Delimara Gas and Power

Combined Cycle Gas Turbine

and

Liquefied Natural Gas
receiving, storage, and re-gasification facilities

Delimara Power Station

Triq il-Power Station – Marsaxlokk

ENVIRONMENTAL IMPACT STATEMENT

Environmental Survey Reports

Appendix Two

Volume Seven

prepared by
ERSLI Consultants Ltd
on behalf of
Enemalta Corporation

20 December 2013

Volumes	Consultants	Fields
One	Archaeology Services Cooperative	Cultural Heritage (Terrestrial)
	Axiak, Victor	Marine Water Bodies
Two	Borg, John J	Vertebrate Fauna
	Borg, Joseph A & Evans, Julian	Marine Ecology
Three	Calleja, Christian (2 reports)	Noise
	Cassar, Louis F	Land Use and Land Cover
	Conrad, Elisabeth	Landscape and Visual Assessment
Four	Fedra, Kurt (3 reports)	Air Dispersion
	Formosa, Marvin	Social Impact Assessment
Five	Gambin, Timothy	Marine Archaeology
	Lanfranco, Sandro & Cassar, Louis F	Terrestrial Ecology
	Mamo, Julian & Cauchi, John P	Health Impact Assessment
Six	Meli, Anthony	Agricultural Land
	Scerri, Saviour	Geology – Geomorphology – Hydrogeology – Hydrology – Soils
Seven	Vaccari, Roberto (2 reports)	Quantitative Risk Assessment

Project for a new LNG regasification facility to be located in the Marsaxlokk Bay

QRA PRELIMINARY REPORT

Barcelona, July, 11th, 2013
Report nº.: 02-901-188098-12141 – review 0.1

Prepared for:

ENEMALTA Corporation

Prepared by:

Mr. Roberto Vaccari

Process Safety Development Manager
SGS Tecnos SA

DISCLAIMER

Unless otherwise agreed, orders are executed in accordance with the latest version of the SGS' General Conditions. Upon request the conditions will again be sent to you. Attention is drawn to the limitation of liability, indemnification and jurisdiction issues defined therein.

Any holder of this document is advised that information contained herein reflects the company's findings at the time of its intervention only and within the limits of Client's instructions, if any. The Company's sole responsibility is to its Client and this document does not exonerate parties to a transaction from exercising all their rights and obligations under the transaction documents. Any unauthorized alteration, forgery or falsification of the content or appearance of this document is unlawful and offenders may be prosecuted to the fullest extent of the law.

CONTENTS

1. SCOPE

Malta has no indigenous mineral primary energy sources and therefore relies on imported fuels, mainly heavy fuel oil and light distillate, for generation purposes.

Enemalta Corporation is the main producer of electricity in Malta with the exception of a small contribution from relatively small producers generating electricity from renewable energy. The total electricity load in Malta in 2012 was 2,269 TWh. This demand was mostly met by two Enemalta-owned power stations using heavy fuel oil (HFO) and gasoil.

The current fossil fuel generation capacity is 620 MW distributed across the two power station sites owned by Enemalta. This includes a new power block with a capacity of 149 MW which commenced operation at the end of 2012. In addition a 200 MW interconnector to Sicily is currently under construction and is projected to be completed by the end of 2014. The remaining operational 2x steam turbine generators at the Marsa B station, with a total nominal capacity of 130 MW are due to be shut down by the end of 2015 under the terms of the Large Combustion Plant Directive. In addition, the Government of Malta has committed itself to shut down the 2 x 60 MW steam turbine generators of the Delimara 1 power plant once sufficient replacement capacity is available.

In the next years, base load electricity should be sourced by Enemalta from an independently-owned, state of the art, high-efficiency power plant powered by natural gas. This power plant is expected to be based on an advanced design Combined Cycle Gas Turbine (CCGT) plant.

ENEMALTA plans to contract the engineering, purchasing, construction, commissioning and operation of a Liquefied Natural Gas (LNG) import terminal (LNG Terminal) and associated regasification plant in order to supply the CCGT to a third party [1].

This plant will be an ‘upper tier’ establishment as defined by the Control of Major Accident Hazards (COMAH) Regulations that implement the latest version of the ‘Seveso’ Directive (Directive 2003/105/EC, which amended Directive 96/82/EC). The Directive has been transposed into Maltese law through the Control of Major Accident Hazards (COMAH) Regulations - L.N. 37 of 2003 as amended by L.N. 6 of 2005. The competent Authority is the Occupational Health and Safety Authority (OHSA) together with the Malta Environment and Planning Authority (MEPA) and the Civil Protection Department of the Ministry for Home Affairs and National Security (CPD).

For this reason, and in order to fulfil the land-use planning and environment permitting requirements, Malta Environmental & Planning Authority (MEPA[1]) requests that operators applying for development permission and environmental permission (in this case, a permission issued under the Industrial Emissions Directive) for new COMAH establishments submit a quantitative risk assessment (QRA) report with their planning application.

In this case, the preliminary project includes several options for the LNG terminal location and for the technical solution to be adopted for the regasification facility. The scope of the QRA would be extended to the comparison between three final realistic options, as described in detail in the following chapters.

The aim of the QRA is to compare the risk level of the proposed options for the population in the surroundings, as well as to define the preliminary location for the LNG tanker and/or the FSU/FSRU in the harbour.

[1] Malta Environment & Planning Authority website: http://www.mepa.org.mt/home

2. DESCRIPTION OF THE AREA OF CONCERN

The proposed new LNG terminal will be located in the Marsaxlokk Bay, close to the existing ENEMALTA facilities in the Delimara peninsula, onshore, on reclaimed land, or offshore, in the harbour, depending on the option finally chosen.

The site is bounded on the east side by the Delimara Peninsula, on the north side by the existing facilities owned and operated by ENEMALTA and on the west by the coastline to be modified. The access to the proposed facilities is a public road that runs in a North-South direction, bordering the coastline and currently stopping at ENEMALTA entrance. In the future, this road should be enlarged up to the entrance of the LNG terminal. The area of concern, as well as the proposed site for each option, is shown in the drawing in Attachment #1.

2.1. METEOROLOGY

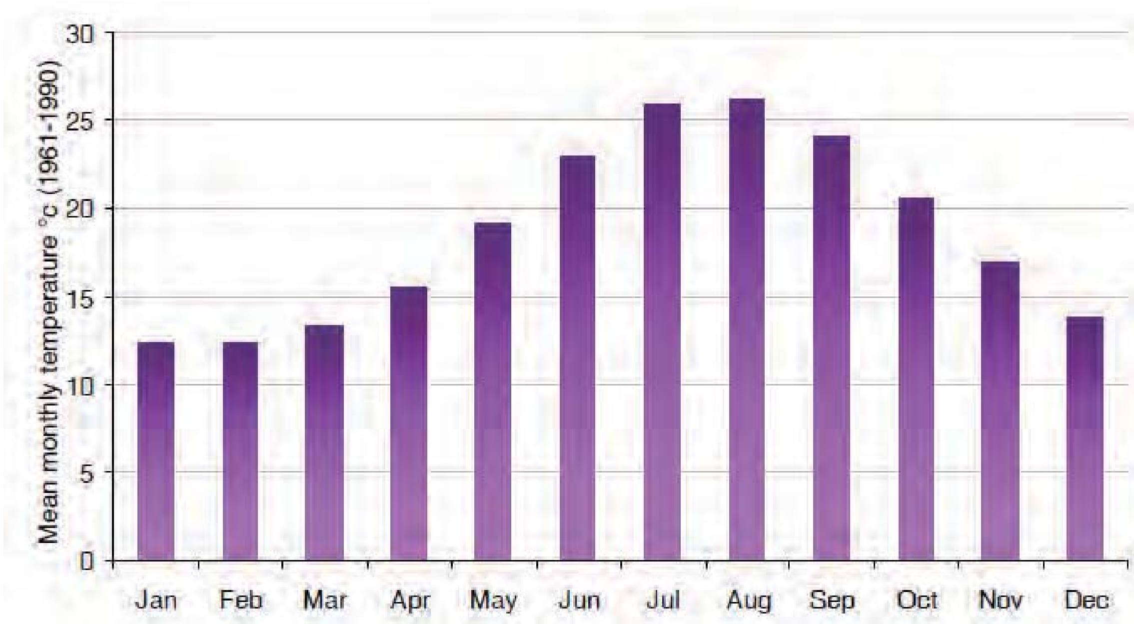
The seasonal features of the Mediterranean can be traced from the motion and development of the pressure systems over the Atlantic, Eurasia and Africa [2]. While the Mediterranean spring is often a period of indecisive weather, summer is characterised by the intensification of the Azores High Pressure which tends to extend up to the Central Mediterranean, giving general weather conditions consisting of light surface winds ranging from the northwest to northeast. Autumn is relatively short and leads to wintry conditions in a fairly decisive and quick way. During this season, Atlantic depressions move eastwards across northern Europe into the Mediterranean bringing with them waves of cold air. In its path, this cold air comes into contact with warm moist air causing vertical instability, the development of vigorous depressions, rainfall and frequent gales. From time to time the eastward march of travelling depressions is interrupted by cold air coming from the Arctic via the Norwegian Sea or Russia. This great thermal contrast leads to very active depressions.

In the Central Mediterranean region both Sicily and the Tunisian peninsula may play an important part on the local weather. Under certain prevailing conditions Sicily can act as a barrier against strong low-level northerly winds. This Italian island can also create local instabilities due to land heating effects or heat lows which may be advected towards the Maltese Islands depending on the prevailing winds.

Transient North African low pressure systems have the potential to produce strong winds over the Central Mediterranean. When for example North African lows occur south of the Atlas Mountains, strong easterly to south-easterly winds are likely over the Central Mediterranean resulting in high seas.

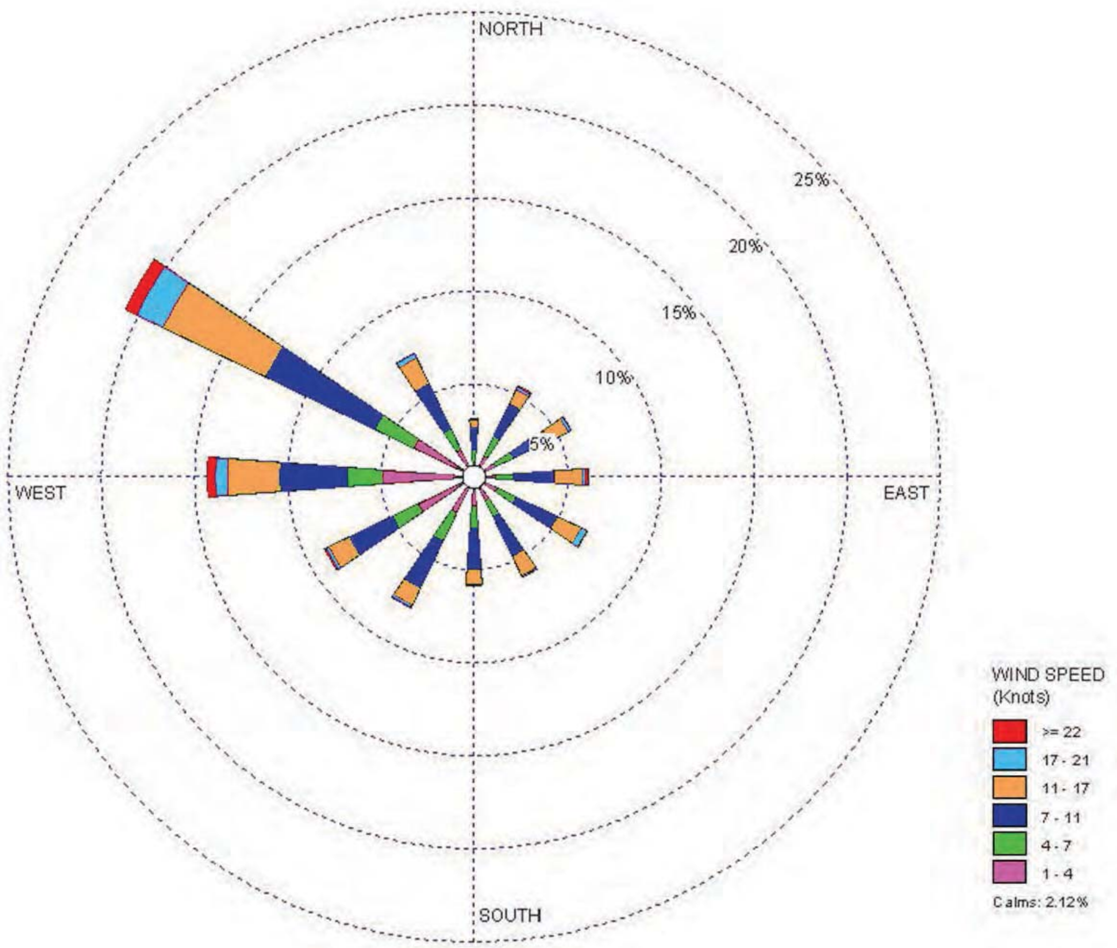
The presence of the surrounding water mass significantly shapes the climate of the Maltese Islands. The general weather is often cooler and more humid than what is experienced in inland areas of larger land masses. The high thermal capacity of the sea also reduces large fluctuations in the ambient temperature 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 [2].

Variable	Value	Unit
Ambient Temperature	19	ºC
Ambient Humidity	75	%
Cloud cover	75	%
Average wind speed	4.52	m/s



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.



2.2. GEOLOGY

The Maltese Islands are composed of Tertiary limestone and marls with subsidiary Quaternary deposits [3]. The strata consist of layers of Lower and Upper Coralline Limestone with intervening soft Globigerina Limestone and Blue Clay. The stratigraphy of the Maltese Islands is generally in accordance with the following table.

Formation	Approx. Age	Max. Thickness (m)
Upper Coralline Limestone	12-7.5 Ma	104-175
Greensand	12-7.5 Ma	0-16
Blue Clay	13-12 Ma	0-175
Upper Globigerina Limestone	15-13 Ma	5-20
Middle Globigerina Limestone	20-15 Ma	0-110
Lower Globigerina Limestone	20-15 Ma	5-110
Lower Coralline Limestone	--	140-236
Clays and dolomitised limestone	--	>3000

These rocks are sporadically overlain by terrestrial, Aeolian and alluvial deposits, laid down following the emergence of the Maltese Islands above sea level. Most of the central and south eastern sections of Malta comprise outcrops of Globigerina Limestone, whilst in the north and north western sections, Coralline Limestone predominates.

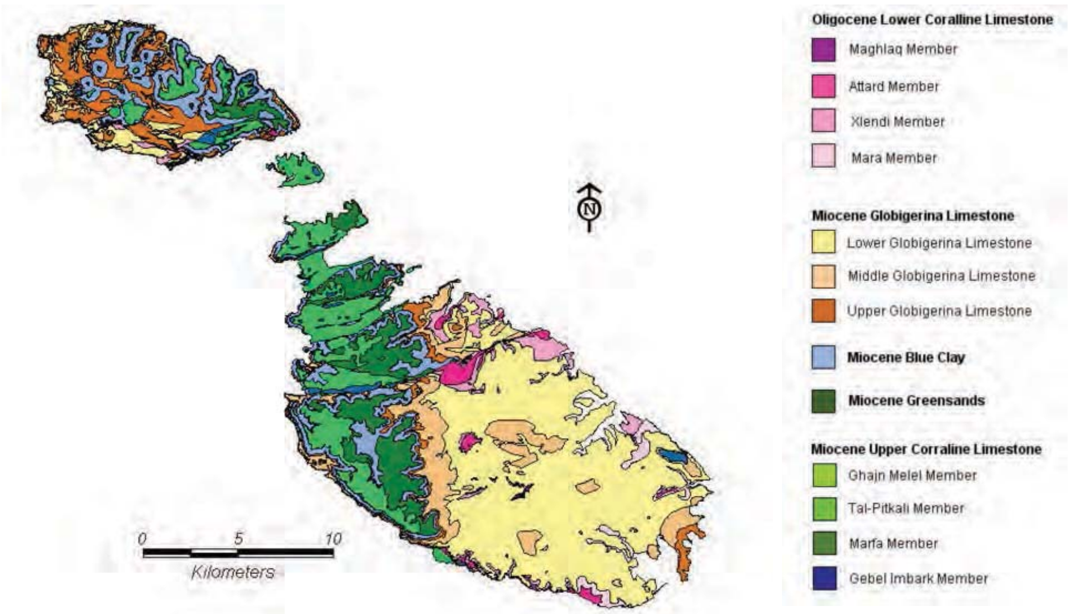


Figure 1.- Geological Map. [3]

Lower Coralline Limestone [3] is the oldest exposed rock in the Maltese Islands, outcropping to a height of 140m in the vertical cliffs near Xlendi, Gozo. It is mainly composed of the tests of coralline algae indicating deposition in a shallow gulf environment.. Globigerina Limestone outcrops in over 70% of the Maltese Islands. It erodes to form a rolling landscape and varies in thickness from 23 m near Fort Chambray to 207m around Marsaxlokk. Blue Clay overlays the Globigerina Limestone formation. This material erodes easily when wet and flows out over underlying formations leading to wide variations in thickness of the deposit.

Greensand is made up of bioclastic limestone, rich in glauconite. It is generally less than 1m thick.

Upper Coralline Limestone is the youngest tertiary formation in the islands and reaches a thickness of approximately 160m in the Bingemma area.

Geologically, the south of Malta is important for soft stone quarries, which are mainly located in Mqabba and Qrendi. The area is mainly made up of gently undulating Globigerina plains. It forms part of the South Horst, which is a tilted structural block, bounded on the North West by the Victoria Lines Fault and on the south by the Maghlaq Fault.

The proposed project, if located totally or partially onshore, would lay down on reclaimed land, therefore specific geological assessment must be carried out in order to ensure minimum conditions of mechanical resistance. Any possible mechanical failure associated with ground settlement must be considered in the design phase and avoided, thus any possible scenarios associated with geology is out of the scope of the QRA.

2.3. SEISMOLOGY

The Maltese Islands lie in the middle of an extensive fault system affecting the central Mediterranean from Tunisia to Sicily. The faults are potential earthquake sources and are expressions of the stress field that has created the system of grabens in the central Mediterranean, known as the Pantelleria Rift. Some of the faults are still active whilst others are believed to be stable [4].

Detailed historical data for earthquake events affecting the Maltese Islands have not been published. However, some records of previous earthquakes are available and can be used to assess possible risks from a major seismic event.
The maximum intensity of any earthquake recorded for Malta since 1500 was a level VII on the European Macroseismic Scale (EMS), which corresponds to a "damaging" earthquake. Widespread damage to buildings was reported in many parts of Malta during this event. Earthquakes of lesser intensity (EMS VI) have been reported on four occasions between 1743 and 1923. An event also occurred in 1972, about 50 km south east of Malta which produced a local EMS of V.

The University of Malta operates a digital seismograph which has been recording small scale seismic events since 1995. About 20 minor events are recorded on average per year within a radius of 100 km of Malta, the majority of which are not noticed by the general population and have no effect on structures.

It is considered that the Maltese Islands have a low to moderate risk of being affected by a significant seismic event. Within a 100km radius of the islands, seismic activity is generally low or diffuse, with a magnitude not exceeding 5 on the Richter Scale.

For QRA purposes, the seismology has not been taken into account, even if all the selected scenarios can be the result of a minor earthquake. The onshore installation, if chosen as the preferred option, must be designed and built according to standards protecting against earthquakes.

2.4. HYDROGRAPHY

The geological structure of the Maltese Islands permits the division of the islands into several distinct aquifer blocks with limited communication of the groundwater. The main source of groundwater is the Mean Sea Level Aquifer, which provides about 76% of Malta's groundwater resource. The main aquifer bearing rocks are the Upper and Lower Coralline Limestone. The Globigerina Limestone, which overlays the main aquifer over most of central and southern Malta, has very low permeability and average porosity. It is only locally important as a groundwater resource. The freshwater is in the form of a lens (Ghyben-Herzberg lens) with the thicker part situated in the central part of Malta, thinning towards the coast. The aquifer floats on top of the sea water, due to the density differential [3].

Replenishment of the aquifer is by rainwater. Percolation of rainwater into the Sea Level Aquifer is through fissures or other discontinuities. However, in some areas, the Globigerina Limestone is fractured below the water table and it becomes part of the Lower Coralline Limestone aquifer.

Because of the presence of fissures and other recharge pathways, such as fault lines, the Sea Level Aquifer is susceptible to surface derived contamination.

Perched aquifers are present in the Upper Coralline Limestone, sustained by the underlying impervious Blue Clay. These perched aquifers have only a small potential for water extraction but are used extensively for agricultural purposes.
Public supply is abstracted from a network of around 100 boreholes. In addition there are over 5,000 privately registered boreholes and an un-quantified number of unregistered ones.

The area in which the establishment is located is not important for potable supply or for agricultural purposes, and the risks proceeding from such type of substance is not directed on superficial or underground waters, thus any effects on hydrography is out of scope of the QRA.

2.5. LAND USE

The site proposed for the new LNG terminal is designated in the Marsaxlokk Bay Local Plan as part of the existing ENEMALTA facilities, being the adjacent area mainly dedicated to agricultural use, with a few isolated buildings.

The description is based on drawing #2 attached in Annex #1. The Delimara Power Station is shown there. All the numbers referenced in the following lines are shown in the same drawing.

Considering the land use map, the principal land uses in Marsaxlokk Bay can be listed as follows:

1. Important archaeological find
2. Low density residential
3. Convent / chapel
4. Low density residential
5. Low density residential
6. Predominantly residential
7. Parish church and square
8. Primary school
9. Fishing, recreation and tourism
10. Site of Community Importance
11. Low density residential
12. Historic fort
13. Low density residential
14. Low density residential
15. Fish farm
16. Low density residential
17. Medium density
18. Light Industry
19. Low density residential
20. Coastal ecology/swimming
21. Petroleum tank
22. Historic fort/research centre (fish)
23. Fish cages
24. Dolphin
25. Horse farm
26. Low density residential
27. Low density residential
28. Historic fort
29. Light house
30. Farm

The scattered houses include some cottages (#13, 14, 16, 19, 26 and 27), a horse farm (#25), an historic fort (#28) and a farm in the extreme South of the peninsula.

