitative approach [27]. As the following will describe, decisions of whether to permit the construction of new or modified industrial facilities are based upon consideration of a societal risk measure, while land use planning decisions are based upon individual risk considerations.

To conduct the risk assessment, potential human health effects are first estimated and categorized according to effect thresholds for toxic, thermal (i.e, fire exposure) and overpressure (i.e., explosion) effects, corresponding to four intensity levels:

- Significant lethal effect (5% fatalities)
- First lethal effect (1% fatalities)
- Irreversible effect
- Reversible effect

A societal risk perspective is then obtained by considering the number of persons exposed when determining the consequence severity rating described by Table 4.

Severity of Consequences	Significant lethal effect	First letal effect	Irreversible effect
Extreme	PE > 10	PE > 100	PE > 1000
Catastrophic	1 < PE < 10	10 < PE < 100	100 < PE < 1000
Significant	1 < PE <= 10	1 < PE <= 10	10 < PE <= 100
Medium	0	PE <= 1	PE <= 10
Moderate	Moderate lethal effects outside the facility		PE <= 1

Severity of Consequences	Significant lethal effect	First letal effect	Irreversible effect
Note: PE = Persons Exposed			

Table 4.- French matrix for determining severity of consequences

Frequency estimates for the assessed scenarios are expressed in ranges from A (most frequent) to E, as shown in Table 5**.**

Range designation	A	B	C	D	E
Frequency, year^{-1}	< 10^{-2}	10^{-3} to 10^{-2}	10^{-4} to 10^{-3}	10^{-5} to 10^{-4}	< 10^{-5}

Table 5.- French Risk Assessment Frequency Ranges

Based upon the estimates of frequency and severity of consequences, the planning authority can make a determination of whether authorization should be given to build a new facility or modify an existing facility. The risk matrix used to make this determination is shown in Table 6.

Severity of consequences	Frequency Range				
	E	D	C	B	A
Extreme	NO (new plant) RRM2 (existing plant)	NO	NO	NO	NO
Catastrophic	RRM1	RRM2	NO	NO	NO
Significant	RRM1	RRM1	RRM2	NO	NO
Medium			RRM1	RRM2	NO
Moderate					RRM1
Note: NO indicates an unacceptable risk, and any proposed new facility or modification would be denied. RRM2 and RRM1 indicate the need for risk reduction measures, with the requirements for RRM2 being the more stringent.					

Table 6.- French decision Matrix for Permitting New or Modified Facilities

The results of this exercise are also used to develop hazard level maps for use in land use planning decisions in the PPRT exercise. These maps are prepared by aggregating the risk information from all industrial facilities in the area, reflecting the fact that a particular area on the map may be impacted by multiple facilities. For each health effect intensity level and for each location on the map, the frequencies of the scenarios are summed.

The 2003 legislation provided for the formation of local citizen advisory committees to work with planning authorities on certain aspects of the land use decision process.

7 LAND USE PLANNING CRITERIA IN UNITED STATES FEDERAL COVERNMENT AGENCIES

7.1 DEPARTMENT OF ENERGY (DOE)

DOE'S standards and guidance for the preparation of nuclear safety analysis reports [28] and [29] uses a risk matrix approach from which an underlying quantitative basis might be inferred. However, a more basic approach to a perspective on DOE risk criteria, with obvious linkage to the NRC precedent described above is provided in a 1991 DOE directive [28]:

> "The risk to an average individual in the vicinity of a DOE nuclear facility for prompt fatalities that might result from accidents should not exceed one-tenth of one percent (0.1%) of the sum of prompt fatalities resulting from other accidents to which members of the population are generally exposed. For evaluation purposes, individuals are assumed to be located within one mile of the site boundary.
>
> The risk to the population in the area of a DOE nuclear facility for cancer fatalities that might result from operations should not exceed one-tenth of one percent (0.1%) of the sum of all cancer fatality risks resulting from all other causes. For evaluation purposes, individuals are assumed to be located within 10 miles of the site boundary."

Various DOE field offices have based explicit numerical risk criteria on the above precepts; for example [30] and [31]:

- A prompt fatality risk of **4×10^{-7}** fatality/year (This is comparable to the NRC value above with the difference, presumably, due to difference in the database selected to establish background accidental fatality risks)
- A latent cancer fatality risk of **2×10^{-6}** fatality/year

DOE guidance for nonreactor facilities is addressed in DOE-STD-3009- 94. The purpose of safety analysis for nonreactor facilities is not so much to quantify the risk, but to identify Design Basis Accidents with emphasis on identifying safeguards to be credited. DOE-STD-3009-94 states that events with an estimated frequency of occurrence of less than fatality/year should be excluded from further consideration. These low frequency scenarios are considered in a qualitative process hazard analysis and, if judged to be 'Beyond Extremely Unlikely' (i.e., less than fatality/year), are not carried forward to Accident Analysis (primarily a consequence analysis).[8]

8 DOE's guidance on this point is in conflict with commentary elsewhere in the Guidelines that no scenario should be excluded a priori from a risk assessment because of a perceived low likelihood of occurrence.

At least one DOE field office has identified the need to fully evaluate the risk spectrum [32]:

> "To demonstrate conformance with these risk goals, the risk assessment should consider the risk of events that are less frequent than the extremely unlikely event category (i.e., with frequencies less than per year)."

7.2 ENVIRONMENTAL PROTECTION AGENCY (EPA)

The EPA uses QRA to support decision making in the implementation of a number of regulations for which the Agency is responsible (e.g., to determine the degree of decontamination required for a waste site or the permissible levels of impurities in drinking water). In each case, the risk criterion pertains to the risk to individuals of dying from cancer as a consequence of lifetime exposure to the chemical, termed by EPA as 'lifetime excess fatality risk'.

While risks associated with chronic chemical exposures are not within the scope of this report, the risk criteria associated with a number of regulations are summarized for contrast in Table 7 [33]:

Regulation	Typical Acceptable Residual Risk, Fatality / lifetime	Comments
TSCA (Toxic Substances Control Act)	Occupational: 10^{-4} to 10^{-5} Non-occupational: 10^{-5} to 10^{-6}	Unstated, but values are typical
FIFRA (Federal Insecticide, Fungicide, and Rodenticide Act)	Occupational: 10^{-4} to 10^{-5} Non-occupational: 10^{-5} to 10^{-6}	Unstated, but values are typical
FFDCA (Federal Food, Drug, and Cosmetic Act)	Zero for additives Average diet: 10^{-6} Non-dietary: 10^{-6}	
SDWA (Safe Drinking Water Act)	10^{-4} to 10^{-6}	
CWA (Clean Water Act)	10^{-5} to 10^{-7}	
RCRA (Resource Conservation and Recovery Act)	For listing of a site: 10^{-6} Corrective action: 10^{-4} to 10^{-6} Incinerators: 10^{-5}	
CERCLA (Comprehensive Environmental Response, Compensation, and Liability Act)	10^{-4} to 10^{-6}	Depending in part on intended future use of site
CAA (Clean Air Act)	10^{-6}	Legislative trigger in Clean Air Act Amendments for enhancement of Maximum Available Control Technology requirements

Table 7.- Various Risk Criteria Used by EPA (as of 1996)

Note that the risk discussed is the risk of dying from cancer over a lifetime, which the EPA assumes to be 70 years (40 years for a working lifetime, for occupational exposures).

To contrast the EPA risk criteria with the risk criteria for acute exposures presented in this report, the values in Table 7 must be divided by either 40 or 70.

In some cases, the acceptable residual risk is presented as a range, such as to fatality/lifetime. The application of this range has been described as follows: [33]

> "EPA … has decided that it cannot use any single metric as a measure of whether a risk should be considered negligible. Instead, it has adopted a general presumption that a lifetime excess risk of cancer of about one in 10,000 (**10^{-4}**) for the most exposed person constitutes negligible risk and that the margin of safety should reduce the risk for the greatest possible number of persons to an individual lifetime excess risk no higher than one in 1 million (**10^{-6}**)."