Heading north, there's the Marsaxlokk village with a total population of more than 3,000, at a distance of less than 1,000 m. On the other side of Birzebbuga Bay, Freeport closer docks are located at more than 1,000 m.

The biggest centre of population is Birzebbuga (population 8,800), which is located approximately 1.8 km west of the site. The town comprises a mix of residential, commercial and industrial developments.

Additionally, there are a number of environmentally sensitive areas in the vicinity of the site. They are those areas which could be adversely affected by the consequences of a major accident at the establishment. This includes natural environmental features, land in agricultural production, archaeological/cultural resources and the built environment.

These include:

- Forts and sites of archaeological interest
- Sites of community importance
- Coastal ecology / swimming areas

2.6. PRESENCE OF OTHER COMAH ESTABLISHMENTS

Marsaxlokk and Birzebbugia harbours gather most of the COMAH establishments existing in Malta:

- Delimara Power Station
- 31st March 1979 Installation
- Oil Tanking Malta
- Qajjenza LPG Plant (currently out of service)
- Wied Dalam Installation
- Mediterranean Offshore Bunkering Co Ltd
- San Lucian Oil Co. Ltd

The presence of all these installations must be considered in the COMAH documentation, due the possible domino effects between them. For QRA purposes, domino effect is not taken into account in the calculations, even if possible effects proceeding from the projected LNG terminal to the existing establishments would be qualitatively commented on the conclusions.

2.7. MARITIME TRAFFIC

The nautical traffic in the harbour was registered over the past year, with the following general results, provided by Transport Malta Authority [2]

Shipping Movements - Year 2012			
Type	**Calls**	**GRT**	**NRT**
Cargo Operations			
Container Operations	1,484	51,874,005	26,679,275
Dry Bulk Operations	7	32,133	14,508
Unitised Operations	60	1,673,423	569,812
Liquid Bulk Operations	474	8,221,243	3,625,504
General Cargo Operations	79	1,459,037	678,468
Passenger Operations			
Cruise Liners	0	0	0
Ferry	0	0	0
Passenger Catamaran Ferry	0	0	0
Repairs	7	16,250	8,186
Supplies			
Bunkers	7	30,861	14,610
Conveyance	0	0	0
Provisions	70	10,332	6,472
Water Supply	0	0	0
Others			
Service Provisions	8	80,357	29,067
Courtesy Visit	0	0	0
Shelter	0	0	0
Others	505	323,435	130,174
Total	**2,701**	**63,721,076**	**31,756,076**

The number of cargo operations is relevant if considered on the basis of the harbour dimensions and in comparison with others ports, so marine traffic in the harbour must be taken into account for QRA purposes.

[2] Transport Malta website: www.transport.gov.mt

3. DESCRIPTION OF THE PROPOSED FACILITIES: LNG REGASIFICATION PLANT

The project for an LNG plant to be studied in the QRA is at a very preliminary stage. According to ENEMALTA estimations, the expected average daily natural gas consumption would be up to about 48,314 MMBTU (~1,464,058 m^3). This equates to approximately 2,440 m^3 of LNG per day. The total capacity to fulfil ENEMALTA's needs is established to be 180,000 m^3.

In order to meet these requirements, a few options are under evaluation:

- Option A: the whole regasification plant onshore, to be built on reclaimed land close to the ENEMALTA fuel oil tank farm, currently an artificial hill.
- Option B: floating LNG storage (FSU) moored in the southern part of the harbour plus regasification plant onshore, to be built in the same location, but without any clearing of the hill.
- Option C: floating storage and regasification (FSRU), moored in the southern part of the harbour.

For the purposes of QRA, it's necessary to represent a realistic profile of equipments and operations for each option. Based on the energy and mass balance set by ENEMALTA, the consulting team proposed realistic layouts and minimum equipments definition to be used as inputs data in QRA calculations. All the data presented in the following descriptions are an estimation based on similar facilities. The consulting team has to advise again that the final adoption of different technical solution for the selected option may affect the results of the present assessment.

The equipment, utilities and possible layouts for each option are described in the following lines, and the description is based on the state-of-art facilities worldwide: The three options are shown in drawings #4, 5 and 6 attached in Annex #1.

3.1. DESCRIPTION OF OPTION A

Option A consists of an on-shore regasification plant to be built according to the requirements of EN 1473 [5] and NFPA 59A [6]. This option is most common in Europe, Japan and USA. The following description is based on state-of-the-art plants across Europe, such as: Zeebrugge (Belgium), Shannon (Ireland), Barcelona, Bilbao, Cartagena, Ferrol, Huelva, Musel, Sagunto, (Spain), Milford Haven (UK).

<u>LNG tanker</u>

The majority of the LNG transport worldwide is delivered in large LNG carriers with a capacity varying from 50,000 m^3 of the oldest vessels up to 250,000 m^3. Carriers are normally classified as follows:

- Standard class: 125-150,000 m^3
- Q-Flex class: 210-217,000 m^3 [7] [8]
- Q-Max class: 250,000 m^3 [9] [10] [11]

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

- 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

<u>Jetty and unloading arms</u>

The marine facilities envisaged in this project consist of:

- A jetty with mooring facilities which can admit ships of up to 140,000 m^3 capacity (more than 300m long).
- two LNG un-loading arms each capable of unloading 4,000 m^3/hr of LNG.
- A 3rd arm which is the vapour return

LNG is discharged by the ship pumps to either one or both of the storage tanks. The tanks boil-off is sent back to the ship via the return gas arm 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.

Full containment tanks

The tanks are to be of the full containment type, comprising a pre-stressed concrete outer wall and concrete roof with a cryogenic steel inner container. Typically tanks of this type have a design pressure of a few hundred mbarg.

The outer tank consists of a reinforced base slab (electrically heated to prevent frost heave), a pre-stressed concrete wall and roof ring beam, and a reinforced concrete roof.

Containment is provided by a reinforced concrete tank base, monolithically connected to a cylindrical tank wall, which is pre-stressed in the vertical and circumferential directions.

One important feature of the tanks is that there are no base or sidewall penetrations. All tank connections, including those for filling and emptying, are made through the roof so that the failure of a line will not result in emptying of the tanks.

The outer tank provides protection of the inner tank from a number of potential hazards, including Earthquakes.

Primary (LP) and secondary (HP) pumps

The LNG is pumped from the two storage tanks by primary or low pressure pumps located in several wells inside the tanks and submerged in the liquid.

The liquid is passed, directly or indirectly through an absorber, to the high pressure pumps (HP pumps) which feed the vapourisers at approximately 28 barg.

Regasification unit (vaporizers)

The LNG is re-gasified in submerged combustion vaporizers, which operate at send-out pressure prior to export from the LNG TERMINAL. The battery limit conditions are 25 barg with a minimum temperature of 5 °C. A small part of the gas from the vaporizers is routed separately to satisfy the LNG TERMINAL internal needs.

The vaporizers are provided with a gas turbine cogeneration unit from which waste heat is used to warm the water contained in a pool, where heat exchanger is submerged. The outlet gas will be at a minimum temperature of 0°C.

Boil Off Gas treatment (compressor and liquefier)

During ship unloading, the level in the on-shore storage tanks increases causing a vapour displacement. Simultaneously, the level in the tanker decreases at the same rate, causing a negative displacement effect and therefore a pressure drop.

To prevent vacuum in the tanker, a part of the vapour displaced in the storage tanks is sent back to the ship by means of return gas line through the boil-off header, the vapour return line and the vapour arm.

Excess boil-off gas is handled by boil-off compressors and mixed with the subcooled LNG pumped by the in-tank low pressure pumps (LP pumps).

The pressure in the storage tank is controlled by starting the boil-off compressors and sending the excess boil-off to the absorber for re-liquefaction.

Metering station and odourization

Before export to the CCGT, the gas passes through the gas metering station. The metering consists of two parallel metering lines including filters, turbine meters and odourizing unit.

3.2. DESCRIPTION OF OPTION B

LNG tanker

Expected to be the same as per Option A.

Unloading arms

The unloading arms are expected to be similar to the described in Option A, but located on the FSU, instead of on the jetty. Unloading operation is carried out in the same way, with liquid unloading through two arms and a 3rd for gas return. The visiting LNG carrier would be moored to the FSU and/or to the jetty.

Floating storage unit (FSU)

According to Maltese requirements, the FSU storage capacity would be a maximum amount 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 be similar to the one proposed for Option A, but with a bigger capacity, in order to allow mooring of the FSU and to provide services to the ship.

Regasification Unit

The regasification unit can be mounted on a skid and located in some point onshore, such as a reinforced part of the jetty or a platform close to the existing hill in the pathway to Delimara Power Station.

The Unit must include at least the following principal equipments:

- Secondary pumps
- Vaporizers
- Compressor
- Liquefier / absorber
- Metering station and odourization

This equipment and its operational mode are considered to be similar to that described for Option A and located in an open platform, this being the worst case scenario for risk assessment.

3.3. DESCRIPTION OF OPTION C

Option C is the newest solution in regasification, with all the equipment and vessels needed for the process installed on an LNG tanker. This option is called Floating Regasification and Storage Unit (FSRU). This solution will be adopted in some locations in Europe in the next few years.

In this case, a regasification unit, assembled on a skid, is mounted onboard an existing LNG tanker (normally on the bow side) or is a purpose-built LNG tanker that incorporates a regasification unit. The facilities consist of the following items:

LNG tanker

Expected to be the same as per Option A.

Unloading arms

Expected to be the same as per Option B.

Floating storage regasification unit (FSRU)

According to Maltese requirements, the FRSU storage capacity would be a maximum amount 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 gas phase on the port side (left) and common unloading arms for liquid and vapour phase on the starboard (right), for LNG unloading from a visiting LNG carrier.

The assumption is that all equipment will be located on the bow side of the vessel, in a superstructure with a distribution similar to the onshore distribution, with HP pumps, submerged combustion vaporizers, compressor and liquefier / absorber in order to re-liquefy the Boil Off Gas.

4. LNG 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.

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 mixture of low molecular weight hydrocarbons held at cryogenic temperatures. Physical properties for methane, ethane and propane (the principal constituents of LNG) are provided in the following table. [12]

Substance	Methane	Ethane	Propane
Chemical Name	Methane	Ethane	Propane
Chemical Formula	CH_4	C_2H_6	C_3H_8
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

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 not 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

LNG 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.

Roll-over in tanks (onshore or offshore)

A “roll-over” [13], [14] 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 LGN to leak due to the difference in densities and to vapourize 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 leakeage of LNG form the tank, due to pressure.

Rapid Phase Transitions

The effect called Rapid Phase Transitions (RPT) [14] 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.

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.

Gas odorization and false gas leakage alarm

Natural gas is completely odourless, reason for which must be artificially odorized with the addition of traces (parts per million or ppm) of substances called mercaptans, in order to provide the characteristic and alarming odour in case of leakage. This method is used for other products, such as LPG. The presence of a container of the additive is common in regasification plants.

Mercaptans are among the smelliest susbances in the world, thus any minor spillage, even if non lethal for the public, can disperse and be smelled at very large distances, and obviously, can lead to a false alarm, inducing the public to call the emergency services.

5. IDENTIFICATION OF VULNERABLE TARGETS

Considering the land use map, drawing #2 attached in Annex #1, the following vulnerable targets can be identified in the surroundings of the proposed LNG terminal and in Marsaxlokk community. The population zones can be listed as follows:

2. Low density residential
3. Convent / chapel
4. Low density residential
5. Low density residential
6. Predominantly residential
7. Parish church and square
8. Primary school
9. Fishing, recreation and tourism
11. Low density residential
13. Low density residential
14. Low density residential
16. Low density residential
17. Medium density
19. Low density residential
25. Low density residential
26. Low density residential
27. Low density residential
29. Lighthouse
30. Farm

The population data to be considered in the calculation of societal risk is shown in drawing #3 attached in Annex #1. The estimation of population in scattered houses, farms, touristic places and fishing / swimming zones are according to the Dutch model [15].

The scattered houses include some cottages (#13, 14, 16, 19, 26 and 27), a horse farm (#25), an historic fort (#28) and a farm in the extreme South of the peninsula. For each cottage, the presence of three persons is estimated. For the farm, the presence of 10 persons during daytime.

Heading north, there's the Marsaxlokk village with a total population of more than 3,000, at a distance of less than 1,000 m. On the other side of Birzebbuga Bay, Freeport closer docks are located at more than 1,000 m.

The biggest centre of population is Birzebbuga (population 8,800), which is located approximately 1.8 km west of the site. The town comprises of a mix of residential, commercial and industrial developments.

Additionally, there are a number of environmentally sensitive areas in the vicinity of the site. They are those areas which could be adversely affected by the consequences of a major accident at the establishment. This includes natural environmental features, land in agricultural production, archaeological/cultural resources and the built environment.

These include:

- Forts and sites of archaeological interest
- Sites of community importance
- Coastal ecology / swimming areas

Forts and Sites of Archaeological Importance

The presence of Fort Delimara, in the extreme South of the Delimara peninsula, must be considered for its archaeological importance. Regarding the presence of tourists, a total amount of 40 persons is estimated during daytime, based on car park lot dimensions.

Sites of community importance

A site of community importance must be considered north from the proposed facilities.

Coastal ecology / swimming areas

The cliffs and bays in the Eastern side of the Delimara peninsula present a number of beaches which receive local and foreign visitors. The marine coastal ecosystem adjacent to the site is populated by beds of Posidonia oceanica. These plants provide the basis of an extensive food web and a highly productive and diverse coastal ecosystem. In these areas, the presence of tourists should be considered, for a total amount of 40 persons during daytime, based on car park lot dimensions.

Fishery

The inner part of the bay is dedicated to fishery and / or mooring of sports and fishing boat. A total presence of 1 person per hectare is considered during daytime.

6. METHODOLOGY FOR QUANTITATIVE RISK ASSESSMENT

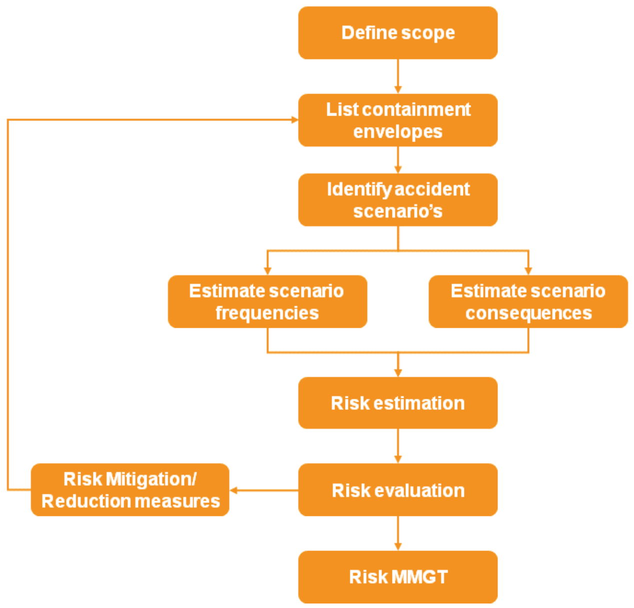
A Quantitative Risk Assessment is used to make decisions about the acceptability of risk in relation to developments for a company or in the area surrounding an establishment or transport route. The criteria for assessing the acceptability of risks for a large number of categories of establishments are 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) [16], [17], [18], [19], [20] or BEVI [21] [22] 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.



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 [22], Handbook failure frequencies [23], PERD, HSE FRED [24],…. 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:

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

$IR_{(x,y)}$ = 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.

6.1. INPUT INFORMATION AND DATA

The QRA is based on information and data strictly associated to the location, the site facilities and surroundings, listed below. For the Delimara project, due to the preliminary stage, most of the data is not yet available, and expert estimation is required in order to carry out the QRA. In these cases, the data is commented on the list below.

Facility

- Plot plan with :
  - Fence/border
  - Entry
  - Pipe routing (estimation according to minimum length, influence on calculation is limited)
  - Production facilities (estimated lay out, based on logical process flow, any mayor change can affect the final curves)
  - Storage facilities (estimated lay out, no changes expected for Option A)
  - (un-)loading facilities (estimated lay out, the position may considerably vary depending on risk limitation, port availability, draft and others parameters. Final position recommended in conclusions)
  - Offices and administrative buildings (estimated lay out, not relevant for preliminary QRA purposes)

- Installations with respect to natural gas (LNG, CNG) :
  - Location on the site (estimated lay out, final position of each equipment and vessel may vary in the same area, no relevant influence on final risk is expected)
  - Dimensions (estimated based on annual consumption, any variation exceeding 30% could affect the result of QRA)
  - volume (m^3) (estimated based on annual consumption, any variation exceeding 30% could affect the result of QRA)
  - filling degree (estimated according to normal operation for this plants)
  - Content in metric tonnes (estimated based on annual consumption, any variation exceeding 30% could affect the result of QRA)
  - Bunds (area and volume) (estimated presence of bunds in onshore facilities, with a maximum area similar to tank surface for tank area or limited to 1,500 m^2 for regasification area)
  - Pressure and temperature (operating and design) (estimated by comparison with similar facilities, any variation exceeding 30% could affect the result of QRA)
  - Connections (size – phase) (estimated by comparison with similar facilities, any variation exceeding 30% could affect the result of QRA)

- Unloading/loading facilities

  - number of transfers per year (estimated based on annual consumption, any variation exceeding 30% could affect the result of QRA)
  - transfer volume per delivery (estimated based on annual consumption, any variation exceeding 30% could affect the result of QRA)
  - unloading rate (m^3/h) (estimated by comparison with similar facilities, any variation exceeding 30% could affect the result of QRA)
  - unloading arm (diameter) (estimated by comparison with similar facilities, any variation exceeding 30% could affect the result of QRA)
  - Pressure and temperature (operating and design) (estimated by comparison with similar facilities, any variation exceeding 30% could affect the result of QRA)

- Piping (>10 m)
  - Diameter (estimated by comparison with similar facilities, any variation exceeding 30% could affect the result of QRA)
  - Pressure and temperature (estimated by comparison with similar facilities, any variation exceeding 30% could affect the result of QRA)
  - Flow (m^3/h) (estimated by comparison with similar facilities, any variation exceeding 30% could affect the result of QRA)

- Description of normal operation (not available at this stage, regasification operation estimated in comparison with other facilities)

- PFD's (not available at this stage, regasification operation estimated in comparison with other facilities, no details available nor considered for auxiliary equipments)

Surroundings

- Population grid day/night (estimated using official population data according to 2011 census, no major changes expected)

- Neighbouring
  - Residential areas including:
    - Individual houses (population in scattered houses estimated considering presence of three persons each, any important difference regarding this parameter can affect the calculated societal risk)
    - Vulnerable objects such as schools, hospitals, homes for elderly:
      - Name and location (no vulnerable objects identified in the area of concern according to Land use Map)
      - Presence of people (day, night) (not required according to previous point)
    - Public locations
      - Touristic areas (camping sites, museums, hotels, etc.)
        - Name and location (shown in Land Use Map)
        - Presence of people (day, night) (population during daytime estimated according with space availability in each car park lot)

- Environmental information
  - Average temperature of subsoil, air, water (annual) (available from Meteorological Service)
  - Average humidity (%) (annual) (available from Meteorological Service)
  - Meteorological information (annual) (available from Meteorological Service)
    - Stability classes (pasquil) vs. wind direction and wind speed at 10 m (not available for Malta, estimated using data from other similar port)

6.2. MODELLING SOFTWARE

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 examine 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 [25].

EFFECTS contain 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. [26]

6.3. 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. 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.

In the case of Malta, any similar port area in Mediterranean would present similar conditions, thus the decision to look for another port of the Mediterranean Sea, open to the South and surrounded by hills and for which data is available. The final decision was the Port of Cartagena, Spain, only 2º North of Marxaslokk. Data from this reference is shown in the following table.

	Stability class					
Wind velocity m/s	**A**	**B**	**C**	**D**	**E**	**F**
0 – 1	128	0.23	0.05	0.19	0.03	4.36
1 – 3	4.55	1.95	2.08	11.26	0.78	8.85
3 – 5	--	6.11	7.31	21.99	1.34	--
5 – 7	--	--	8.15	12.46	0.12	--
7 – 9	--	--	1.84	3.97	--	--
> 9	--	--	0.36	0.74	--	--

Using this data, 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.

Stability class and wind speed scenario	Total Percentage	Daytime percentage	Night-time percentage
D3	57	36	21
D9	27.52	18	9.52
E5	2.27	0	2.27
F2	13.21	0	13.21
Total	100	54	46

It's important to explain the relevance of this decision, and to highlight the scarce 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. For the case of Malta, the only practical relevance is to give the corresponding weight to the daytime, larger than the nigh time, due to the latitude, and to the stable weather conditions, due to the Mediterranean climate. Thus, Spanish data seems to be the best choice to simulate the Maltese conditions, introducing a minimum error, completely negligible in comparison to other general assumptions necessary for the study.

Fraction of day and night time

The fraction of time considered to be 'day' was calculated by assigning day and night hours to different months of the year, then calculating the number of daytime hours. Note that 'day' and 'night' were defined according to hypothetical resident behaviour (i.e. on when people may typically get up and go to bed, and not sunrise and sunset). Within the weather calculation, this has been defined as a 14 hour period during summer (defined as the period from April to the end of October, when daylight saving time operates) from 07:00 GMT (06:00 DST) until 21:00 GMT (20:00 DST); and a 12 hour period during winter (all months not defined as summer) from 06:00 GMT to 18:00 GMT. Thus, medium daytime is considered to be 13 hours over 24 hours, or 54% of total time.

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 [16] [25] [22]:

- **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 jetty and on land. All the leaks from the unloading arms are assumed to fall onto the water. All the leaks in the pipeline are assumed to fall onto the jetty or on land, so the calculation is done in both locations.