7.3 Occupational Safety and Health Administration (OSHA)

In 1980, the Supreme Court invalidated an OSHA standard for workplace benzene exposure because OSHA had not demonstrated the risk associated with the 1 part per million (ppm) exposure limit that it had established. This, in effect, obligated OSHA to conduct QRAs to support the development of future exposure standards. With regard to how great a risk was required to be significant, Justice Stevens opined: [33]

> "If, for example, the odds are one in a billion…, the risk clearly could not be considered significant. On the other hand, if the odds are one in a thousand… a reasonable person might well consider the risk significant and take appropriate steps to decrease or eliminate it."

While OSHA has not established an explicit criterion defining what is a significant level of risk, in application it appears that fatality/year is the value commonly used. As with the EPA and FDA risk criteria, this is a lifetime cancer risk from chronic exposure. Note, also, that OSHA assumes a 45 year 'career lifetime' for workplace exposure to chemicals, in contrast with the 40 year career lifetime assumed by EPA.

8 INTERNATIONAL MARITIME ORGANIZATION (IMO)

In 1997, IMO published interim guidelines for the conduct of formal safety assessments (FSA)s [35]. IMO defines an FSA as “a rational and systematic process for assessing the risks relating to maritime safety and the protection of the marine environment and for evaluating the costs and benefits of IMO’s options for reducing these risks.” Missing from the interim guidelines, and the subsequently issued final guidelines [36], were criteria for evaluating the risk.

Norway proposed individual risk and societal risk criteria for use in the FSA process in 2000. [37] While not yet formally adopted by IMO, these criteria were discussed extensively in a recent IMO publication on Risk Evaluation Criteria. [38] The individual risk and societal risk criteria are summarized on Table 8 and Table 9

Individual Risk criteria, fatality/year	Existing Ships	New Ships
Maximum tolerable risk to workers (i.e., crew)	10^{-3}	10^{-4}
Maximum tolerable risk to the public (i.e., passengers or persons on shore)	10^{-4}	10^{-5}
Broadly acceptable risk	10^{-6}	10^{-6}

Table 8.- Proposed IMO Individual Risk Criteria

Societal Risk criteria		
Tankers	Maximum tolerable risk	(10, $2x10^{-3}$, -1)
	Broadly acceptable risk	(10, $2x10^{-5}$, -1)
Bulk and ore Carriers	Maximum tolerable risk	(10, 10^{-3}, -1)
	Broadly acceptable risk	(10, 10^{-5}, -1)
Passenger Roll On – Roll Off Ferries	Maximum tolerable risk	(10, 10^{-2}, -1)
	Broadly acceptable risk	(10, 10^{-4}, -1)

Table 9.- Proposed IMO Societal Risk Criteria

In defining the individual risk for existing ships, IMO chose the UK HSE criteria described in [5]. Recognizing the potential for the implementation of newer technologies, IMO proposed setting the risk criteria for maximum tolerable risks for new ships one order of magnitude lower.

The societal risk criteria are all expressed as F-N curves having a -1 slope, with the anchor points given in Table 8. As shown in Table 8, the risk criteria are a function of the type of ship. To determine the anchor points for the various ship types, IMO proposed an approach premised on the assertion that “evaluation criteria may be associated with the economic importance of the activity in question, and calibrated against the average fatality rate per unit economic production.” While the detailed mathematics will not be presented here, the approach can be outlined as follows: [38]

1. From historical data, calculate an index defined as the ratio of the number of occupational fatalities to an associated measure of economic activity, such as the Gross National Product.
2. Determine the economic value of the activity being analyzed – in this case, the operation of a particular type of ship.
3. Calculate the tolerable average potential loss of life (PLL) for the activity (the product of the results of 1 and 2).
4. From the PLL, calculate the frequency, F, of one or more fatalities (N=l) for a F-N curve with a slope of -1 (the mathematics for doing so are described in Annex C of [38].
5. Set the maximum tolerable risk one order of magnitude higher and the broadly acceptable risk one order of magnitude lower.