Effect of dikes, drainage channels and impounding basins

Most of the process areas would be provided with impounding basins for containment of incidental releases proceeding from equipment or vessels such as pumps, liquefier / absorber and roof top connections for tanks, according to recommendations of norm EN 1473 [5]. Any spillage is contained by walls and physical limitations around the equipment and transported by gravity to the basin by open drainage channels, in a way that ensures the possibility to cover the spillage with foam and to minimize the contact surface of the LGN, or, in other words, to minimize the generation of vapours from the basin.

In general for onshore terminal such as that described for Option A, up to three impounding basins are expected, covering the following zones: jetty, tanks roofs, secondary pumps and other equipments. For Option B, one basin is expected on the jetty and another in the location of the Regasification Unit. Also, any spillage in the LNG tanker deck is expected to be collected in the same way and conducted up to a basin. For Option C, no basin out of the tanker is expected, not being possible any spillage of LNG out of the tanker deck.

For the purposes of the QRA the final effect of the impoundment basins have not been considered, but the effects of the walls and barriers against spillages has been considered generically limiting the spillages to 1,500 m^2 [25] [22].

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. A general criterion is to limit the extension to 10,000 m^2 [25], [21], [22].

Effects of Topography

At the proposed location, heading in any direction except West, the land rises to a height of approximately 30-40 m up to the top of the hills configuring the Delimara peninsula. This difference in elevation and the slope between the platform and jetty where the process equipment is located will provide effective mitigation of any cold cloud formed on LNG spills, as well as limitation to thermal effect of large pool fire. The limitation in the extension of the cloud has been shown in drawing #13.

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 [25].

The classification provided here is based on table 3.1 from the Yellow Book [25]:

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

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.

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 [25].

Thermal Radiation

The probit most commonly used to determine the risk from thermal radiation is the Eisenberg et al (1975) probit. [22] [27]

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

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 [25] is 18.75 s. But, according to the HSA criteria [16], the value proposed for long duration fires is 75 s.

It is sometimes necessary to make some further refinement and assumptions for people indoors, based on Crosthwaite et al (1988) [28]. 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 [29] and takes into account that the people are fully clothed.

For some types of major hazard installation, damage contours associated with various levels of harm to property and buildings will be produced and provided to the Malta Environment and Planning Authority, showing the maximum possible extent of any particular level of damage.

Estimation of likelihood

There are two reference manuals [16] [21] 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 [21] and [24]. 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.

HSA [16] has defined the boundaries of the inner, middle and outer LUP zones as:

- 10^{-5} / year: risk of fatality for Inner Zone (Zone 1) boundary.
- 10^{-6} / year: risk of fatality for Middle Zone (Zone 2) boundary.
- 3×10^{-7} / year: risk of fatality for Outer Zone (Zone 3) boundary.

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. [30]

As the HSA conditions [16], the methodology for calculating the Societal Risk Index (SRI) is described by Carter (1995) [31] and Hirst and Carter (2000) [32] 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

7. IDENTIFICATION OF MAJOR ACCIDENT 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 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. [33] 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.

The list of proposed scenarios for each option is shown in the following tables, together with the input data for each one. Data definitions as follows:

ITEM is referred to the code of the scenarios and allows data crossing between tables;
EQUIPMENT is referred to the vessel / pipe / pump / tanker;
REFERENCE is the bibliographic source according to which the scenario is proposed;
DEFINITION is the complete name of the scenario;
PHASE is liquid or gas phase of the vessel content;
DENSITY may vary according to phase;
BUND is referred to the presence or not of physical limitations to the extension of liquid releases;
PIPELINE DIAMETER is referred to the considered pipeline diameter;
HOLE DIAMETER is referred to the diameter which must be chosen for the leakage calculation according to the bibliographic source;
DISCHARGE COEFFICIENT is a hydraulic factor to be considered depending on phase;
PIPELINE LENGTH is the estimated length for the leaking pipeline;
VOLUME is the total volume for a vessel, when present;
FILLING DEGREE is the percentage of fill in the volume;
H, L and D are the dimensions of the vessel;

OPERATION TEMPERATURE is the temperature at which the release is expected;
OPERATION PRESSURE is the pressure at which the release is expected;
PUMP NOMINAL RATE is the flow delivered by a pump, when present;
RELEASE TIME is the total time during which the release take place, before the action of emergency shut down systems.

LIST OF SCENARIO'S INPUTS																			
ITEM	EQUIPMENT	REFERENCE	SCENARIO DEFINITION	GAS / LIQ / LNG	DENSITY	BUND	PIPELINE DIAMETER (inch)	HOLE DIAMETER (M)	DISCHARGE COEFFICIENT	PIPELINE LENGTH (m)	VOLUME (m^3)	FILLING DEGREE	H (m)	L(m)	D (m)	OPERATION TEMPERATURE (ºC)	OPERATION PRESSURE (bar)	PUMP NOMINAL RATE (m^3/h)	RELEASE TIME (s)
Option A																			
A01.a	GAS TANKER (RELEASE ON WATER)	See paragraph 10.1 [34] [22]	Rupture of one tank of the Gas tanker due to ship collision	LNG	422	NO	N/A	0.36	N/A	N/A	35,000	95%	N/A	N/A	20.3	-161	1.03	N/A	Until empty vessel
A01.b	GAS TANKER (RELEASE ON WATER)	See paragraph 10.1 [34] [22]	Rupture of one tank of the Gas tanker due to ship collision	LNG	422	NO	N/A	0.50	N/A	N/A	35,000	95%	N/A	N/A	20.3	-161	1.03	N/A	Until empty vessel
A02.a	GAS TANKER UNLOADING ARM - LNG (RELEASE ON WATER)	FR 3.3.1 Ship Hardarms	GUILLOTINE BREAK Total failure rate when two arms used	LNG	422	NO	12	0.30	1	N/A	100	99	N/A	N/A	N/A	-161	4	8,000	120
A02.b	GAS TANKER UNLOADING ARM - LNG (RELEASE ON WATER)	FR 3.3.1 Ship Hardarms	Hole = 0.1 cross sectional area of pipe (two arms used)	LNG	422	NO	12	0.03	0.62	N/A	100	99	N/A	N/A	N/A	-161	4	8,000	120
A03.a	GAS TANKER LOADING ARM - GAS RETURN TO GAS TANKER	FR 3.3.1 Ship Hardarms	GUILLOTINE BREAK Total failure rate when one arm used	GAS	1.66	N/A	12	0.30	1	N/A	N/A	N/A	0	N/A	N/A	-151	2	N/A	120
A03.b	GAS TANKER LOADING ARM - GAS RETURN TO GAS TANKER	FR 3.3.1 Ship Hardarms	Hole = 0.1 cross sectional area of pipe	GAS	1.66	N/A	12	0.03	0.62	N/A	N/A	N/A	0	N/A	N/A	-151	2	N/A	120
A04	PIPELINE FROM GAS TANKER TO SHORE (RELEASE ON WATER)	Item FR 3.1.2 Above Ground Pipelines	Total rupture in the pipeline	LNG	422	NO	24	0.61	1	935	100	99	N/A	N/A	N/A	-161	4	8,000	1800
A05	PIPELINE FROM SHORE TO GAS TANKER - GAS RETURN TO GAS TANKER	Item FR 3.1.2 Above Ground Pipelines	Total rupture in the pipeline	GAS	1.6608	N/A	8	0.20	1	935	N/A	N/A	N/A	N/A	N/A	-151	1.03	N/A	1800
A06.a	LNG GROUND TANK	ITEM FR 1.1.2.1. LNG Refrigerated Vessels	Catastrophic failure	LNG	422	YES	N/A	53,000	1	N/A	90,000	90	40	N/A	53	-161	1.03	N/A	Until empty vessel
A06.b	LNG GROUND TANK	ITEM FR 1.1.2.1. LNG Refrigerated Vessels	Major failure (deq =1000 mm)	LNG	422	YES	N/A	1000	1	N/A	90,000	90	40	N/A	53	-161	1.03	N/A	Until empty vessel
A06.c	LNG GROUND TANK	ITEM FR 1.1.2.1. LNG Refrigerated Vessels	Minor failure (deq= 300 mm)	LNG	422	YES	N/A	300	1	N/A	90,000	90	40	N/A	53	-161	1.03	N/A	Until empty vessel
A07	PIPELINE FROM GROUND TANK TO SECONDARY PUMP - SUCTION	Item FR 3.1.2 Above Ground Pipelines	Total rupture in the pipeline	LNG	422	YES	4	0.10	1	304	N/A	99	N/A	N/A	N/A	-161	1.03	1,860	1800
A08	SECONDARY PUMP	Item FR 1.2.2 Pumps	Failure of casing	LNG	422	YES	4	0.10	1	N/A	N/A	99	N/A	N/A	N/A	-161	28	1,855	1800
A09	PIPELINE FROM SECONDARY PUMP TO	Item FR 3.1.2 Above Ground	Total rupture in the pipeline	LNG	422	YES	6	0.15	1	26.5	N/A	99	N/A	N/A	N/A	-161	28	4,600	1800

LIST OF SCENARIO'S INPUTS

ITEM	EQUIPMENT	REFERENCE	SCENARIO DEFINITION	GAS / LIQ / LNG	DENSITY	BUND	PIPELINE DIAMETER (inch)	HOLE DIAMETER (M)	DISCHARGE COEFFICIENT	PIPELINE LENGTH (m)	VOLUME (m^3)	FILLING DEGREE	H (m)	L(m)	D (m)	OPERATION TEMPERATURE (ºC)	OPERATION PRESSURE (bar)	PUMP NOMINAL RATE (m^3/h)	RELEASE TIME (s)
	RU - DISCHARGE	Pipelines																	
A10	REGASIFICATION UNIT (RU)	BEVI	Rupture of 10 pipes at the same time	GAS	1.66	N/A	1.5	0.04	1	N/A	N/A	N/A	N/A	N/A	N/A	5	25	N/A	120
A11	PIPELINE FROM RU TO GAS METERING STATION	Item FR 3.1.2 Above Ground Pipelines	Total rupture in the pipeline	GAS	1.66	N/A	10	0.25	1	26.5	N/A	N/A	N/A	N/A	N/A	-5	25	N/A	120
A12	PIPELINE FROM GROUND TANK TO COMPRESSOR	Item FR 3.1.2 Above Ground Pipelines	Total rupture in the pipeline	GAS	1.66	N/A	6	0.15	1	304	N/A	N/A	N/A	N/A	N/A	19	15	N/A	120
A13	COMPRESSOR (BOIL-OFF COMPRESSOR)	Item FR 3.1.3 Centrifugal compressors	Rupture (>110mm diameter)	GAS	1.66	N/A	6	0.15	1	N/A	N/A	N/A	N/A	N/A	N/A	19	15	3,011	N/A
A14	PIPELINE FROM BOC TO LIQUIFIER - DISCHARGE	Item FR 3.1.2 Above Ground Pipelines	Total rupture in the pipeline	GAS	1.66	N/A	6	0.15	1	29	N/A	N/A	N/A	N/A	N/A	19	15	3,011	N/A
A14	PIPELINE FROM BOC TO LIQUIFIER - DISCHARGE	Item FR 3.1.2 Above Ground Pipelines	Total rupture in the pipeline	GAS	1.66	N/A	6	0.15	1	25,000	N/A	N/A	N/A	N/A	N/A	19	15	3,011	N/A
A15	PIPELINE FROM LIQUIFIER TO GROUND TANK	Item FR 3.1.2 Above Ground Pipelines	Total rupture in the pipeline	LNG	422	YES	4	0.10	1	304	50	50	N/A	N/A	N/A	161	6	n/a	Until empty vessel
Option B																			
B01.a	GAS TANKER (RELEASE ON WATER)	See paragraph 10.1 [34] [22]	Rupture of one tank of the Gas tanker due to ship collision	LNG	422	NO	N/A	0.36	N/A	N/A	35,000	95%	N/A	N/A	20.3	-161	1.03	N/A	Until empty vessel
B01.b	GAS TANKER (RELEASE ON WATER)	See paragraph 10.1 [34] [22]	Rupture of one tank of the Gas tanker due to ship collision	LNG	422	NO	N/A	0.5	N/A	N/A	35,000	95%	N/A	N/A	20.3	-161	1.03	N/A	Until empty vessel
B02.a	GAS TANKER TO FSU UNLOADING ARM - LNG (RELEASE ON WATER)	FR 3.3.1 Ship Hardarms	GUILLOTINE BREAK Total failure rate when three arms used	LNG	422	NO	12	0.30	1	N/A	100	99	N/A	N/A	N/A	-161	4	8,000	120
B02.b	GAS TANKER TO FSU UNLOADING ARM - LNG (RELEASE ON WATER)	FR 3.3.1 Ship Hardarms	Hole = 0.1 cross sectional area of pipe	LNG	422	NO	12	0.03	0.62	N/A	100	99	N/A	N/A	N/A	-161	4	8,000	120
B03.a	FSU UNLOADING ARM - LNG (RELEASE ON WATER)	FR 3.3.1 Ship Hardarms	GUILLOTINE BREAK Total failure rate when two arms used	LNG	422	NO	6	0.15	1	N/A	100	99	N/A	N/A	N/A	-161	4	200	120
B03.b	FSU UNLOADING ARM - LNG (RELEASE ON WATER)	FR 3.3.1 Ship Hardarms	Hole = 0.1 cross sectional area of pipe	LNG	422	NO	6	0.01	0.62	N/A	100	99	N/A	N/A	N/A	-161	4	200	120
B04.a	GAS TANKER UNLOADING ARM - GAS RETURN TO GAS TANKER	FR 3.3.1 Ship Hardarms	GUILLOTINE BREAK Total failure rate when one arm used (8)	GAS	1.66	N/A	12	0.30	1	N/A	N/A	N/A	0	N/A	N/A	-151	1.03	N/A	Until empty vessel
B04.b	GAS TANKER UNLOADING ARM - GAS	FR 3.3.1 Ship Hardarms	Hole = 0.1 cross sectional area of	GAS	1.66	N/A	12	0.030	1	N/A	N/A	N/A	0	N/A	N/A	-151	1.03	N/A	Until empty vessel

SGS

LIST OF SCENARIO'S INPUTS																			
ITEM	EQUIPMENT	REFERENCE	SCENARIO DEFINITION	GAS / LIQ / LNG	DENSITY	BUND	PIPELINE DIAMETER (inch)	HOLE DIAMETER (M)	DISCHARGE COEFFICIENT	PIPELINE LENGTH (m)	VOLUME (m^3)	FILLING DEGREE	H (m)	L(m)	D (m)	OPERATION TEMPERATURE (ºC)	OPERATION PRESSURE (bar)	PUMP NOMINAL RATE (m^3/h)	RELEASE TIME (s)
	RETURN TO GAS TANKER		pipe																
B05	PIPELINE FROM FSU TANK TO SECONDARY PUMP - SUCTION (RELEASE ON WATER)	Item FR 3.1.2 Above Ground Pipelines	Total rupture in the pipeline	LNG	422	YES	4	0.10	1	304	N/A	99	N/A	N/A	N/A	-161	1.03	1,860	1,800
B06	SECONDARY PUMP	Item FR 1.2.2 Pumps	Failure of casing	LNG	422	YES	4	0.10	1	N/A	N/A	99	N/A	N/A	N/A	-161	28	1,855	1,800
B07	PIPELINE FROM SECONDARY PUMP TO RU - DISCHARGE	Item FR 3.1.2 Above Ground Pipelines	Total rupture in the pipeline	LNG	422	YES	6	0.15	1	26.5	N/A	99	N/A	N/A	N/A	-161	28	4,600	1,800
B08	REGASIFICATION UNIT (RU)	BEVI	Rupture of 10 pipes at the same time	GAS	1.66	N/A	1.5	0.04	1	N/A	N/A	N/A	N/A	N/A	N/A	5	25	N/A	120
B09	PIPELINE FROM RU TO GAS METERING STATION	Item FR 3.1.2 Above Ground Pipelines	Total rupture in the pipeline	GAS	1.66	N/A	10	0.25	1	26.5	N/A	N/A	N/A	N/A	N/A	-5	25	N/A	120
B10	PIPELINE FROM FSU TANK TO COMPRESSOR	Item FR 3.1.2 Above Ground Pipelines	Total rupture in the pipeline	GAS	1.66	N/A	6	0.15	1	849	N/A	N/A	N/A	N/A	N/A	19	15	N/A	120
B11	COMPRESSOR	Item FR 3.1.3 Compressors	Rupture (>110mm diameter)	GAS	1.66	N/A	6	0.15	1	N/A	N/A	N/A	N/A	N/A	N/A	19	15	3,011	N/A
B12	PIPELINE FROM COMPRESSOR TO FSU LIQUIFIER - DISCHARGE	Item FR 3.1.2 Above Ground Pipelines	Total rupture in the pipeline	GAS	1.66	N/A	6	0.15	1	22	N/A	N/A	N/A	N/A	N/A	19	15	3,011	N/A
B12	PIPELINE FROM FSU BOC TO FSU LIQUIFIER - DISCHARGE	Item FR 3.1.2 Above Ground Pipelines	Total rupture in the pipeline	GAS	1.66	N/A	6	0.15	1	22	N/A	N/A	N/A	N/A	N/A	19	15	3,011	N/A
B13	PIPELINE FROM FSU LIQUIFIER TO FSU TANK	Item FR 3.1.2 Above Ground Pipelines	Total rupture in the pipeline	LNG	422	YES	4	0.10	1	849	50	50	N/A	N/A	N/A	161	6	n/a	Until empty vessel
Option C																			
C01.a	GAS TANKER (RELEASE ON WATER)	See paragraph 10.1 [34] [22]	Rupture of one tank of the Gas tanker due to ship collision	LNG	422	NO	N/A	0.36	N/A	N/A	35,000	95%	N/A	N/A	20.3	-161	1.03	N/A	Until empty vessel
C01.b	GAS TANKER (RELEASE ON WATER)	See paragraph 10.1 [34] [22]	Rupture of one tank of the Gas tanker due to ship collision	LNG	422	NO	N/A	0.5	N/A	N/A	35,000	95%	N/A	N/A	20.3	-161	1.03	N/A	Until empty vessel
C02.a	GAS TANKER TO FSRU UNLOADING ARM - LNG (RELEASE ON WATER)	FR 3.3.1 Ship Hardarms	GUILLOTINE BREAK Total failure rate when three arm used (8)	LNG	422	NO	12	0.30	1	N/A	100	99	N/A	N/A	N/A	-161	4	8,000	120
C02.b	GAS TANKER TO FSRU UNLOADING ARM - LNG (RELEASE ON WATER)	FR 3.3.1 Ship Hardarms	Hole = 0.1 cross sectional area of pipe	LNG	422	NO	12	0.03	0.62	N/A	100	99	N/A	N/A	N/A	-161	4	8,000	120
C03.a	GAS TANKER UNLOADING ARM - GAS RETURN TO GAS TANKER	FR 3.3.1 Ship Hardarms	GUILLOTINE BREAK Total failure rate when one arm used (8)	GAS	1.66	N/A	12	0.30	1	N/A	N/A	N/A	0	N/A	N/A	-151	1.03	N/A	Until empty vessel

LIST OF SCENARIO'S INPUTS																			
ITEM	EQUIPMENT	REFERENCE	SCENARIO DEFINITION	GAS / LIQ / LNG	DENSITY	BUND	PIPELINE DIAMETER (inch)	HOLE DIAMETER (M)	DISCHARGE COEFFICIENT	PIPELINE LENGTH (m)	VOLUME (m^3)	FILLING DEGREE	H (m)	L(m)	D (m)	OPERATION TEMPERATURE (ºC)	OPERATION PRESSURE (bar)	PUMP NOMINAL RATE (m^3/h)	RELEASE TIME (s)
C03.b	GAS TANKER UNLOADING ARM - GAS RETURN TO GAS TANKER	FR 3.3.1 Ship Hardarms	Hole = 0.1 cross sectional area of pipe	GAS	1.66	N/A	12	0.03	1	N/A	N/A	N/A	0	N/A	N/A	-151	1.03	N/A	Until empty vessel
C04	PIPELINE FROM FSRU TANK TO FSRU SECONDARY PUMP - SUCTION	Item FR 3.1.2 Above Ground Pipelines	Total rupture in the pipeline	LNG	422	YES	4	0.10	1	304	N/A	99	N/A	N/A	N/A	-161	1.03	1860	1,800
C05	FSRU SECONDARY PUMP	Item FR 1.2.2 Pumps	Failure of casing	LNG	422	YES	4	0.10	1	N/A	N/A	99	N/A	N/A	N/A	-161	28	1,855	1,800
C06	PIPELINE FROM FSRU SECONDARY PUMP TO FSRU RU - DISCHARGE	Item FR 3.1.2 Above Ground Pipelines	Total rupture in the pipeline	LNG	422	YES	6	0.15	1	36	N/A	99	N/A	N/A	N/A	-161	28	4,600	1,800
C07	FSRU REGASIFICATION UNIT (RU)	BEVI	Rupture of 10 pipes at the same time	GAS	1.66	N/A	1.5	0.03	1	N/A	N/A	N/A	N/A	N/A	N/A	5	25	N/A	120
C08.a	FSRU UNLOADING ARM TO METERING STATION - GAS	FR 3.3.1 Ship Hardarms	GUILLOTINE BREAK Total failure rate when one arm used (8)	GAS	1.66	N/A	10	0.25	1	26.5	N/A	N/A	N/A	N/A	N/A	-5	25	N/A	120
C08.b	FSRU UNLOADING ARM TO METERING STATION - GAS	FR 3.3.1 Ship Hardarms	Hole = 0.1 cross sectional area of pipe	GAS	1.66	N/A	10	0.02	1	1,008	N/A	N/A	N/A	N/A	N/A	-5	25	N/A	120
C09	PIPELINE FROM FSRU RU TO GAS METERING STATION	Item FR 3.1.2 Above Ground Pipelines	Total rupture in the pipeline	GAS	1.66	N/A	10	0.25	1	1,008	N/A	N/A	N/A	N/A	N/A	-5	25	N/A	120
C10	PIPELINE FROM FSU TANK TO COMPRESSOR	Item FR 3.1.2 Above Ground Pipelines	Total rupture in the pipeline	GAS	1.66	N/A	6	0.15	1	282	N/A	N/A	N/A	N/A	N/A	19	15	N/A	120
C11	FSU BOC	Item FR 3.1.3 Compressors	Rupture (>110mm diameter)	GAS	1.66	N/A	6	0.15	1	N/A	N/A	N/A	N/A	N/A	N/A	19	15	3,011	N/A
C12	PIPELINE FROM FSU COMPRESSOR TO FSU LIQUIFIER - DISCHARGE	Item FR 3.1.2 Above Ground Pipelines	Total rupture in the pipeline	GAS	1.66	N/A	6	0.15	1	36	N/A	N/A	N/A	N/A	N/A	19	15	3,011	N/A
C12	PIPELINE FROM FSU COMPRESSOR TO FSU LIQUIFIER - DISCHARGE	Item FR 3.1.2 Above Ground Pipelines	Total rupture in the pipeline	GAS	1.66	N/A	6	0.15	1	25,000	N/A	N/A	N/A	N/A	N/A	19	15	3,011	N/A
C13	PIPELINE FROM FSU LIQUIFIER TO FSU TANK	Item FR 3.1.2 Above Ground Pipelines	Total rupture in the pipeline	LNG	422	YES	4	0.10	1	282	50	50	N/A	N/A	N/A	161	6	n/a	Until empty vessel

8. DEVELOPMENT OF ESCALATION SCENARIOS

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.

8.1. FINAL EVENTS

In general, the most common effects are well known, typified and modelled. 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 in the following paragraphs.

<u>Pool Fire</u>

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.

<u>Flammable Gas Cloud</u>

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.

<u>Flash-fire</u>

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.

<u>UVCE</u>

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.

<u>Jet-fire</u>

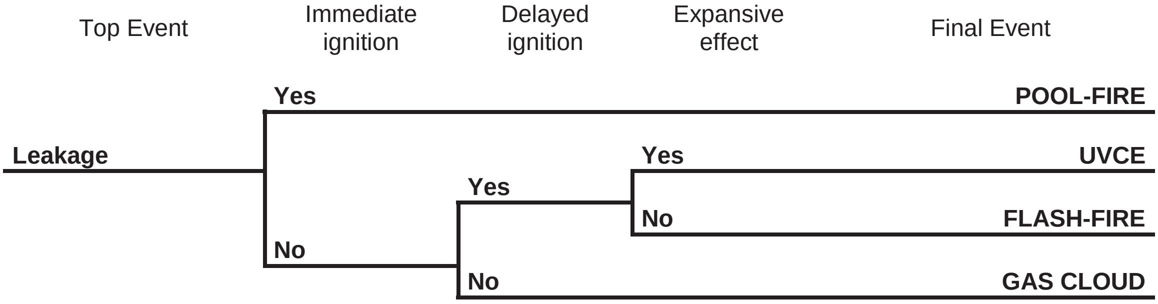
A jet-fire is the direct combustion of a substance leaking from a pressurized vessel. The leakage can be in vapour or in a liquid phase. In this last case, the liquid is spread at high pressure forming fine drops which can be ignited.

8.2. EVENT TREES

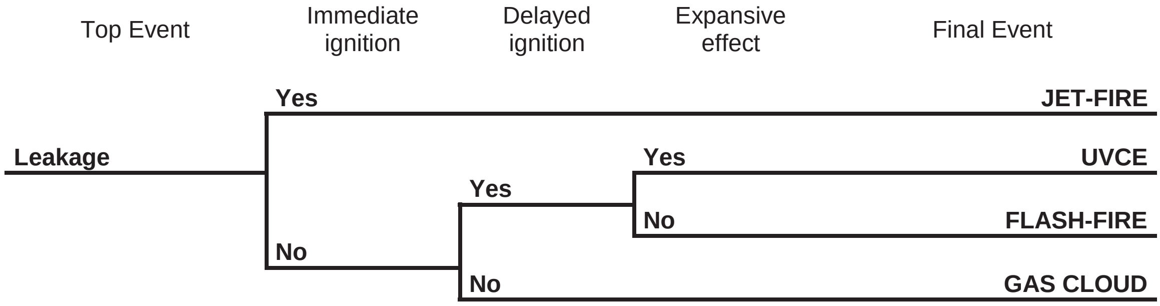
The final effects described in the previous chapter are related to the LOC event by the so-called Event Trees. An event tree is a graphical representation which helps the study of chronological and subsequent events or consequences.

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)



9. ESTIMATION OF CONSEQUENCES

The list of consequences for each scenario, and for each option, is shown in the following tables, together with the output data for each one. Data definitions as follows:

ITEM is referred to the code of the scenarios and allows data crossing between tables;
EQUIPMENT is referred to the vessel / pipe / pump / tanker;
VAPORIZATION (%) is the calculated percentage of liquid which vaporizes after leakage;
MASS FLOW RELEASE (kg/s) is the mass flow rate at which the release takes place;
MASS (kg) is the weight of the quantity released;
VOLUME (m3) is the volume of the quantity released;
PIPELINE SECTION MASS (m3) is the inventory contained in the considered section of the pipe;
TOTAL VOLUME RELEASED (M3) is the volume of the total quantity released;
POOL FIRE AREA (m2) is the surface covered by the extension of the pool fire;
REMARKS is reserved to comments and remarks on the previous data;
POOL FIRE AREA (m2) is referred to the maximum extension on which the pool fire is burning;
EVAPORATION AREA(m2) is referred to the maximum extension on which the gas is evaporating;
EVAPORATION TIME(s) is referred to the minimum duration of the evaporation considered in the calculation;
FLAMMABLE DISPERSION (kg/s) is the flow rate proceeding from the leakage.

LIST OF SCENARIO'S CONSEQUENCES														
ITEM	EQUIPMENT	VAPORIZATION (%)	MASS FLOW RELEASE (kg/s)	MASS (kg)	VOLUME (m^3)	PIPELINE SECTION MASS (m^3)	TOTAL VOLUME RELEASED (m^3)	POOL FIRE AREA (m^2)	REMARKS	POOL FIRE AREA (m2)	EVAPORATION AREA (m2)	EVAPORATION TIME (s)	FLAMMABLE DISPERSION (kg/s)
Option A													
A01.a	GAS TANKER (RELEASE ON WATER)	99	926	1.09E+07	35000	N/A	0.00	10,000	Hole height 10.15 m	10,000	10,000	1,800	732
A01.b	GAS TANKER (RELEASE ON WATER)	99	1,769	1.09E+07	35000	N/A	0.00	10,000	Hole height 10.15 m	10,000	10,000	1,800	856
A02.a	GAS TANKER UNLOADING ARM - LNG (RELEASE ON WATER)	100	1,407	168,800	400	0	400	29,050	Unconfined	Unconfined	10,000	1,800	166
A02.b	GAS TANKER UNLOADING ARM - LNG (RELEASE ON WATER)	100	94	112,53	26.67	0	26.67	1,364	Unconfined	1,364	1,364	1,800	41
A03.a	GAS TANKER LOADING ARM - GAS RETURN TO GAS TANKER	N/A	1.56	9,265	5578.64	N/A	772.52	N/A		N/A	N/A	N/A	1.56
A03.b	GAS TANKER LOADING ARM - GAS RETURN TO GAS TANKER	N/A	0.033	1,265	761.68	N/A	0.00	N/A		N/A	N/A	N/A	0.033
A04	PIPELINE FROM GAS TANKER TO SHORE (RELEASE ON WATER)	72	521.8	202,000	479	100	578.67	34,284,000	Release during 120 s at nominal pump rate * 1.5 and depressurization of pipe containing 100 m^3.	10,000	10,000	1,800	521
A05	PIPELINE FROM SHORE TO GAS TANKER - GAS RETURN TO GAS TANKER	100	1.4633	9,286	5591.28	0	5,591.28	N/A		N/A	N/A	N/A	0.43
A06.a	LNG GROUND TANK	100	2.28E+07	3.08E+07	7.29E+04	N/A	72,938.39	2,206	Limited to the equivalent to the base surface of the tank	2,206	2,206	1,800	119
A06.b	LNG GROUND TANK	100	8,364	3.08E+07	7.29E+04	N/A	72,938.39	2,206	Limited to the equivalent to the base surface of the tank	2,206	2,206	1,800	85
A06.c	LNG GROUND TANK	100	767	3.08E+07	7.29E+04	N/A	72,938.39	2,206	Limited to the equivalent to the base surface of the tank	2,206	2,206	1,800	71
A07	PIPELINE FROM GROUND TANK TO SECONDARY PUMP - SUCTION	100	218	1.23E+05	2.90E+02	N/A	290.38	29,037.92		1,500	1,500	1,800	66
A08	SECONDARY PUMP	100	217.35	3.64E+06	8.62E+03	N/A	8,617.30	861,729.86		1,500	1,500	1,800	49
A09	PIPELINE FROM SECONDARY PUMP TO RU - DISCHARGE	100	539.25	970,650	2300.12	0	2,300.12	230,011.84	Limited	1,500	1,500	1,800	53
A10	REGASIFICATION UNIT (RU)	100	12.80	1,536	924.86	0	924.86	N/A		1,500	1,500	1,800	1,848
A11	PIPELINE FROM RU TO GAS METERING STATION	N/A	188.45	22,614	13616.33	N/A	13,616.33	N/A		N/A	N/A	N/A	189
A12	PIPELINE FROM GROUND TANK TO COMPRESSOR	N/A	47.672	5,720.64	3444.51	N/A	3,444.51	N/A		N/A	N/A	N/A	49
A13	COMPRESSOR (BOIL-OFF COMPRESSOR)	N/A	1.49	N/A	N/A	N/A	N/A	N/A		N/A	N/A	N/A	49
A14	PIPELINE FROM BOC TO LIQUIFIER - DISCHARGE	N/A	33.48	N/A	N/A	N/A	N/A	N/A	Pipeline length input data has been modified to be realistic with the compressor operability	N/A	N/A	N/A	33

SGS

LIST OF SCENARIO'S CONSEQUENCES													
ITEM	EQUIPMENT	VAPORIZATION (%)	MASS FLOW RELEASE (kg/s)	MASS (kg)	VOLUME (m^3)	PIPELINE SECTION MASS (m^3)	TOTAL VOLUME RELEASED (m^3)	POOL FIRE AREA (m^2)	REMARKS	POOL FIRE AREA (m2)	EVAPORATION AREA (m2)	EVAPORATION TIME (s)	FLAMMABLE DISPERSION (kg/s)
A14	PIPELINE FROM BOC TO LIQUIFIER - DISCHARGE	N/A	1.49	N/A	N/A	N/A	N/A	N/A	Pipeline length input data has been modified to be realistic with the compressor operability	N/A	N/A	N/A	1.5
A15	PIPELINE FROM LIQUIFIER TO GROUND TANK	100	9.15	13,479	31.95	0	31.94	2206	Pipeline length input data has been modified to be realistic with the compressor operability		2,206	1,800	9.15
Option B													
B01.a	GAS TANKER (RELEASE ON WATER)	99	926	1.09E+07	35,000	N/A	0.00	10,000	Hole height 10.15 m	10,000	10,000	1,800	732
B01.b	GAS TANKER (RELEASE ON WATER)	99	1769	1.09E+07	35,000	N/A	0.00	10,000	Hole height 10.15 m	10,000	10,000	1,800	856
B02.a	GAS TANKER UNLOADING ARM - LNG (RELEASE ON WATER)	100	1407	168800	400	0	400	29,050	Unconfined	Unconfined	10,000	1,800	166
B02.b	GAS TANKER UNLOADING ARM - LNG (RELEASE ON WATER)	100	94	11253	26.67	0	26.67	1,364	Unconfined	1364	1,364	1,800	41
B03.a	FSU UNLOADING ARM - LNG (RELEASE ON WATER)	100	353.00	42360.00	100.38	0.00	100.38	10037.91	Unconfined	Unconfined	10,000	1,800	353
B03.b	FSU UNLOADING ARM - LNG (RELEASE ON WATER)	100	2.18	261.60	0.62	0.00	0.62	62	Unconfined	62	62	1,800	2.18
B04.a	GAS TANKER UNLOADING ARM - GAS RETURN TO GAS TANKER	N/A	1.56	9265	5578.64	N/A	772.52	N/A		N/A	N/A	N/A	1.56
B04.b	GAS TANKER UNLOADING ARM - GAS RETURN TO GAS TANKER	N/A	0.033	1265	761.68	N/A	0.00	N/A		N/A	N/A	N/A	0.033
B05	PIPELINE FROM FSU TANK TO SECONDARY PUMP - SUCTION (RELEASE ON WATER)	100	218.00	122540.00	290.38	N/A	290.38	29037.91		1,500	1,500	1,800	65.94
B06	SECONDARY PUMP	100	217.35	3.64E+06	8.62E+03	N/A	8617.30	861729.86		1,500	1,500	1,800	49
B07	PIPELINE FROM SECONDARY PUMP TO RU - DISCHARGE	100	539.25	970650	2300.12	0	2300.12	230011.84	Limited	1,500	1,500	1,800	53
B08	REGASIFICATION UNIT (RU)	100	12.80	1536	924.86	0	924.86	N/A		1,500	1,500	1,800	1,848
B09	PIPELINE FROM RU TO GAS METERING STATION	N/A	188.45	22614	13616.33	N/A	13616.33	N/A		N/A	N/A	N/A	189
B10	PIPELINE FROM FSU TANK TO COMPRESSOR	N/A	47.672	5720.64	3444.51	N/A	3444.51	N/A		N/A	N/A	N/A	49
B11	COMPRESSOR	N/A	1.49	N/A	N/A	N/A	N/A	N/A		N/A	N/A	N/A	49
B12	PIPELINE FROM COMPRESSOR TO FSU LIQUIFIER - DISCHARGE	N/A	33.48	N/A	N/A	N/A	N/A	N/A	Pipeline length input data has been modified to be realistic with the compressor operability	N/A	N/A	N/A	33
B12	PIPELINE FROM FSU BOC TO FSU LIQUIFIER - DISCHARGE	N/A	1.49	N/A	N/A	N/A	N/A	N/A	Pipeline length input data has been modified to be realistic with the compressor operability	N/A	N/A	N/A	1.5

LIST OF SCENARIO'S CONSEQUENCES													
ITEM	EQUIPMENT	VAPORIZATION (%)	MASS FLOW RELEASE (kg/s)	MASS (kg)	VOLUME (m^3)	PIPELINE SECTION MASS (m^3)	TOTAL VOLUME RELEASED (m^3)	POOL FIRE AREA (m^2)	REMARKS	POOL FIRE AREA (m2)	EVAPORATION AREA (m2)	EVAPORATION TIME (s)	FLAMMABLE DISPERSION (kg/s)
B13	PIPELINE FROM FSU LIQUIFIER TO FSU TANK	100	9.15	13,479	31.95	0	31.94	2,206	Pipeline length input data has been modified to be realistic with the compressor operability	Confined	2,206	1,800	9.15
Option C													
C01.a	GAS TANKER (RELEASE ON WATER)	99	926	1.09E+07	35,000	N/A	0.00	10,000	Hole height 10.15 m	10,000	10,000	1,800	732
C01.b	GAS TANKER (RELEASE ON WATER)	99	1,769	1.09E+07	35,000	N/A	0.00	10,000	Hole height 10.15 m	10,000	10,000	1,800	856
C02.a	GAS TANKER TO FSRU UNLOADING ARM - LNG (RELEASE ON WATER)	100	1,407	168800	400	0	400	29,050	Unconfined	Unconfined	10,000	1,800	166
C02.b	GAS TANKER TO FSRU UNLOADING ARM - LNG (RELEASE ON WATER)	100	94	11253	26.67	0	26.67	1,364	Unconfined	1,364	1,364	1800	41
C03.a	GAS TANKER UNLOADING ARM - GAS RETURN TO GAS TANKER	N/A	18.60		0	N/A		N/A		N/A	N/A	N/A	18.6
C03.b	GAS TANKER UNLOADING ARM - GAS RETURN TO GAS TANKER	N/A	0.25		0	N/A		N/A		N/A	N/A	N/A	0.25
C04	PIPELINE FROM FSRU TANK TO FSRU SECONDARY PUMP - SUCTION	100	218	1.23E+05	2.90E+02	N/A	290.38	29037.92		1,500	1,500	1,800	66
C05	FSRU SECONDARY PUMP	100	217.35	3.64E+06	8.62E+03	N/A	8617.30	861729.86		1,500	1,500	1,800	49
C06	PIPELINE FROM FSRU SECONDARY PUMP TO FSRU RU - DISCHARGE	100	539.25	970650	2300.12	0	2300.12	230011.84	Limited	1,500	1,500	1,800	53
C07	FSRU REGASIFICATION UNIT (RU)	100	12.80	1536	924.86	0	924.86	N/A		1,500	1,500	1,800	1,848
C08.a	FSRU UNLOADING ARM TO METERING STATION - GAS	N/A	188.45	22614	13616.33	N/A	13616.33	N/A		N/A	N/A	N/A	580
C08.b	FSRU UNLOADING ARM TO METERING STATION - GAS	N/A				N/A	0.00	N/A		N/A	N/A	N/A	37
C09	PIPELINE FROM FSRU RU TO GAS METERING STATION	N/A	188.45	22614	13616.33	N/A	13616.33	N/A		N/A	N/A	N/A	189
C10	PIPELINE FROM FSU TANK TO COMPRESSOR	N/A	47.672	5720.64	3444.51	N/A	3444.51	N/A		N/A	N/A	N/A	49
C11	FSU BOC	N/A	1.49	N/A	N/A	N/A	N/A	N/A		N/A	N/A	N/A	49
C12	PIPELINE FROM FSU COMPRESSOR TO FSU LIQUIFIER - DISCHARGE	N/A	33.48	N/A	N/A	N/A	N/A	N/A	Pipeline length input data has been modified to be realistic with the compressor operability	N/A	N/A	N/A	33
C12	PIPELINE FROM FSU COMPRESSOR TO FSU LIQUIFIER - DISCHARGE	N/A	1.49	N/A	N/A	N/A	N/A	N/A	Pipeline length input data has been modified to be realistic with the compressor operability	N/A	N/A	N/A	1.5

LIST OF SCENARIO'S CONSEQUENCES													
ITEM	EQUIPMENT	VAPORIZATION (%)	MASS FLOW RELEASE (kg/s)	MASS (kg)	VOLUME (m^3)	PIPELINE SECTION MASS (m^3)	TOTAL VOLUME RELEASED (m^3)	POOL FIRE AREA (m^2)	REMARKS	POOL FIRE AREA (m2)	EVAPORATION AREA (m2)	EVAPORATION TIME (s)	FLAMMABLE DISPERSION (kg/s)
C13	100	9.15	13,479	31.95	0	31.94	2206	Pipeline length input data has been modified to be realistic with the compressor operability		2206	1,800	9.15	100

10. ESTIMATION OF LIKELIHOOD

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 [24] [21] and have been adapted to the period of use of the facilities, especially in the case of the LNG unloading facilities.

10.1. IMPACT FREQUENCY OF MANOEUVRING SHIPS ON LNG TANKER OR FSU/FSRU

The impact frequency cannot be directly extracted from bibliographical sources, but should be estimated depending on surrounding conditions.

From the data presented in chapter 2.7, and depending on manoeuvring routes, the probability of impact can be estimated, considering the following general topics:

- Impact between two manoeuvring ships
- Impact between a manoeuvring ship and a moored ship
- Impact of a ship due to grounding
- Impact of moored ship with the jetty or dock

Also, the final results of an impact can be associated with the gross weight of the moving ship and its velocity. The higher the weight and the velocity at the moment of the impact, the larger the size of the hole would be in the affected tanker. Generally, operation in a port area can be subdivided by ship classes according to the naval register. Also, manoeuvring velocity is limited by port pilots according to the ship class. Thus, from the general statistic, percentage of each class presence can be extracted. For the Marsaxlokk Bay, the data is not disaggregated and the manoeuvring routes are not available, so that the impact frequency is only a first and overestimated approach to the real impact frequency.

The calculation of the frequency was done on the following basis:

TYPE OF DATA	External impact on moored LNG tanker (all options)	External impact on moored FSU / FSRU
Impact probability per visit [34]	5,00E-05	5,00E-05
Release probability in case of major accident [34], [22]	1,20E-04	1,20E-04
Release probability in case of minor accident [34], [22]	2,50E-02	2,50E-02
Moored ships presence per year	1,11E+02	8,76E+03
Maneuvering ships per year	2150	2150
Total impact probability (impact probability per number of maneuvering ships)	1,08E-01	1,08E-01
Total release frequency due to a major impact	1,63E-07	1,29E-05
Total release frequency due to a minor impact	3,41E-05	3,41E-05

The final data must be considered as an overestimation of the frequency, because all passing ships are considered sensitive for an impact, while most of them are manoeuvring close to Freeport and their routes are not compatible with a collision on the moored LNG tanker or FSU/FSRU, even in case of engine failure, propeller failure, mooring rope breakage, etc.

10.2. 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 chapter 8. In the case of natural gas, the probability of each final event scenario depends on the ignition frequency.

The ignition frequency is considered to be 0.065 for immediate ignition and variable depending on the release rate for delayed ignition and for a low reactivity gas, such as methane, as shown in the following table [22].