Comparison of the F-N curves described in Table 9 shows them to be one to two orders less conservative than the UK public societal risk criteria F-N curves. Presumably, the ship's crew and passengers will be more aware of the hazards of the operation than would be the bulk of the off-site population around a chemical plant. And, the passengers demonstrate the concept of knowingly accepting a risk for the benefits derived from the risky activity.

The IMO approach to risk management provides for application of the ALARP principle. Analysis of historical risk data has shown that, for a variety of ship types, the historical risks are in the ALARP regions for the individual risk criteria and the appropriate societal risk criteria. IMO cites this in support of its traditional emphasis on cost/benefit analysis in decisions related to potential risk reduction options [38].

10 SUMMARY

Table 10 and Table 11 summarize relevant information from this report for individual risk criteria for the public and for workers, respectively. Figure 8 summarizes relevant public societal risk criteria.

Regulation	Entities / Applications	Comments
Upper limit Values, fatality / year		
1×10^{-4}	State of Sao Paulo, Brazil, Pipelines	
	State of Rio Grande do Sul, Brazil, Pipelines	
	UK HSE/Fixed Facilities and dangerous goods transport	
	International Maritime Organization (IMO) / Existing Ships	Applies to both passengers and public ashore
1×10^{-5}	State of Sao Paulo, Brazil, Fixed Installations	New Installations and significant modifications to existing
	State of Rio Grande do Sul, Brazil, Fixed Installations	New Installations
	International Maritime Organization (IMO) / New Ships	Applies to both passengers and public ashore
	UK HSE	PADHI System
Lower limit Values, fatality / year		
1×10^{-5}	State of Sao Paulo, Brazil, Pipelines	
	State of Rio Grande do Sul, Brazil, Pipelines	
1×10^{-6}	State of Sao Paulo, Brazil, Fixed Installations	New Installations and significant modifications to existing
	State of Rio Grande do Sul, Brazil, Fixed Installations	New Installations
	International Maritime Organization (IMO) / New Ships	Applies to both passengers and public ashore
	UK HSE/Fixed Facilities and dangerous goods transport	PADHI System
Upper limit Values, fatality / year		

Regulation	Entities / Applications	Comments
1×10^{-5}	Hong Kong	New Installations. Existing installations exceeding this value should seek risk reductions
	The Netherlands	Applies to vulnerable objects. Existing situations. Interim value, existing situations must meet value for new situations (10-6 fatality/year) by 2010
	State of Rio de Janeiro, Brazil, Fixed Installations and Pipelines	For existing facilities
	US DOE / Risk of latent fatalities from nuclear facility accidents	Calculated from the criterion that risks should not exceed 0.1% of cancer fatalities risks from all other causes
1×10^{-6}	The Netherlands	Applies to (1) new permits for fixed installations, (2) new land use plans, and (3) transport of dangerous goods, including transport by pipelines.
	State of Rio de Janeiro, Brazil, Fixed Installations and Pipelines	For new facilities
4×10^{-7}	US DOE / Risk of "prompt" fatalities from nuclear facility accidents	Calculated from the criterion that risks should not exceed 0.1% of prompt fatalities risks from all other accidental sources, assuming an accidental fatality rate of 10^{-4} fatality/year
$1{,}4 \times 10^{-7}$	Various EPA Regulations	Upper range value for cancer risk to the public (10^{-5} cancer fatality/lifetime) divided by assumed lifetime of 70 years
3×10^{-7}	UK HSE	PADHI System

Regulation	Entities / Applications	Comments
1 x 10^{-7}	US NRC / Risk of "prompt" fatalities from nuclear facility accidents	Calculated from the criterion that risks should not exceed 0.1% of prompt fatalities risks from all other accidental sources, assuming an accidental fatality rate of 10^{-4} fatality/year
1,4 x 10^{-8}	Various EPA Regulations	Lower range value for cancer risk to the public (10^{-6} cancer fatality/lifetime) divided by assumed lifetime of 70 years
	Various EPA Regulations	Cancer risk to the public (10^{-6} cancer fatality/lifetime) divided by assumed lifetime of 70 years