Release rate	Frequency	Value
<10Kg/s	Delayed Ignition Small	0.02
10-100 Kg/s	Delayed Ignition Medium	0.04
>100 kg/s	Delayed Ignition Large	0.09

10.3. EVENT TREES

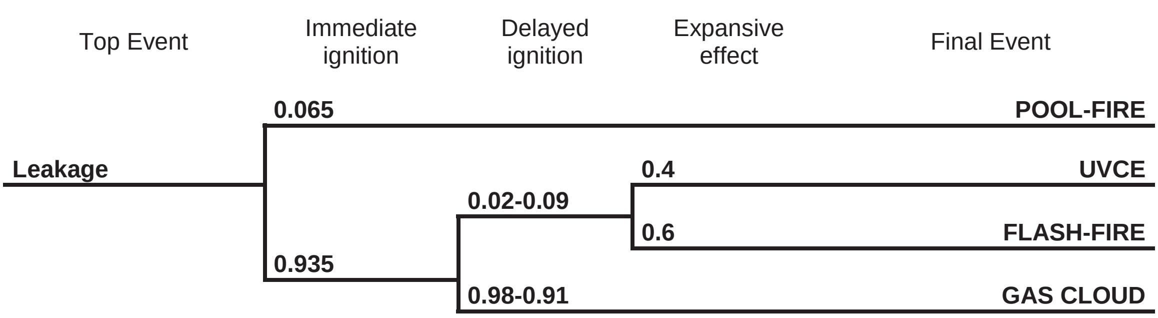
Starting from the literature, the goal is to quantify the probability of events that determine the evolution from the initial event and end up causing damage. This can be done by using the event tree technique.

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.

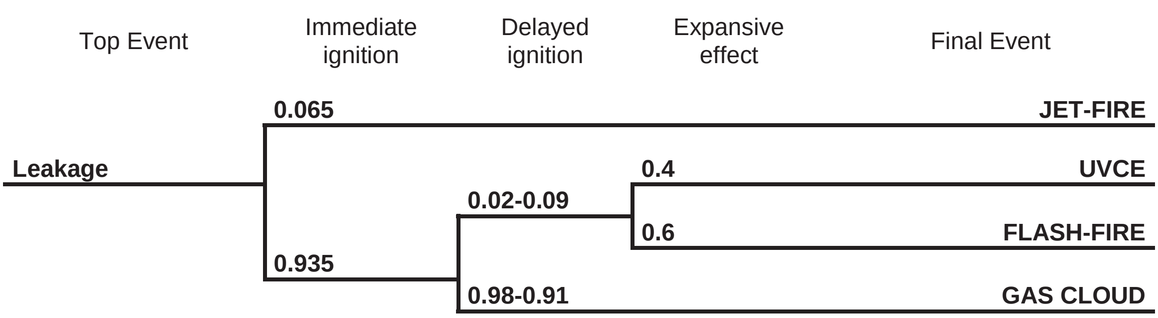
From the initial failure or initiator and considering the conditioning factors involved, the tree describes the accident sequences leading to possible events. The construction and evaluation of the tree begins by identifying the conditions and their probabilities of occurrence of each of them.

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.

Event tree for liquid release (LNG)



Event tree for gas release (GAS PHASE)



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

LIST OF SCENARIO'S FREQUENCIES										
ITEM	EQUIPMENT	FAILURE FREQUENCY	UNITS	OPERATING HOURS	UNITS	WEIGHTED FREQUENCY	UNITS	POOL FIRE / JET FIRE FREQUENCY	FLASH FIRE FREQ	REMARKS
Option A										
A01.a	GAS TANKER (RELEASE ON WATER)	1.63E-07	-	-	-	1.63E-07	-	1.06E-08	1.38E-08	Related: impacts/visits
A01.b	GAS TANKER (RELEASE ON WATER)	3.41E-05	-	-	-	3.41E-05	-	6.37E-07	2.87E-06	Related: impacts/visits
A02.a	GAS TANKER UNLOADING ARM - LNG (RELEASE ON WATER)	1.30E-05	h^{-1}	111	h	1.65E-07	y^{-1}	1.07E-08	1.39E-08	Total failure rate when 2 arms used
A02.b	GAS TANKER UNLOADING ARM - LNG (RELEASE ON WATER)	1.60E-05	h^{-1}	111	h	2.03E-07	y^{-1}	1.32E-08	7.58E-09	Total failure rate when 2 arms used
A03.a	GAS TANKER LOADING ARM - GAS RETURN TO GAS TANKER	7.00E-06	h^{-1}	111	h	8.87E-08	y^{-1}	5.77E-09	1.66E-09	Total failure rates when one arm used
A03.b	GAS TANKER LOADING ARM - GAS RETURN TO GAS TANKER	8.00E-06	h^{-1}	111	h	1.01E-07	y^{-1}	6.59E-09	1.90E-09	Total failure rates when one arm used
A04	PIPELINE FROM GAS TANKER TO SHORE (RELEASE ON WATER)	6.50E-09	$m \cdot y^{-1}$	111	h	7.70E-08	y^{-1}	5.01E-09	6.48E-09	Pipeline diameter > 110 mm
A05	PIPELINE FROM SHORE TO GAS TANKER - GAS RETURN TO GAS TANKER	6.50E-09	$m \cdot y^{-1}$	111	h	7.70E-08	y^{-1}	5.01E-09	1.44E-09	Pipeline diameter > 110 mm
A06.a	LNG GROUND TANK	5.00E-08	y^{-1}	8,760	h	5.00E-08	y^{-1}	3.25E-09	4.21E-09	CATASTROPHIC FAILURE - FULL CONTAINMENT TANK
A06.b	LNG GROUND TANK	1.00E-06	y^{-1}	8,760	h	1.00E-06	y^{-1}	6.50E-08	8.42E-08	1000 mm diameter hole-FULL CONTAINMENT TANK

LIST OF SCENARIO'S FREQUENCIES										
ITEM	**EQUIPMENT**	**FAILURE FREQUENCY**	**UNITS**	**OPERATING HOURS**	**UNITS**	**WEIGHTED FREQUENCY**	**UNITS**	**POOL FIRE / JET FIRE FREQUENCY**	**FLASH FIRE FREQ**	**REMARKS**
A06.c	LNG GROUND TANK	3.00E-06	y^{-1}	8,760	h	3.00E-06	y^{-1}	1.95E-07	2.52E-07	300 mm diameter hole- FULL CONTAINMENT TANK
A07	PIPELINE FROM GROUND TANK TO SECONDARY PUMP - SUCTION	6.50E-09	$m \cdot y^{-1}$	8,760	h	1.98E-06	y^{-1}	1.28E-07	7.39E-08	PIPELINE DIAMETER > 110 mm
A08	SECONDARY PUMP	3.00E-05	pump-1·y-1	8,760	h	3.00E-05	y^{-1}	1.95E-06	7.57E-06	
A09	PIPELINE FROM SECONDARY PUMP TO RU - DISCHARGE	6.50E-09	$m \cdot y^{-1}$	8,760	h	1.72E-07	y^{-1}	1.12E-08	1.45E-08	PIPELINE DIAMETER > 110 mm
A10	REGASIFICATION UNIT (RU)	1.00E-06	y-1	8,760	h	1.00E-06	y^{-1}	1.30E-07	1.68E-07	Table 38 Scenarios for pipe heat exchangers where the hazardous substance is located inside the pipes and where the casing has a design pressure that is greater than or equal to the maximum pressure of the hazardous substance occurring in the pipe
A11	PIPELINE FROM RU TO GAS METERING STATION	6.50E-09	$m \cdot y^{-1}$	8,760	h	1.72E-07	y^{-1}	1.12E-08	1.45E-08	PIPELINE DIAMETER > 110 mm
A12	PIPELINE FROM GROUND TANK TO COMPRESSOR	6.50E-09	$m \cdot y^{-1}$	8,760	h	1.98E-06	y^{-1}	1.28E-07	7.39E-08	PIPELINE DIAMETER > 110 mm
A13	COMPRESSOR (BOIL-OFF COMPRESSOR)	2.90E-06	compr·y-1	8,760	h	2.90E-06	y^{-1}	1.89E-07	5.42E-08	
A14	PIPELINE FROM BOC TO LIQUIFIER - DISCHARGE	6.50E-09	$m \cdot y^{-1}$	8,760	h	1.89E-07	y^{-1}	1.23E-08	7.05E-09	PIPELINE DIAMETER > 110 mm

LIST OF SCENARIO'S FREQUENCIES										
ITEM	EQUIPMENT	FAILURE FREQUENCY	UNITS	OPERATING HOURS	UNITS	WEIGHTED FREQUENCY	UNITS	POOL FIRE / JET FIRE FREQUENCY	FLASH FIRE FREQ	REMARKS
A14	PIPELINE FROM BOC TO LIQUIFIER - DISCHARGE	6.50E-09	$m \cdot y^{-1}$	8,760	h	1.63E-04	y^{-1}	1.06E-05	3.04E-06	PIPELINE DIAMETER > 110 mm
A15	PIPELINE FROM LIQUIFIER TO GROUND TANK	6.50E-09	$m \cdot y^{-1}$	8,760	h	1.98E-06	y^{-1}	1.28E-07	3.70E-08	PIPELINE DIAMETER > 110 mm
Option B										
B01.a	GAS TANKER (RELEASE ON WATER)	1.63E-07	-	-	-	1.63E-07	-	1.06E-08	1.38E-08	Related: impacts/visits
B01.b	GAS TANKER (RELEASE ON WATER)	3.41E-05	-	-	-	3.41E-05	-	6.37E-07	2.87E-06	Related: impacts/visits
B02.a	GAS TANKER TO FSU UNLOADING ARM - LNG (RELEASE ON WATER)	1.90E-05	h-1	111	h	2.41E-07	y-1	1.56E-08	2.03E-08	Total failure rate when 3 arms used
B02.b	GAS TANKER TO FSU UNLOADING ARM - LNG (RELEASE ON WATER)	2.40E-05	h-1	111	h	3.04E-07	y-1	1.98E-08	1.14E-08	Total failure rate when 3 arms used
B03.a	FSU UNLOADING ARM - LNG (RELEASE ON WATER)	1.30E-05	h-1	8,760	h	1.30E-05	y-1	8.45E-07	1.09E-06	Total failure rate when 2 arms used
B03.b	FSU UNLOADING ARM - LNG (RELEASE ON WATER)	1.60E-05	h-1	8,760	h	1.60E-05	y-1	1.04E-06	5.98E-07	Total failure rate when 2 arms used
B04.a	GAS TANKER UNLOADING ARM - GAS RETURN TO GAS TANKER	7.00E-06	h-1	8,760	h	7.00E-06	y-1	4.55E-07	1.31E-07	Total failure rates when one arm used
B04.b	GAS TANKER UNLOADING ARM - GAS RETURN TO GAS TANKER	8.00E-06	h-1	8,760	h	8.00E-06	y-1	5.20E-07	1.50E-07	Total failure rates when one arm used

LIST OF SCENARIO'S FREQUENCIES										
ITEM	**EQUIPMENT**	**FAILURE FREQUENCY**	**UNITS**	**OPERATING HOURS**	**UNITS**	**WEIGHTED FREQUENCY**	**UNITS**	**POOL FIRE / JET FIRE FREQUENCY**	**FLASH FIRE FREQ**	**REMARKS**
B05	PIPELINE FROM FSU TANK TO SECONDARY PUMP - SUCTION (RELEASE ON WATER)	6.50E-09	m·y-1	8,760	h	1.98E-06	y-1	1.28E-07	7.39E-08	PIPELINE DIAMETER > 110 mm
B06	SECONDARY PUMP	3.00E-05	pump-1·y-1	8,760	h	3.00E-05	y-1	5.85E-06	7.57E-06	
B07	PIPELINE FROM SECONDARY PUMP TO RU - DISCHARGE	6.50E-09	m·y-1	8,760	h	1.72E-07	y-1	1.12E-08	1.45E-08	Pipeline diameter > 110 mm
B08	REGASIFICATION UNIT (RU)	1.00E-06	y-1	8,760	h	1.00E-06	y-1	6.50E-08	8.42E-08	Table 38 Scenarios for pipe heat exchangers where the hazardous substance is located inside the pipes and where the casing has a design pressure that is greater than or equal to the maximum pressure of the hazardous substance occurring in the pipe
B09	PIPELINE FROM RU TO GAS METERING STATION	6.50E-09	m·y-1	8,760	h	1.72E-07	y-1	1.12E-08	1.45E-08	Pipeline diameter > 110 mm
B10	PIPELINE FROM FSU TANK TO COMPRESSOR	6.50E-09	m·y-1	8,760	h	5.52E-06	y-1	3.59E-07	2.06E-07	Pipeline diameter > 110 mm
B11	COMPRESSOR	2.90E-06	compr·y-1	8,760	h	2.90E-06	y-1	1.89E-07	5.42E-08	
B12	PIPELINE FROM COMPRESSOR TO FSU LIQUIFIER - DISCHARGE	6.50E-09	m·y-1	8,760	h	1.43E-07	y-1	9.30E-09	5.35E-09	Pipeline diameter > 110 mm
B12	PIPELINE FROM FSU BOC TO FSU LIQUIFIER - DISCHARGE	6.50E-09	m·y-1	8,760	h	1.43E-07	y-1	9.30E-09	2.67E-09	Pipeline diameter > 110 mm

LIST OF SCENARIO'S FREQUENCIES

ITEM	EQUIPMENT	FAILURE FREQUENCY	UNITS	OPERATING HOURS	UNITS	WEIGHTED FREQUENCY	UNITS	POOL FIRE / JET FIRE FREQUENCY	FLASH FIRE FREQ	REMARKS
B13	PIPELINE FROM FSU LIQUIFIER TO FSU TANK	6.50E-09	m·y-1	8,760	h	5.52E-06	y-1	3.59E-07	1.03E-07	Pipeline diameter > 110 mm
Option C										
C01.a	GAS TANKER (RELEASE ON WATER)	1.63E-07	-	-	-	1.63E-07	-	1.06E-08	1.38E-08	Related: impacts/visits
C01.b	GAS TANKER (RELEASE ON WATER)	3.41E-05	-	-	-	3.41E-05	-	6.37E-07	2.87E-06	Related: impacts/visits
C02.a	GAS TANKER TO FSRU UNLOADING ARM - LNG (RELEASE ON WATER)	1.90E-05	h-1	111	h	2.41E-07	y-1	1.56E-08	2.03E-08	Total failure rate when 3 arms used
C02.b	GAS TANKER TO FSRU UNLOADING ARM - LNG (RELEASE ON WATER)	2.40E-05	h-1	111	h	3.04E-07	y-1	1.98E-08	1.14E-08	Total failure rate when 3 arms used
C03.a	GAS TANKER UNLOADING ARM - GAS RETURN TO GAS TANKER	7.00E-06	h-1	111	h	8.87E-08	y-1	5.77E-09	1.66E-09	Total failure rates when one arm used
C03.b	GAS TANKER UNLOADING ARM - GAS RETURN TO GAS TANKER	8.00E-06	h-1	111	h	1.01E-07	y-1	6.59E-09	1.90E-09	Total failure rates when one arm used
C04	PIPELINE FROM FSRU TANK TO FSRU SECONDARY PUMP - SUCTION	6.50E-09	m·y-1	8,760	h	1.98E-06	y-1	1.28E-07	7.39E-08	Pipeline diameter > 110 mm
C05	FSRU SECONDARY PUMP	3.00E-05	pump-1·y-1	8,760	h	3.00E-05	y-1	1.95E-06	2.52E-06	
C06	PIPELINE FROM FSRU SECONDARY PUMP TO FSRU RU - DISCHARGE	6.50E-09	m·y-1	8,760	h	2.34E-07	y-1	1.52E-08	1.97E-08	Pipeline diameter > 110 mm

LIST OF SCENARIO'S FREQUENCIES										
ITEM	EQUIPMENT	FAILURE FREQUENCY	UNITS	OPERATING HOURS	UNITS	WEIGHTED FREQUENCY	UNITS	POOL FIRE / JET FIRE FREQUENCY	FLASH FIRE FREQ	REMARKS
C07	FSRU REGASIFICATION UNIT (RU)	1.00E-06	y-1	8,760	h	1.00E-06	y-1	6.50E-08	8.42E-08	Table 38 Scenarios for pipe heat exchangers where the hazardous substance is located inside the pipes and where the casing has a design pressure that is greater than or equal to the maximum pressure of the hazardous substance occurring in the pipe
C08.a	FSRU UNLOADING ARM TO METERING STATION - GAS	1.30E-05	h-1	8,760	h	1.30E-05	y-1	8.45E-07	2.43E-07	Total failure rate when 2 arms used
C08.b	FSRU UNLOADING ARM TO METERING STATION - GAS	1.60E-05	h-1	8,760	h	1.60E-05	y-1	1.04E-06	1.35E-06	Total failure rate when 2 arms used
C09	PIPELINE FROM FSRU RU TO GAS METERING STATION	6.50E-09	m·y-1	8760	h	6.55E-06	y-1	4.26E-07	5.51E-07	Pipeline diameter > 110 mm
C10	PIPELINE FROM FSU TANK TO COMPRESSOR	6.50E-09	m·y-1	8,760	h	6.50E-09	y-1	4.23E-10	2.43E-10	Pipeline diameter > 110 mm
C11	FSU BOC	2.90E-06	compr·y-1	8,760	h	2.90E-06	y-1	1.89E-07	5.42E-08	Compressor
C12	PIPELINE FROM FSU COMPRESSOR TO FSU LIQUIFIER - DISCHARGE	6.50E-09	m·y-1	8,760	h	2.34E-07	y-1	1.52E-08	8.75E-09	Pipeline diameter > 110 mm
C12	PIPELINE FROM FSU COMPRESSOR TO FSU LIQUIFIER - DISCHARGE	6.50E-09	m·y-1	8,760	h	0.0001625	y-1	1.06E-05	3.04E-06	Pipeline diameter > 110 mm
C13	PIPELINE FROM FSU LIQUIFIER TO FSU TANK	6.50E-09	m·y-1	8,760	h	1.83E-06	y-1	1.19E-07	6.86E-08	Pipeline diameter > 110 mm

11. PRESENTATION OF RESULTING RISK AND COMPARISON WITH ESTABLISHED TOLERABILITY CRITERIA

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 for each option is shown in drawing #7, 8 and 9 attached in Annex 1.

The risk contours must be drawn in accordance with HSA criteria for the boundaries of the inner, middle and outer LUP zones as [16]:

- 10^{-5} / year : risk of fatality for Inner Zone (Zone 1) boundary.
- 10^{-6} / year: risk of fatality for Middle Zone (Zone 2) boundary.
- 3×10^{-7} / year: risk of fatality for Outer Zone (Zone 3) boundary.

As can be easily noticed, there is no incompatibility between the projected terminal and the land use planning.

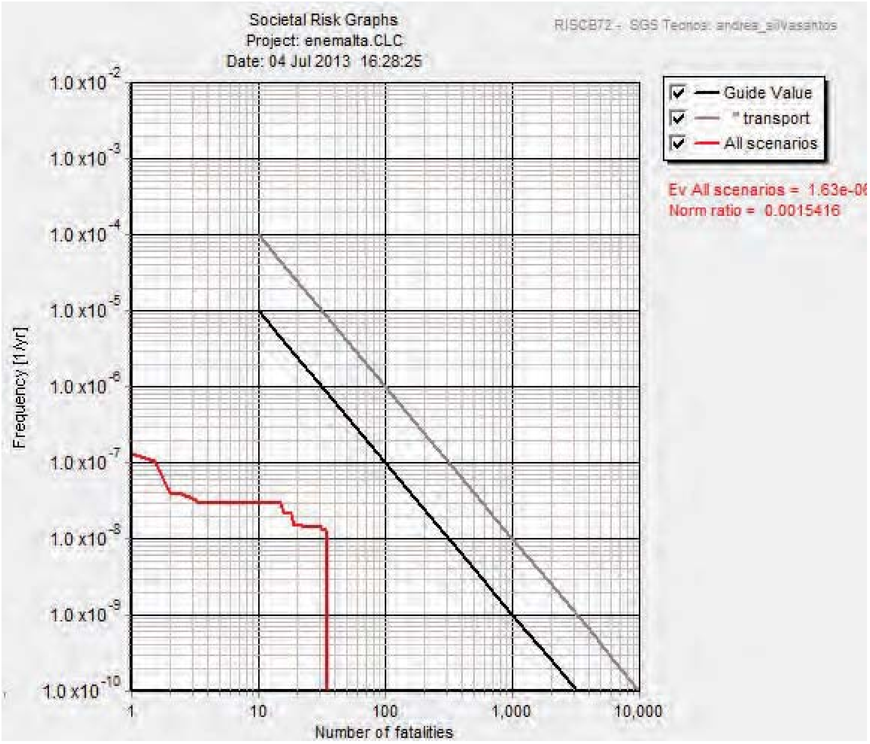
Also, the societal risk calculation has been performed, considering the resident population plus the possible presence of people in touristic zones, such as the Fort Delimara, the beaches, etc.

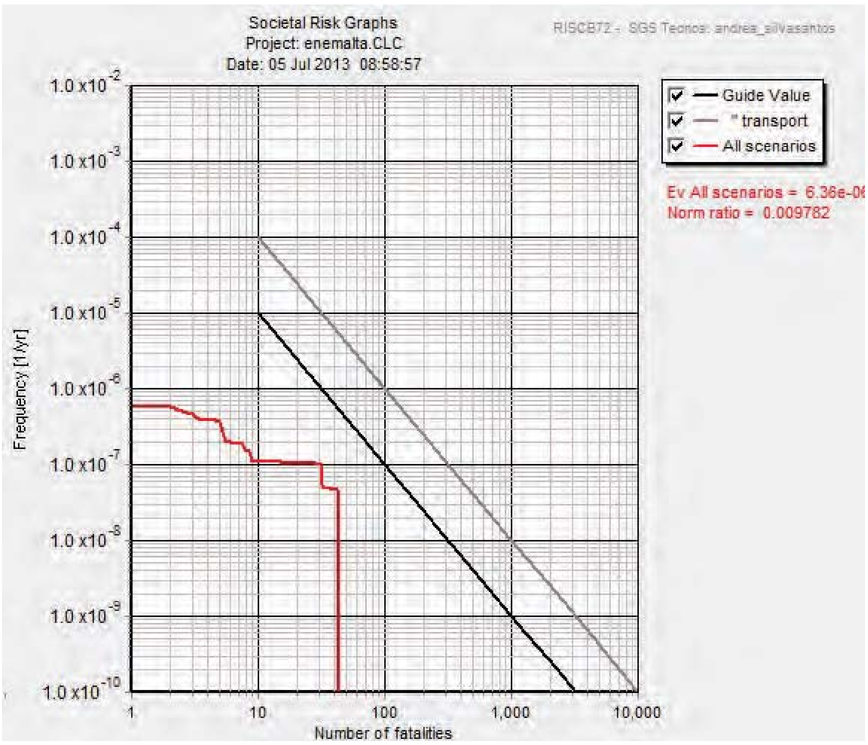
Societal risk is defined [35] [36] as the relationship between frequency and the number of people suffering from a specified level of harm in a given population from the realization of specified hazards [36]. Societal risk evaluation is concerned with estimation of the chances of more than one individual 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.

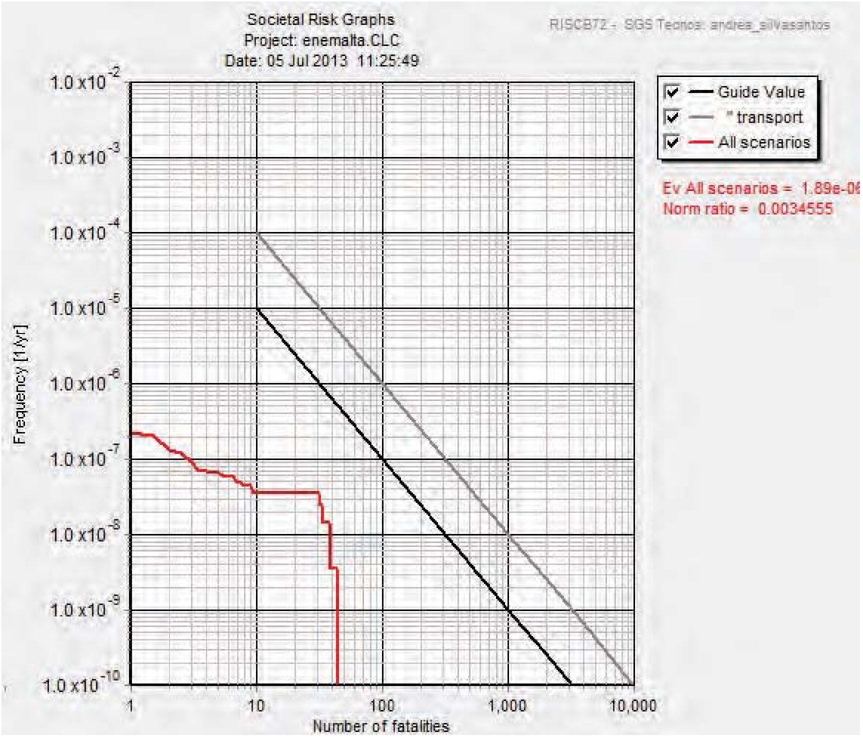
Societal risk is dependent on the risks from the substances and processes located on a major hazard installation. A key factor in estimating societal risk is the population around the site, in particular its location and density.

Societal risk can be represented by FN curves [22], which are plots of the cumulative frequency (F) of various accident scenarios against the number (N) of casualties associated with the modeled 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 curves are shown in the following figures for three options.







Additionally, following Maltese legislation [35], the "applications for new hazardous installations will be approved only if they:

a) will have no harmful or adverse impact on the environment due to the inherent hazardous nature of the installation or on existing or proposed adjoining land uses;
b) are located so as to ensure adequate separation from other uses, including residential areas, areas of public use and areas of particular natural sensitivity or interest, so as to guarantee safety and amenity;
c) are located so as to ensure adequate separation from other hazardous installations, to minimise the likelihood of the exacerbation of the consequences of a major accident;
d) comply with other relevant Structure Plan and Local Plan policies.

Proposals for development at existing hazardous installations which involves the addition of new dangerous substances or an increase in the quantity of existing dangerous substances will be assessed against the criteria set out above."

According to the performed calculations, all requirements can be considered as fulfilled by the three options.

12. OTHER CRITERIA FOR RISK MINIMISATION

Addition to the findings shown in the previous chapter, other criteria should be considered in order to choose the suitable option for minimising the risk over the population and the surroundings.

Even if the frequencies for a pipe or vessel failure, and therefore, for an LNG leakage are reduced, and the final risk contour is acceptable, the tremendous difference is between a leakage without damages and the ignition of the same leakage must be considered as a decisive factor. Focusing the attention on the event tree shown in chapter 10.3, it's easy to perceive how significant the difference between the dispersion of the gas cloud without any final effect and the immediate or delayed ignition, which can eventually lead to an explosion.

Thus, in this chapter a selection of the maximum extension of the calculated gas clouds is made, based on the maximum length and the frequency of the top event. Scenarios with a frequency below 1E-09 are discarded. The results are shown in the following tables. Also, the final contour resulting from the overlap of all the selected distances from their release point, is presented for each option in drawings #10, 11 and 12.

Gas cloud extensions					
ITEM	**FREQUENCY**	**UTM X**	**UTM Y**	**DISTANCE**	**REMARKS**
Option A					
A01.a	--	459,669	3,965,013	129	
A01.b	--	459,669	3,965,013	133	
A01.c	--	459,669	3,965,013	138	
A02.a	1.30E-05	459,692	3,695,026	523	
A02.b	1.60E-05	459,692	3,695,026	320	
A03.a	7.00E-06	459,692	3,695,026	150	
A03.b	8.00E-06	459,692	3,695,026	13	
A04	6.50E-09	pipeline		720	Discarded
A05	6.50E-09	pipeline		33	Discarded
A06.a	5.00E-08	459,834	3,965,215	276	
A06.b	1.00E-06	459,834	3,965,215	307	
A06.c	3.00E-06	459,834	3,965,215	219	
A07	6.50E-09	pipeline		183	Discarded
A08	3.00E-05	459,872	3,965,269	192	
A09	6.50E-09	pipeline		120	Discarded
A10	1.00E-06	459,858	3,965,297	558	
A11	6.50E-09	pipeline		358	Discarded
A12	6.50E-09	pipeline		--	Discarded
A13	2.90E-06	459,858	3,965,298	32	

Gas cloud extensions – Option B

Gas cloud extensions					
ITEM	FREQUENCY	UTM X	UTM Y	DISTANCE	REMARKS
B01.a	--	459,605	3,964,999	129	
B01.b	--	459,605	3,964,999	133	
B01.c	--	459,605	3,964,999	138	
B02.a	1.90E-05	459,626	3,964,995	523	
B02.b	2.40E-05	456,626	3,964,995	320	
B03.a	1.30E-05	456,693	3,965,024	962	
B03.b	1.60E-05	456,693	3,965,024	36	
B04.a	7.00E-06	456,626	3,964,995	150	
B04.b	8.00E-06	456,626	3,964,995	13	
B05	6.50E-09	pipeline		--	Discarded
B06	3.00E-05	459,799	3,965,197	192	
B07	6.50E-09				Discarded
B08	1.00E-06	459,797	3,965,217	558	
B09	6.50E-09	pipeline		---	Discarded
B10	6.50E-09	pipeline		--	Discarded
B11	2.90E-06	459,799	3,965,236	32	
B12	6.50E-09	pipeline		--	Discarded
B13	6.50E-09	pipeline		--	Discarded
Gas cloud extensions – Option C					
C01.a	--	459,605	3,964,994	129	
C01.b	--	459,605	3,964,994	133	
C01.c	--	459,605	3,964,994	138	
C02.a	1.90E-05	459,628	3,965,003	523	
C02.b	2.40E-05	459,628	3,965,003	320	
C03.a	7.00E-06	459,628	3,965,003	150	
C03.b	8.00E-06	459,628	3,965,003	13	
C04	6.50E-09	459,704	3,964,887	183	
C05	3.00E-05	459,700	3,964,898	558	
C06	6.50E-09	Pipeline		--	Discarded
C07	1.00E-06	459,700	3,964,898	558	
C08.a	1.30E-05	459,687	3,965,030	962	
C08.b	1.60E-05	459,687	3,965,030	36	
C09	6.50E-09	Pipeline		--	Discarded
C10	6.50E-09	Pipeline		--	Discarded
C11	2.90E-06	459,708	3,964,877	32	
C12	6.50E-09	Pipeline		--	Discarded
C13	6.50E-09	Pipeline		--	Discarded

The analysis of the drawing shows that for options B and C, there's an extremely large gas cloud, which cannot be discarded by frequency. This is associated with the unloading arm, permanently connected between the floating unit and the onshore plant. For option B, this gas cloud proceeds from a pool of LNG spilled onto the water due to the failure of the unloading arm connecting the FSU to the onshore RU, while for option C, the gas cloud proceeds from the leaking unloading arm delivering the regasified natural gas from the FSRU.

Both situations can be easily limited adopting special technologies not normally adopted for unloading arms (hence the high frequency), limiting the extension of a pool in case of LNG spillage or implementing a hydro-shield system around the area which disperses and dilutes the flammable cloud. Thus this extremely large cloud can be discarded from the generation of the final contour.

With the remaining contours, it's easy to see how a flammable gas cloud can rapidly travel from the release point to some part of the Delimara peninsula or to the existing Delimara Power Station. Specially in the DPS, a large number of different ignition points would be present, so that ignition in this zone is almost certain.

In order to reduce the possibility of an ignition, the whole plant (for Option C) or part of it (for Option B), can be relocated and the distance between the release point and the possible ignition point can be increased.

Drawing # 13 shows the suggested position for the unloading arm of the permanently moored FSU or FRSU. The unloading arm has been chosen as the central point of any FSU/FRSU installation and the origin of the major spillage of LNG: The red contour is the maximum distance at which a cloud of gas can travel with a concentration higher than the lower flammability limit. The aim of this drawing is to suggest (in green in the drawing) a position for the jetty which ensures that no ignition point is found in the range of the cloud. This can easily be done for the existing facilities, the Freeport and the rest of the bay. The only ignition points which cannot be avoided are those in the Delimara peninsula and passing boats in the harbour. Also, in case of ignition, the flash fire would be limited to the water surface and south of Delimara peninsula, reducing the damage to the population and the DPS, which must be protected against any possible flash-fire, being the main power plant on the island.

Regarding the presence of a dolphin, used for fuel unloading to onshore facilities, it can be kept in place if the jetty is located on east side of the part marked in red, otherwise have to be removed in order to reduce the possibility of a collision or spillage from other tankers affecting the LNG tanker. Also, the unloading operation at existing the dock in DPS is out of the red contour and is not affected nor affecting.

13. CONCLUSIONS

A preliminary quantitative risk assessment (QRA) of the proposed LNG terminal to be located in the Marsaxlokk Bay has been carried out. Results for the three proposed options have been calculated, in accordance with the current HSA criteria. The following results have been obtained:

- individual risk contours;
- societal risk FN curves;
- maximum extension of the gas clouds.

The findings drawn from the results are as follows:

- The three options proposed, as well as the three layouts, have been engineered as a first approach specifically for carrying out the quantitative risk assessment. They are based on general and open assumptions. The solution finally adopted could significantly vary according to engineering criteria adopted by the contractor. Obviously, the layout must be decided according to geological and nautical limitations and could be completely different from the proposed one, especially in reference to the position of the jetty and the on-shore regasification unit.
- There is no incompatibility between the land use and the presence of an LNG terminal in the Delimara peninsula;
- In case of accident, the number of fatalities is acceptable, if compared with acceptance criteria used in other European Countries with a large tradition of quantitative risk assessment;
- The comparison between the three options using the risk contours (drawing # 7, 8 and 9), shows that option A presents the largest individual risk to some of the scattered houses near the Delimara Power Station. Option C seems to be the better option in order to minimize the risk to the population. Option B can also be taken into account if the regasification unit is relocated as far as possible from the Power Station and as close as possible to the unloading facilities.
- The comparison between the three options using the extension of the gas cloud contour (drawing # 10, 11 and 12), clearly demonstrates that for the three options a flammable gas cloud can travel to the Delimara Power Station and easily find an ignition point, there with devastating effects on the Maltese power system.

- However, it must be considered that the analyzed layouts were designed for a first approach on risk assessment, and are not definitive. The possibility to locate both options B and C in the inner part of the harbour (drawing #13) has been taken into account and a suitable location for the jetty is presented in order to remove most of the possible flash-fires which may be generated from the ignition of the flammable gas cloud. Otherwise, technical solution for minimization of flammable gas cloud can be adopted, as well as solution for the removal of ignition points in the surrounding, such as adoption of ATEX equipment in nearby DPS.

The ultimate conclusion is that a FSRU (Option C) or a FSU plus a RU (Option B), if located in the recommended zone (shown in drawing #13), is the preferred choice in order to minimize the individual risk to the population as well as to minimise the damage to the Delimara Power Station in case of flash-fire. However, the client has to take into account that the suggested position may be not suitable if analysed from a nautical point of view: In fact the FSRU or FSU would be located closer to the mouth of the harbour, increasing the probabilities of a collision with a manoeuvring ship or for damage in the FSRU or FSU itself due to high waves, storms and other atmospheric phenomena, against which the tanker would not be protected. In order to define the optimum location in the harbour, balancing (1) the facilities inherent risk, (2) the nautical collision risk and (3) the meteorological risk, is highly recommended to perform a nautical risk assessment (for #2) as well as a harbour risk assessment (for #3).

Also, the solution finally adopted must be submitted to a detailed quantitative risk assessment, and final risk of the installation must be proven and eventually reduced to meet the conclusions of this preliminary study.

14. REFERENCES

[1] Process Description Statement.

[2] C. Galdies, The climate of Malta: statistics, trends and analysis 1951-2011, National Statistics Office, Malta.

[3] "Malta National Focal Point," EMWIS: Euro-Mediterranean Information System on know-how in the Water sector, [Online]. Available: http://www.emwis-mt.org/documentation/context/physical%20factors_files/Geology.htm. [Accessed June 2013].

[4] P. Galea, "Seismic history of the Maltese islands and considerations on seismic risk," *Annals of Geophysics,* vol. 50, no. 6, pp. 725-740, December 2007.

[5] EN 1473 (2007): Installation and Equipment for Liquefied Natural Gas - Design of Onshore Installations, 2007.

[6] "NFPA 59AS: Standard for the Production, Storage, and Handling of Liquefied Natural Gas (LNG)," March 27, 2013.

[7] "Wikipedia," [Online]. Available: http://en.wikipedia.org/wiki/Q-Flex. [Accessed June 2013].

[8] "Ship Technology," [Online]. Available: http://www.ship-technology.com/projects/tembek/. [Accessed Juny 2013].

[9] "Oil & Gas Journal," June 2013. [Online]. Available: http://www.ogj.com/articles/2008/07/new-q-max-lng-vessel-is-worlds-largest.html.

[10] «Maritime Connector,» June 2013. [En línea]. Available: http://maritime-connector.com/wiki/q-max/.

[11] "Wikipedia," [Online]. Available: http://en.wikipedia.org/wiki/Q-Max. [Accessed June 2013].

[12] (Ph. D.) Vianello, Chiara, "Risk analysis of gas distribution network".

[13] P. Michele Michot Foss, "LNG Safety and Security," Sugar Land, Texas, 2006.

[14] Health & Safety Executive (HSE), «LNG source term models for hazard analysis "A review of the state-of-the-art and an approach to model assessment",» 2010.

[15] VROM, Publication Series on Dangerous Substances (PGS 1) - Methods for the determination of possible damage "Green Book" CPR 16E.

[16] Health and Safety Authority (HSA), Policy & Approach of the Health & Safety Authority to COMAH Risk-based Land-use Planning, 07 September 2009.

[17] A. Franks, «A Review of HSE's Risk Analysis and Protection - Based Analysis Approaches for Land-Use Planning,» Health and Safety Executive (HSE), 2004.

[18] Health And Safety Executive (HSE), "Offshore Installations (Safety Case) Regulations 2005 Regulation 12 Demonstrating compliance with the relevant statutory provisions".

[19] Health and Safety Executive (HSE), «Fire, Explosion and Risk Assessment,» February 2003.

[20] Health and Safety Executive (HSE), «Application of QRA in operational safety issues,» 2002.

[21] RIVM, Reference Manual Bevi Risk Assessment version 3.2, 2009.

[22] VROM, Publication Series on Dangerous Substances (PGS 3) - Guideline for quantitative risk assessment 'Purple book' CPR 18E., 2005.

[23] Flemish Government, LNE Department, Environment, Nature and Energy Policy Unit, Safety Reporting Division, «Handbook Failure Frequencies,» 2009.

[24] HSE, Failure Rate and Event Data for use within Risk Assessment.

[25] VROM, Publication Series on Dangerous Substances (PGS 2) - Methods for the calculation of physical effects - due to releases of hazardous materials (liquids and gases)- "Yellow Book, CPR 14E".

[26] TNO, "TNO innovation for life," [Online]. Available: http://www.tno.nl/index.cfm?Taal=2.

[27] Eisenberg N A, et al. 1975, "Vulnerability model. A simulation system for assessing damage resulting from marine spills," US DoT, US coast guard, 1975.

[28] Crosswaite, P. J.; Fitzpatrick, R. D.; Hurst, N. W.;, "Risk Assessment for the Siting of Developments Near Liquefied Petroleum Gas Installations," in *IChemE Symposium Series 110, Preventing Major Chemical and Related Process Accidents*, London, May 1988.

[29] Building Regulations, "Technical Guidance Document B. Fire Safety," Stationary Office, Dublin, 2006.

[30] Health and Safety Executive (HSE) , "An independent review of HSE methodology for assessing societal risk," January 2006.

[31] Carter, D.A., "The Scaled Risk Integral - A Simple Numerical Representation of Case Societal Risk for Land Use Planning in the Vicinity of Major Accident Hazards," in *Loss Prevention and Safety Promotion in the Process Industries*, vol. II, Elsevier, 1995.

[32] Hirst, I. L.; Carter, D. A.;, "A "Worst Case" Methodology for Risk Assessment of Major Accident Installations," *Process Safety Progress,* vol. 19, no. 2, Summer 2000.

[33] Health and Safety Laboratory (HSL), «Review of Hazard Identification Techniques,» 2005.

[34] Health and Safety Executive (HSE), "Canvey - An Investigation of Potential Hazards from Operations in the Canvey Island/Thurrock Area," HMSO, London, 1978.

[35] COMAH Regulations. Policy & Approach of the Health & Safety Authority to

COMAH Risk-based Land-use Planning.

[36] H. &. S. E. (HSE), «Societal Risk: Initial briefing to Societal Risk Technical Advisory Group,» Buxton, 2009.

[37] D. Jones, Nomenclature for hazard and risk assessment in the process industries. 2nd Edition, IChemE, 1985.

[38] Supplementary Planning Policy Guidance - Major Accident Hazards and Hazardous Substances, HAZARDOUS SUBSTANCES, 2004.

[39] Land Use Planning Guidelines in the context of directives 96/82/EC and 105/2003/EC, Christou et al, 2006. ISBN 978-92-79-09182-7.

[40] Lees' Loss Prevention in the Process Industries. Hazard identification, assessment and control, Elsevier Butterworth Heimann, 2004.

[41] A. Ronza, «A quantitative risk analysis approach to port hydrocarbon logistics,» *Journal of hazardous materials,* 2005.

[42] International Association of Oil & Gas Producers (OGP), "Guidance on performing risk assessment in the design of onshore LNG installations including the ship/shore interface," February 12, 2006.