Table 10.- Summary: Individual Risk to Public

Regulation	Entities / Applications	Comments
Upper limit Values, fatality / year		
1 x 10^{-3}	UK HSE	
	International Maritime Organization (IMO) / Existing Ships	For crew members on existing ships
1 x 10^{-5}	International Maritime Organization (IMO) / New Ships	Proposed for existing facilities. Where are an existing gacilities exceeds $1 \cdot 10^{-3}$ fatality/year, a risk reduction program with an agreed time frame must be implemented to achieve 10^{-3} facility/year
Lower limit Values, fatality / year		
1 x 10^{-6}	UK HSE	
	International Maritime Organization (IMO)	For crew members on new or existing ships
2,2 x 10^{-5}	Various US OHSA Regulations	Cancer risk to workers (10-3 cancer fatality/lifetime) divided by assumed lifetime of 45 years
Upper limit Values, fatality / year		
2,5 x 10^{-6}	Various US OHSA Regulations	Upper range value for cancer risk to workers (10^{-4} cancer fatality/lifetime) divided by assumed lifetime of 40 years

Regulation	Entities / Applications	Comments
2,5 x 10^{-7}	Various US OHSA Regulations	Lower range value for cancer risk to workers (10^{-5} cancer fatality/lifetime) divided by assumed lifetime of 40 years

Table 11.- Summary: Individual Risk to Workers

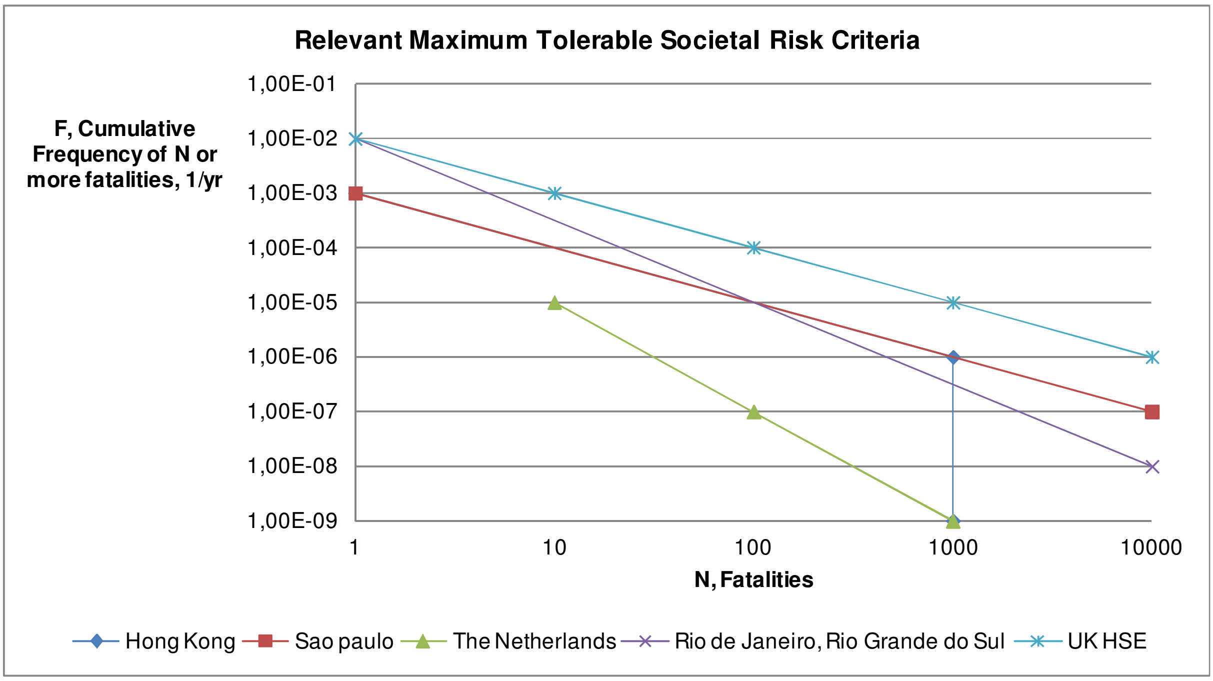

Figure 8.- Summary of relevant Maximum Tolerable Societal Risk Criteria

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