ANNEX A. DRAWINGS

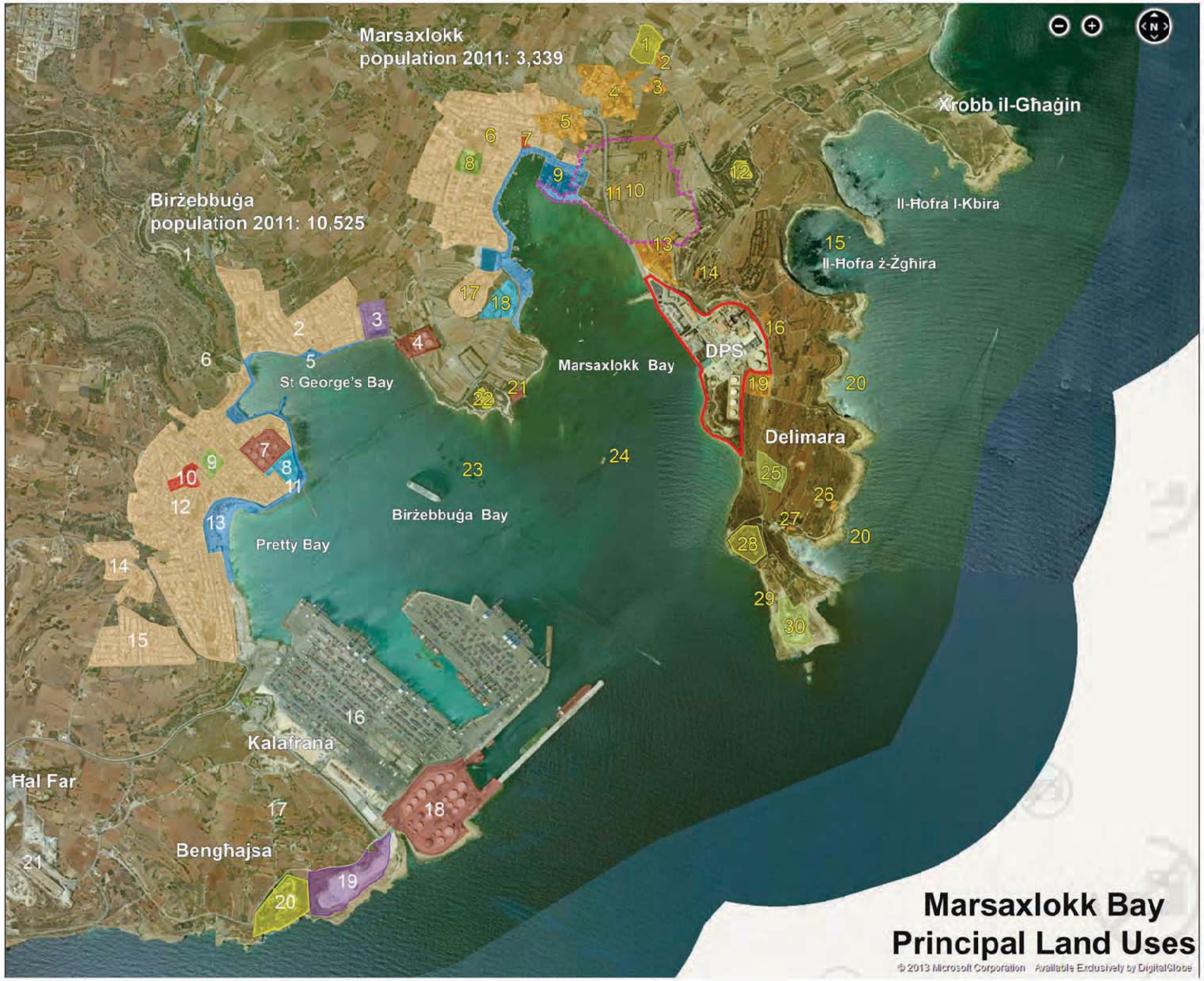
The following drawings are attached in the present Annex:

1. Area of concern (scale 1/10,000)
2. Land use (no scale)
3. Population estimation (scale 1/10,000)
4. Preliminary plot plan – Option A (scale 1/10,000)
5. Preliminary plot plan – Option B (scale 1/10,000)
6. Preliminary plot plan – Option C (scale 1/10,000)
7. Individual risk curve – Option A (scale 1/10,000)
8. Individual risk curve – Option B (scale 1/10,000)
9. Individual risk curve – Option C (scale 1/10,000)
10. Gas cloud extension – Option A (scale 1/10,000)
11. Gas cloud extension – Option B (scale 1/10,000)
12. Gas cloud extension – Option C (scale 1/10,000)
13. Suggested position for offshore options (scale 1/10,000)

	PROJECT:	SCALE:	DRAWING NAME:	DATE:	DRAWING:
SGS	DELIMARA LNG PLANT QRA	A3 : 1/10000	AREA OF CONCERN	JUNE 2013	1

Birżebbuġa

1 Important archaeological find
2 Predominantly residential
3 Unused LPG storage depot
4 Petroleum storage tanks
5 Historic redoubt
6 Important archaeological find
7 Petroleum storage tanks
8 Importer of petroleum products
9 Primary school
10 Parish Church and square
11 Historic redoubt
12 Predominantly residential
13 Recreation & tourism (along coast)
14 Predominantly residential
15 Predominantly residential
16 Malta Freeport (transshipment)
17 Small residential hamlet
18 Active petroleum storage depot
19 Active LPG storage facility
20 Historic fort
21 East of Industrial Estate



Marsaxlokk

1 Important archaeological find
2 Low density residential
3 Convent/Chapel
4 Low density residential
5 Low density residential
6 Predoiminantly residential
7 Parish Church and square
8 Primary school
9 Fishing, recreation, and tourism
10 Site of Community Importance
11 Low density residential
12 Historic fort (used as dog sanctuary)
13 Low density residential
14 Low density residential
15 Fish farm
16 Low density residential
17 Medium density residential
18 Light industry
19 Low density residential
20 Coastal ecology/swimming
21 Petroleum tank
22 Historic fort/research centre (fish)
23 Fish cages
24 Dolphin
25 Horse farm
26 Low density residential
27 Low density residential
28 Historic fort
29 Light house
30 Farm

	SGS	PROJECT: DELIMARA LNG PLANT QRA	SCALE: A3 : NOT SCALE	DRAWING NAME: LAND USE	DATE: JUNE 2013	DRAWING: 2

SGS	PROJECT: DELIMARA LNG PLANT QRA	SCALE: A3 : 1/10000	DRAWING NAME: PRELIMINARY PLOT PLAN_OPTION A	DATE: JUNE 2013	DRAWING: 4

	SGS	PROJECT: DELIMARA LNG PLANT QRA	SCALE: A3 : 1/10000	DRAWING NAME: PRELIMINARY PLOT PLAN_OPTION B	DATE: JUNE 2013	DRAWING: 5

PROJECT:	SCALE:	DRAWING NAME:	DATE:	DRAWING:
DELIMARA LNG PLANT QRA	A3 : 1/10000	PRELIMINARY PLOT PLAN_OPTION C	JUNE 2013	6

	SGS	PROJECT: DELIMARA LNG PLANT QRA	SCALE: A3 : 1/10000	DRAWING NAME: INDIVIDUAL RISK CURVE_OPTION A	DATE: JUNE 2013	DRAWING: 7

SGS	PROJECT: DELIMARA LNG PLANT QRA	SCALE: A3 : 1/10000	DRAWING NAME: INDIVIDUAL RISK CURVE_OPTION B	DATE: JUNE 2013	DRAWING: 8

	PROJECT:	SCALE:	DRAWING NAME:	DATE:	DRAWING:
SGS	DELIMARA LNG PLANT QRA	A3 : 1/10000	INDIVIDUAL RISK CURVE_OPTION C	JUNE 2013	9

SGS	PROJECT: DELIMARA LNG PLANT QRA	SCALE: A3 : 1/10000	DRAWING NAME: GAS CLOUD EXTENSION_OPTION A	DATE: JUNE 2013	DRAWING: 10

SGS	PROJECT: DELIMARA LNG PLANT QRA	SCALE: A3 : 1/10000	DRAWING NAME: GAS CLOUD EXTENSION_OPTION B	DATE: JUNE 2013	DRAWING: 11

PROJECT: DELIMARA LNG PLANT QRA	SCALE: A3 : 1/10000	DRAWING NAME: GAS CLOUD EXTENSION_OPTION C	DATE: JUNE 2013	DRAWING: 12

SGS	PROJECT: DELIMARA LNG PLANT QRA	SCALE: A3 : 1/10000	DRAWING NAME: SUGGESTED POSITION FOR OFFSHORE OPTIONS	DATE: JUNE 2013	DRAWING: 13

Project for a new LNG regasification facility to be located in the Marsaxlokk Bay

QRA PRELIMINARY REPORT

Barcelona, December, 4th, 2013
Report nº.: 02-901-188098-12141 – Revision 2

Prepared for:

ENEMALTA Corporation

Prepared by:

Mr. Roberto Vaccari

Process Safety Development Manager
SGS Tecnos SA

DISCLAIMER

Unless otherwise agreed, orders are executed in accordance with the latest version of the SGS' General Conditions. Upon request the conditions will again be sent to you. Attention is drawn to the limitation of liability, indemnification and jurisdiction issues defined therein.

Any holder of this document is advised that information contained herein reflects the company's findings at the time of its intervention only and within the limits of Client's instructions, if any. The Company's sole responsibility is to its Client and this document does not exonerate parties to a transaction from exercising all their rights and obligations under the transaction documents. Any unauthorized alteration, forgery or falsification of the content or appearance of this document is unlawful and offenders may be prosecuted to the fullest extent of the law.

CONTENTS

ANNEX C. REQUIREMENT FOR USE OF THE FREQUENCY AND CALCULATION OF HARDARMS AND HOSES SCENARIOS

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

ANNEX E. CALCULATION OUTPUT

1. SCOPE

Malta has no indigenous mineral primary energy sources and therefore relies on imported fuels, mainly heavy fuel oil and light distillate, for generation purposes.

Enemalta Corporation is the main producer of electricity in Malta with the exception of a small contribution from relatively small producers generating electricity from renewable energy. The total electricity load in Malta in 2012 was 2,269 TWh. This demand was mostly met by two Enemalta-owned power stations using heavy fuel oil (HFO) and gasoil.

The current fossil fuel generation capacity is 620 MW distributed across the two power station sites owned by Enemalta. This includes a new power block with a capacity of 149 MW which commenced operation at the end of 2012. In addition a 200 MW interconnector to Sicily is currently under construction and is projected to be completed by the end of 2014. The remaining operational 2x steam turbine generators at the Marsa B station, with a total nominal capacity of 130 MW are due to be shut down by the end of 2015 under the terms of the Large Combustion Plant Directive. In addition, the Government of Malta has committed itself to shut down the 2 x 60 MW steam turbine generators of the Delimara 1 power plant once sufficient replacement capacity is available.

In the next years, base load electricity should be sourced by Enemalta from an independently-owned, state of the art, high-efficiency power plant powered by natural gas. This power plant is expected to be based on an advanced design Combined Cycle Gas Turbine (CCGT) plant.

ENEMALTA plans to contract the engineering, purchasing, construction, commissioning and operation of a Liquefied Natural Gas (LNG) import terminal (LNG Terminal) and associated regasification plant in order to supply the CCGT to a third party [1].

This plant will be an ‘upper tier’ establishment as defined by the Control of Major Accident Hazards (COMAH) Regulations that implement the latest version of the ‘Seveso’ Directive (Directive 2003/105/EC, which amended Directive 96/82/EC). The Directive has been transposed into Maltese law through the Control of Major Accident Hazards (COMAH) Regulations - L.N. 37 of 2003 as amended by L.N. 6 of 2005. The competent Authority is the Occupational Health and Safety Authority (OHSA) together with the Malta Environment and Planning Authority (MEPA) and the Civil Protection Department of the Ministry for Home Affairs and National Security (CPD).

For this reason, and in order to fulfil the land-use planning and environment permitting requirements, Malta Environmental & Planning Authority (MEPA[1]) requests that operators applying for development permission and environmental permission (in this case, a permission issued under the Industrial Emissions Directive) for new COMAH establishments submit a quantitative risk assessment (QRA) report with their planning application.

In a first issue, the preliminary project includes several options for the LNG terminal location and for the technical solution to be adopted for the regasification facility. The scope of the QRA was extended to the comparison between three final realistic options.

The aim of the QRA is to compare the risk level of the proposed options for the population in the surroundings, as well as to define the preliminary location for the LNG tanker and/or the FSU/FSRU in the harbour.

On Sunday 13 October, Enemalta Corporation announced that the ElectroGas Malta Consortium is the preferred bidder shortlisted in the competitive process for the gas supply agreement. The ElectroGas Malta technical proposal is according to Option B considered in QRA (Floating Storage Unit + regasification unit onshore) and includes the layout of jetty and onshore facilities and data regarding the conditions of the onshore installation.

Following this decision, this completely revised version of the document is issued, after discarding the proposed options A and C and updating data and layout originally estimated by the consultant (hereafter called the consultant layout) to the ones proposed by ElectroGas Malta Consortium (ElectroGas layout).

Also, following requests from OHSA committee, additional details have been introduced: 1) HAZID study, 2) requirement for use of the frequency and calculation of hardarms and hoses scenarios, 3) comparison of risk criteria acceptance in some eu countries and others, 4) calculation output.

[1] Malta Environment & Planning Authority website: http://www.mepa.org.mt/home

2. DESCRIPTION OF THE AREA OF CONCERN

The proposed new LNG terminal will be located in the Marsaxlokk Bay, close to the existing ENEMALTA facilities in the Delimara peninsula, onshore, on reclaimed land, or offshore, in the harbour, depending on the option finally chosen.

The site is bounded on the east side by the Delimara Peninsula, on the north side by the existing facilities owned and operated by ENEMALTA and on the west by the coastline to be modified. The access to the proposed facilities is a public road that runs in a North-South direction, bordering the coastline and currently stopping at ENEMALTA entrance. In the future, this road should be enlarged up to the entrance of the LNG terminal. The area of concern, as well as the proposed site for each option, is shown in the drawing#1 in Annex B.

2.1. METEOROLOGY

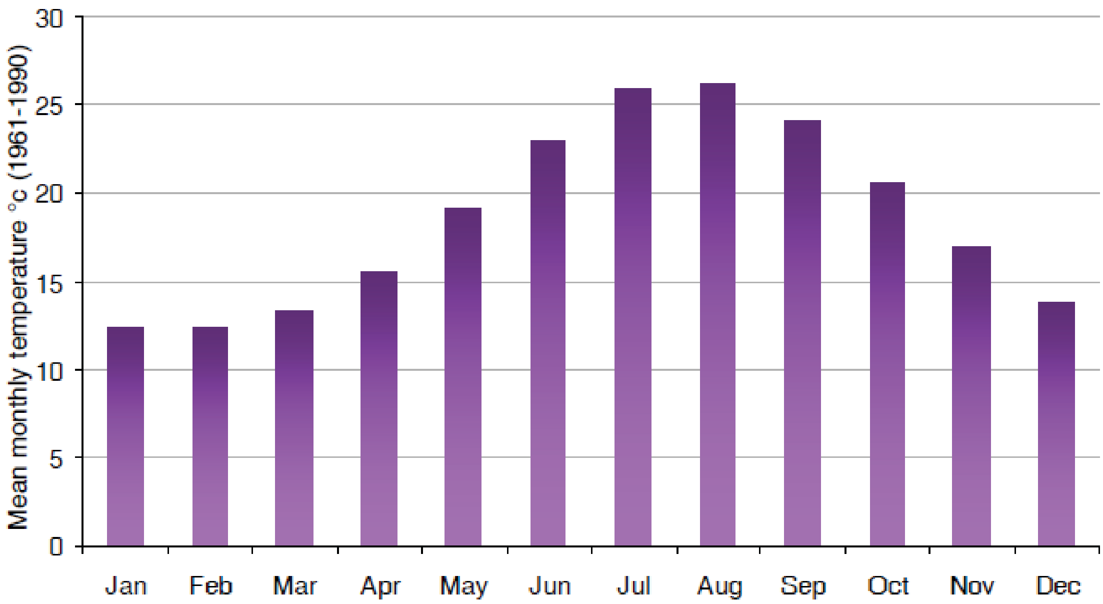
The seasonal features of the Mediterranean can be traced from the motion and development of the pressure systems over the Atlantic, Eurasia and Africa [2]. While the Mediterranean spring is often a period of indecisive weather, summer is characterised by the intensification of the Azores High Pressure which tends to extend up to the Central Mediterranean, giving general weather conditions consisting of light surface winds ranging from the northwest to northeast. Autumn is relatively short and leads to wintry conditions in a fairly decisive and quick way. During this season, Atlantic depressions move eastwards across northern Europe into the Mediterranean bringing with them waves of cold air. In its path, this cold air comes into contact with warm moist air causing vertical instability, the development of vigorous depressions, rainfall and frequent gales. From time to time the eastward march of travelling depressions is interrupted by cold air coming from the Arctic via the Norwegian Sea or Russia. This great thermal contrast leads to very active depressions.

In the Central Mediterranean region both Sicily and the Tunisian peninsula may play an important part on the local weather. Under certain prevailing conditions Sicily can act as a barrier against strong low-level northerly winds. This Italian island can also create local instabilities due to land heating effects or heat lows which may be advected towards the Maltese Islands depending on the prevailing winds.

Transient North African low pressure systems have the potential to produce strong winds over the Central Mediterranean. When for example North African lows occur south of the Atlas Mountains, strong easterly to south-easterly winds are likely over the Central Mediterranean resulting in high seas.

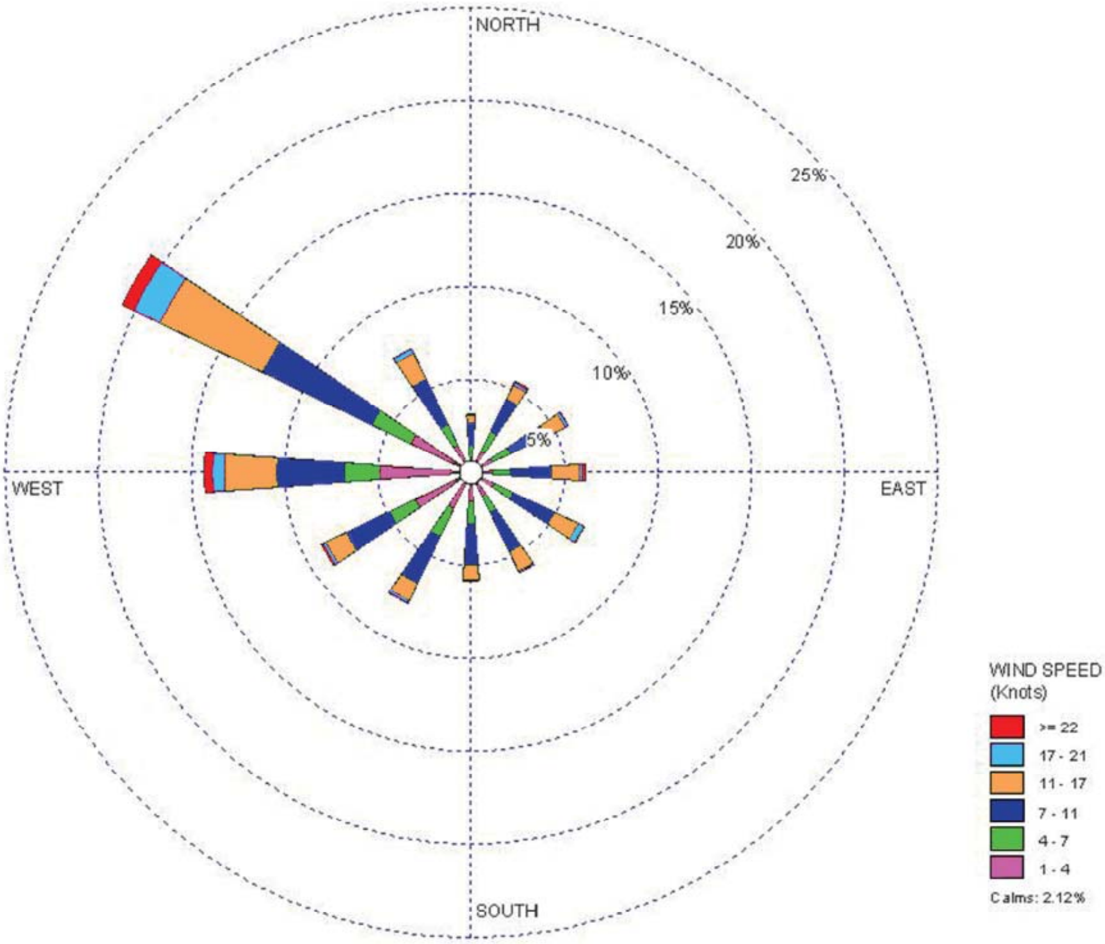
The presence of the surrounding water mass significantly shapes the climate of the Maltese Islands. The general weather is often cooler and more humid than what is experienced in inland areas of larger land masses. The high thermal capacity of the sea also reduces large fluctuations in the ambient temperature 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 [2].

Variable	Value	Unit
Ambient Temperature	19	ºC
Ambient Humidity	75	%
Cloud cover	75	%
Average wind speed	4.52	m/s



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.



2.2. GEOLOGY

The Maltese Islands are composed of Tertiary limestone and marls with subsidiary Quaternary deposits [3]. The strata consist of layers of Lower and Upper Coralline Limestone with intervening soft Globigerina Limestone and Blue Clay. The stratigraphy of the Maltese Islands is generally in accordance with the following table.

Formation	Approx. Age	Max. Thickness (m)
Upper Coralline Limestone	12-7.5 Ma	104-175
Greensand	12-7.5 Ma	0-16
Blue Clay	13-12 Ma	0-175
Upper Globigerina Limestone	15-13 Ma	5-20
Middle Globigerina Limestone	20-15 Ma	0-110
Lower Globigerina Limestone	20-15 Ma	5-110
Lower Coralline Limestone	--	140-236
Clays and dolomitised limestone	--	>3000

These rocks are sporadically overlain by terrestrial, Aeolian and alluvial deposits, laid down following the emergence of the Maltese Islands above sea level. Most of the central and south eastern sections of Malta comprise outcrops of Globigerina Limestone, whilst in the north and north western sections, Coralline Limestone predominates.

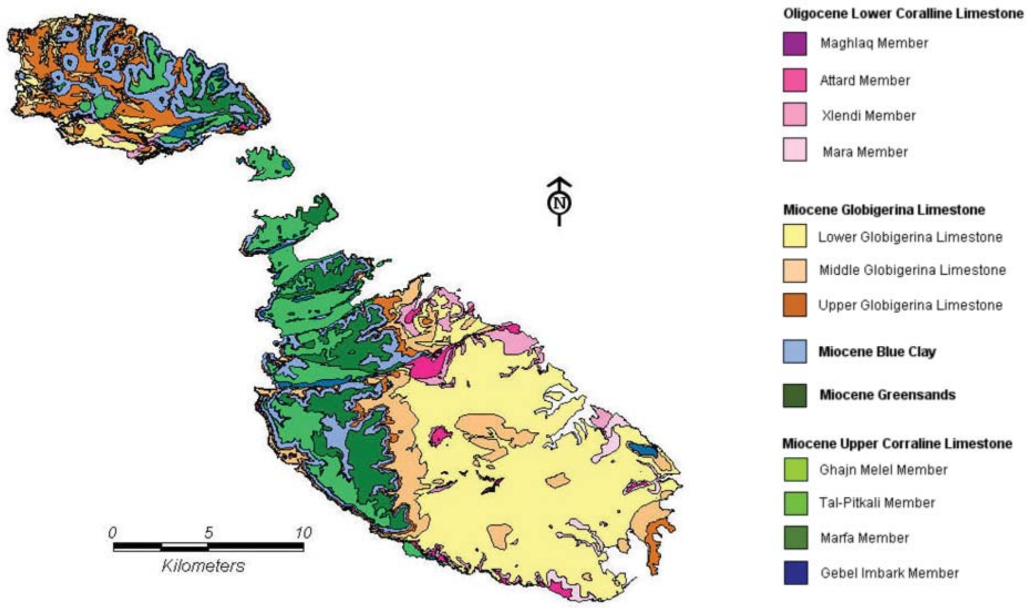


Figure 1.- Geological Map. [3]

Lower Coralline Limestone [3] is the oldest exposed rock in the Maltese Islands, outcropping to a height of 140m in the vertical cliffs near Xlendi, Gozo. It is mainly composed of the tests of coralline algae indicating deposition in a shallow gulf environment. Globigerina Limestone outcrops in over 70% of the Maltese Islands. It erodes to form a rolling landscape and varies in thickness from 23 m near Fort Chambray to 207m around Marsaxlokk. Blue Clay overlays the Globigerina Limestone formation. This material erodes easily when wet and flows out over underlying formations leading to wide variations in thickness of the deposit.

Greensand is made up of bioclastic limestone, rich in glauconite. It is generally less than 1m thick.

Upper Coralline Limestone is the youngest tertiary formation in the islands and reaches a thickness of approximately 160m in the Bingemma area.

Geologically, the south of Malta is important for soft stone quarries, which are mainly located in Mqabba and Qrendi. The area is mainly made up of gently undulating Globigerina plains. It forms part of the South Horst, which is a tilted structural block, bounded on the North West by the Victoria Lines Fault and on the south by the Maghlaq Fault.

The proposed project, if located totally or partially onshore, would lay down on reclaimed land, therefore specific geological assessment must be carried out in order to ensure minimum conditions of mechanical resistance. Any possible mechanical failure associated with ground settlement must be considered in the design phase and avoided, thus any possible scenarios associated with geology is out of the scope of the QRA.

2.3. SEISMOLOGY

The Maltese Islands lie in the middle of an extensive fault system affecting the central Mediterranean from Tunisia to Sicily. The faults are potential earthquake sources and are expressions of the stress field that has created the system of grabens in the central Mediterranean, known as the Pantelleria Rift. Some of the faults are still active whilst others are believed to be stable [4].

Detailed historical data for earthquake events affecting the Maltese Islands have not been published. However, some records of previous earthquakes are available and can be used to assess possible risks from a major seismic event.
The maximum intensity of any earthquake recorded for Malta since 1500 was a level VII on the European Macroseismic Scale (EMS), which corresponds to a “damaging” earthquake. Widespread damage to buildings was reported in many parts of Malta during this event. Earthquakes of lesser intensity (EMS VI) have been reported on four occasions between 1743 and 1923. An event also occurred in 1972, about 50 km south east of Malta which produced a local EMS of V.

The University of Malta operates a digital seismograph which has been recording small scale seismic events since 1995. About 20 minor events are recorded on average per year within a radius of 100 km of Malta, the majority of which are not noticed by the general population and have no effect on structures.

It is considered that the Maltese Islands have a low to moderate risk of being affected by a significant seismic event. Within a 100km radius of the islands, seismic activity is generally low or diffuse, with a magnitude not exceeding 5 on the Richter Scale.

For QRA purposes, the seismology has not been taken into account, even if all the selected scenarios can be the result of a minor earthquake. The onshore installation, if chosen as the preferred option, must be designed and built according to standards protecting against earthquakes.

2.4. HYDROGRAPHY

The geological structure of the Maltese Islands permits the division of the islands into several distinct aquifer blocks with limited communication of the groundwater. The main source of groundwater is the Mean Sea Level Aquifer, which provides about 76% of Malta's groundwater resource. The main aquifer bearing rocks are the Upper and Lower Coralline Limestone. The Globigerina Limestone, which overlays the main aquifer over most of central and southern Malta, has very low permeability and average porosity. It is only locally important as a groundwater resource. The freshwater is in the form of a lens (Ghyben-Herzberg lens) with the thicker part situated in the central part of Malta, thinning towards the coast. The aquifer floats on top of the sea water, due to the density differential [3].

Replenishment of the aquifer is by rainwater. Percolation of rainwater into the Sea Level Aquifer is through fissures or other discontinuities. However, in some areas, the Globigerina Limestone is fractured below the water table and it becomes part of the Lower Coralline Limestone aquifer.

Because of the presence of fissures and other recharge pathways, such as fault lines, the Sea Level Aquifer is susceptible to surface derived contamination.

Perched aquifers are present in the Upper Coralline Limestone, sustained by the underlying impervious Blue Clay. These perched aquifers have only a small potential for water extraction but are used extensively for agricultural purposes.
Public supply is abstracted from a network of around 100 boreholes. In addition there are over 5,000 privately registered boreholes and an un-quantified number of unregistered ones.

The area in which the establishment is located is not important for potable supply or for agricultural purposes, and the risks proceeding from such type of substance is not directed on superficial or underground waters, thus any effects on hydrography is out of scope of the QRA.

2.5. LAND USE

The site proposed for the new LNG terminal is designated in the Marsaxlokk Bay Local Plan as part of the existing ENEMALTA facilities, being the adjacent area mainly dedicated to agricultural use, with a few isolated buildings.

The description is based on drawing #2 attached in Annex B. The Delimara Power Station is shown there. All the numbers referenced in the following lines are shown in the same drawing.

Considering the land use map, the principal land uses in Marsaxlokk Bay can be listed as follows:

1. Important archaeological find
2. Low density residential
3. Convent / chapel
4. Low density residential
5. Low density residential
6. Predominantly residential
7. Parish church and square
8. Primary school
9. Fishing, recreation and tourism
10. Site of Community Importance
11. Low density residential
12. Historic fort
13. Low density residential
14. Low density residential
15. Fish farm
16. Low density residential
17. Medium density
18. Light Industry
19. Low density residential
20. Coastal ecology/swimming
21. Petroleum tank
22. Historic fort/research centre (fish)
23. Fish cages
24. Dolphin
25. Horse farm
26. Low density residential
27. Low density residential
28. Historic fort
29. Light house
30. Farm

The scattered houses include some cottages (#13, 14, 16, 19, 26 and 27), a horse farm (#25), an historic fort (#28) and a farm in the extreme South of the peninsula.

Heading north, there's the Marsaxlokk village with a total population of more than 3,000, at a distance of less than 1,000 m. On the other side of Birzebbuga Bay, Freeport closer docks are located at more than 1,000 m.

The biggest centre of population is Birzebbuga (population 8,800), which is located approximately 1.8 km west of the site. The town comprises a mix of residential, commercial and industrial developments.

Additionally, there are a number of environmentally sensitive areas in the vicinity of the site. They are those areas which could be adversely affected by the consequences of a major accident at the establishment. This includes natural environmental features, land in agricultural production, archaeological/cultural resources and the built environment.

These include:

- Forts and sites of archaeological interest
- Sites of community importance
- Coastal ecology / swimming areas

2.6. PRESENCE OF OTHER COMAH ESTABLISHMENTS

Marsaxlokk and Birzebbugia harbours gather most of the COMAH establishments existing in Malta:

- Delimara Power Station
- 31st March 1979 Installation
- Oil Tanking Malta
- Qajjenza LPG Plant (currently out of service)
- Wied Dalam Installation
- Gasco Energy Ltd
- San Lucian Oil Co. Ltd

The presence of all these installations must be considered in the COMAH documentation, due the possible domino effects between them. For QRA purposes, domino effect is not taken into account in the calculations, even if possible effects proceeding from the projected LNG terminal to the existing establishments would be qualitatively commented on the conclusions.

2.7. MARITIME TRAFFIC

The nautical traffic in the harbour was registered over the past year, with the following general results, provided by Transport Malta Authority [2]

Shipping Movements - Year 2012			
Type	**Calls**	**GRT**	**NRT**
Cargo Operations			
Container Operations	1,484	51,874,005	26,679,275
Dry Bulk Operations	7	32,133	14,508
Unitised Operations	60	1,673,423	569,812
Liquid Bulk Operations	474	8,221,243	3,625,504
General Cargo Operations	79	1,459,037	678,468
Passenger Operations			
Cruise Liners	0	0	0
Ferry	0	0	0
Passenger Catamaran Ferry	0	0	0
Repairs	7	16,250	8,186
Supplies			
Bunkers	7	30,861	14,610
Conveyance	0	0	0
Provisions	70	10,332	6,472
Water Supply	0	0	0
Others			
Service Provisions	8	80,357	29,067
Courtesy Visit	0	0	0
Shelter	0	0	0
Others	505	323,435	130,174
Total	**2,701**	**63,721,076**	**31,756,076**

The number of cargo operations is relevant if considered on the basis of the harbour dimensions and in comparison with others ports, so marine traffic in the harbour must be taken into account for QRA purposes.

[2] Transport Malta website: www.transport.gov.mt

3. DESCRIPTION OF THE PROPOSED FACILITIES: LNG REGASIFICATION PLANT

The project for an LNG plant studied in the first issue of QRA was at a very preliminary stage and description of the facilities was made on the basis of experience and comparison with similar facilities. According to ENEMALTA estimations, the expected average daily natural gas consumption would be up to about 48,314 MMBTU (~1,464,058 m^3). This equates to approximately 2,440 m^3 of LNG per day. The total capacity to fulfil ENEMALTA's needs is established to be a maximum quantity of 180,000 m^3.

In order to meet these requirements, a few options were under evaluation in the first issue of this document:

- Option A (discarded after project has been awarded): the whole regasification plant onshore, to be built on reclaimed land close to the ENEMALTA fuel oil tank farm, currently an artificial hill.
- Option B (chosen by ElectroGas): floating LNG storage (FSU) moored in the southern part of the harbour plus regasification plant onshore, to be built in the same location, but without any clearing of the hill.
- Option C (discarded after project has been awarded): floating storage and regasification (FSRU), moored in the southern part of the harbour.

For the purposes of QRA, it was necessary to represent a realistic profile of equipments and operations for each option. Based on the energy and mass balance set by ENEMALTA, the consulting team proposed realistic layouts and minimum equipments definition to be used as inputs data in QRA calculations. All the data presented in the following descriptions are an estimation based on similar facilities. The consulting team has to advise again that the final adoption of different technical solution for the selected option may affect the results of the present assessment.

The equipment, utilities and possible layouts for chosen option B were described in the following lines, and the description is based on the state-of-art facilities worldwide: The layouts of the preliminary option A and C have been removed from the report, being not necessary their assessment. Layout of option B – consultant layout – is attached as Drawing # 4.

3.1. CONSULTANT LAYOUT

LNG tanker

The majority of the LNG transport worldwide is delivered in large LNG carriers with a capacity varying from 50,000 m^3 of the oldest vessels up to 250,000 m^3. Carriers are normally classified as follows:

- Standard class: 125-150,000 m^3
- Q-Flex class: 210-217,000 m^3 [5] [6]
- Q-Max class: 250,000 m^3 [7] [8][9]

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

- 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 visiting LNG carrier would be moored to the FSU.

Ship to ship unloading by arms

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)

According to Maltese requirements, the FSU storage capacity would be a maximum 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).

Primary (LP) and secondary (HP) pumps

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 liquid is passed, directly or indirectly through an absorber, to the high pressure pumps (HP pumps) which feed the vaporizers at approximately 28 barg.

Regasification Unit

The regasification unit can be mounted on a skid and located in some point onshore, such as a reinforced part of the jetty or a platform close to the existing hill in the pathway to Delimara Power Station.

The Unit must include at least the following principal equipments:

- Secondary pumps
- Vaporizers
- Compressor
- Liquefier / absorber
- Metering station and odourization

The LNG would be re-gasified in submerged combustion vaporizers, which operate at send-out pressure prior to export from the LNG TERMINAL. The battery limit conditions are 25 barg with a minimum temperature of 5 °C. A small part of the gas from the vaporizers is routed separately to satisfy the LNG TERMINAL internal needs.

The vaporizers are provided with a gas turbine cogeneration unit from which waste heat is used to warm the water contained in a pool, where heat exchanger is submerged. The outlet gas will be at a minimum temperature of 0°C.

Boil Off Gas treatment in the FSU

During ship unloading, the level in the FSU storage tanks increases causing a vapour displacement. Simultaneously, the level in the tanker decreases at the same rate, causing a negative displacement effect and therefore a pressure drop.

To prevent vacuum in the tanker, a part of the vapour displaced in the storage tanks is sent back to the ship by means of return gas line through the boil-off header, the vapour return line and the vapour arm.

Excess boil-off gas is handled by boil-off compressors and mixed with the subcooled LNG pumped by the in-tank low pressure pumps (LP pumps).

The pressure in the storage tank is controlled by starting the boil-off compressors and sending the excess boil-off to the absorber for re-liquefaction.

Metering station and odourization

Before export to the CCGT, the gas passes through the gas metering station. The metering consists of two parallel metering lines including filters, turbine meters and odourizing unit.

3.2. COMPARISON WITH PRELIMINARY PROJECT DATA PROPOSED BY ElectroGas

The scope of this chapter is to check possible differences in the layout and the data proposed by the awarded bidder, in comparison to the layout and data assumed by the consultant when carrying out the first issue of this document.

As explained in the introduction, the first issue was carried out in an early stage of the project when no technical proposals from bidders were available. Details of state-of-the-art facilities in Europe, plus a margin of error, were assumed in order to overestimate final risk.

For easier comparison, data is organized in rows in the following table. Remarkable differences are commented on and highlighted in yellow within each row.

ITEM	ESTIMATED DATA	ElectroGas MALTA DATA	REMARKABLE DIFFERENCE
Proposed option	--	QRA – B	Minimal difference: propane storage tank and associated circuit for gas heating
LNG tanker position and unloading arms position	Originally positioned in the inner part of the location	Proposed location is displaced aprox. 100m to the east and 300m to the south	Safer position according to QRA conclusions
LNG tanker max capacity	180,000 m3	Indirect estimation: 125,000 m3 – supplying vessels might be bigger in case of partial discharge	No difference, risk was overestimated

ITEM	ESTIMATED DATA	ElectroGas MALTA DATA	REMARKABLE DIFFERENCE
Maximum capacity of one tanker vessels	35,000 m3, 95% full	31,250 m3 if all of them are the same size, no reasons for tanks bigger than 35,000m3	No difference, risk was overestimated
LNG transfer pressure	4 barg at ship manifold	3 barg at ship manifold	No difference, risk was overestimated
Ship to ship LNG unloading arm diameter	12” 3 arms (2 liquid, 1 vapour)	5 x flexible hoses (4 liquid, 1 vapour) all 250 mm NB. Hoses with emergency release couplings (ERC)	**DIFFERENCE: failure frequency for hoses is generally higher than for arms but no direct comparison is possible. See comparison of frequencies for more details.**
Ship to ship unloading rate	4,000 m3/h x 2 arms	6,000 m3/h	No difference, risk was overestimated
FSU / FSRU position and jetty lay out	Original UTM	Proposed location is inside the safe polygon	No
FSU max capacity	180,000 m3	LNG GEMINI 125,000 m3	No difference, risk was overestimated
LNG unloading pressure	4 barg at ship manifold	3 barg at ship manifold	No difference, risk was overestimated
Ship to shore LNG unloading arm diameter	6”	12”	**DIFFERENCE: Unloading arm size is higher than estimated. Recalculation is carried out with no final difference in gas cloud contour, due to maximum size reached in both cases.**
Ship to shore unloading rate	200 m3/h x 1 arm	145 m3/h	No difference, risk was overestimated
Presence of secondary pump onshore increasing pressure from 4 to 28 barg	UTM	No data but pump must be present in the process area, together with vaporizers.	No difference, risk was overestimated
Size of pipeline from unloading arm to secondary pump	6”	6”	No difference, risk was overestimated
Regas position	Original UTM	Proposed location is displaced to the east and the south	Safer position according to QRA conclusions
Maximum pressure in regas unit	28 barg	Maximum 47.5 barg Nominal 43 barg	**DIFFERENCE: recalculation of scenarios has been done**
Battery limit conditions downstream regas unit	25 barg and 5ºC	New IPP: 35 barg and 5ºC DPS3: 7 barg and 10ºC	**DIFFERENCE: recalculation of scenarios has been done**
Gas pipe to turbine	10”	6”	Minor impact in QRA

ITEM	ESTIMATED DATA	ElectroGas MALTA DATA	REMARKABLE DIFFERENCE
Compressor position	Original UTM	Proposed location is displaced to the east and the south	Safer position according to QRA conclusions
BOG – pipeline to compressor diameter	6”	6”	No difference
Max pressure delivered by BOG compressor	15 barg	38 barg	Scenarios B11, B12 would increase, no impact in final result is expected due to reduced size of consequences
Max flow delivered by compressor	3,000 Nm3/h	5,700 Nm3/h	Minor impact in QRA
Pipe routing	Original UTM	No major changes	Minor impact in QRA
Others	Not included	Propane system, volume aprox 25-30 m3	New pipe rupture scenarios would be negligible. BLEVE scenario can be included, with estimated result of 200-300 m max consequence and very low frequency, but no impact on the final result

As a partial conclusion of this chapter, it should be remarked that the project proposed by ElectroGas is in main part covered by the data and layout suggested in the first issue of this report. The only parts that need updating are the scenarios referring to high pressure natural gas, which should be completely recalculated, and the frequencies referring to unloading arms and hoses which should be compared and / or analyzed in detail in the corresponding chapter. Also, all the scenarios should be relocated in their respective new locations.

4. LNG 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.

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 mixture of low molecular weight hydrocarbons held at cryogenic temperatures. Physical properties for methane, ethane and propane (the principal constituents of LNG) are provided in the following table.[10]

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

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 not 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

LNG 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.

Roll-over in tanks (onshore or offshore)

A “roll-over” [11], [12] 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 LGN to leak due to the difference in densities and to vapourize 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 leakeage of LNG form the tank, due to pressure.

Rapid Phase Transitions

The effect called Rapid Phase Transitions (RPT) [12] 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.

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.

Gas odorization and false gas leakage alarm

Natural gas is completely odourless, reason for which must be artificially odorized with the addition of traces (parts per million or ppm) of substances called mercaptans, in order to provide the characteristic and alarming odour in case of leakage. This method is used for other products, such as LPG. The presence of a container of the additive is common in regasification plants.

Mercaptans are among the smelliest substances in the world, thus any minor spillage, even if non lethal for the public, can disperse and be smelled at very large distances, and obviously, can lead to a false alarm, inducing the public to call the emergency services.

5. IDENTIFICATION OF VULNERABLE TARGETS

Considering the land use map, drawing #2 attached in Annex B, the following vulnerable targets can be identified in the surroundings of the proposed LNG terminal and in Marsaxlokk community. The population zones can be listed as follows:

2. Low density residential
3. Convent / chapel
4. Low density residential
5. Low density residential
6. Predominantly residential
7. Parish church and square
8. Primary school
9. Fishing, recreation and tourism
11. Low density residential
13. Low density residential
14. Low density residential
16. Low density residential
17. Medium density
19. Low density residential
26. Low density residential
27. Low density residential ([3])
29. Lighthouse ([3])
30. Farm

The population data to be considered in the calculation of societal risk is shown in drawing #3 attached in Annex B. The estimation of population in scattered houses, farms, touristic places and fishing / swimming zones are according to the Dutch model[13].

The scattered houses include some cottages (#13, 14, 16, 19, 26 and 27), and an historic fort (#28). The presence of three persons is estimated for each cottage and 40 persons for each fort.

Heading north, there's the Marsaxlokk village with a total population of more than 3,000, at a distance of less than 1,000 m. On the other side of Birzebbuga Bay, Freeport closer docks are located at more than 1,000 m.

The biggest centre of population is Birzebbuga (population 8,800), which is located approximately 1.8 km west of the site. The town comprises of a mix of residential, commercial and industrial developments.

[3] Future small hotels

Additionally, there are a number of environmentally sensitive areas in the vicinity of the site. They are those areas which could be adversely affected by the consequences of a major accident at the establishment. This includes natural environmental features, land in agricultural production, archaeological/cultural resources and the built environment.

These include:

- Forts and sites of archaeological interest
- Sites of community importance
- Coastal ecology / swimming areas

Forts and Sites of Archaeological Importance

The presence of Fort Delimara, in the extreme South of the Delimara peninsula, must be considered for its archaeological importance. Regarding the presence of tourists, a total amount of 40 persons is estimated during daytime, based on car park lot dimensions.

Sites of community importance

A site of community importance must be considered north from the proposed facilities.

Coastal ecology / swimming areas

The cliffs and bays in the Eastern side of the Delimara peninsula present a number of beaches which receive local and foreign visitors. The marine coastal ecosystem adjacent to the site is populated by beds of Posidonia oceanica. These plants provide the basis of an extensive food web and a highly productive and diverse coastal ecosystem. In these areas, the presence of tourists should be considered, for a total amount of 40 persons during daytime, based on car park lot dimensions, finally, in the beaches on the east side of Delimara the presence of 50 persons in each bay has been considered.

Fishery

The inner part of the bay is dedicated to fishery and / or mooring of sports and fishing boat. A total presence of 1 person per hectare is considered during daytime.

Other considerations

Additionally, an extra 70 persons walking or farming in the area has been considered.

6. METHODOLOGY FOR QUANTITATIVE RISK ASSESSMENT

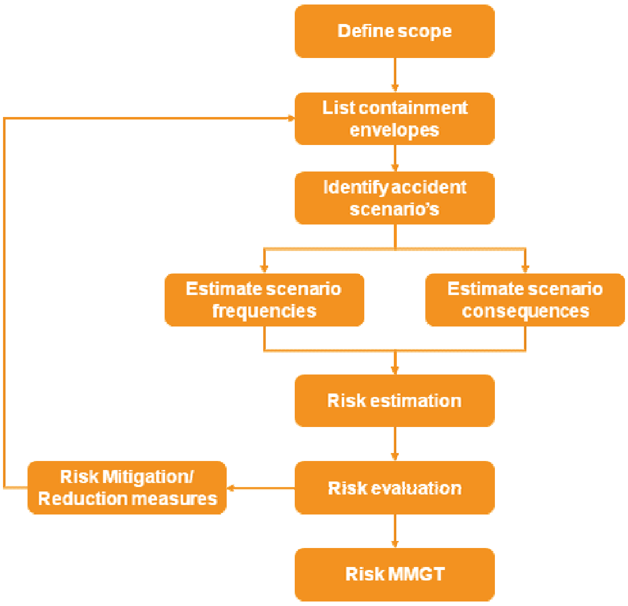
A Quantitative Risk Assessment is used to make decisions about the acceptability of risk in relation to developments for a company or in the area surrounding an establishment or transport route. The criteria for assessing the acceptability of risks for a large number of categories of establishments are 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) [14], [15],[16],[17], [18] or BEVI[19] [20] 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.



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 [20], Handbook failure frequencies [21], PERD, HSE FRED [22],…. 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:

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

$IR_{(x,y)}$ = 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.

6.1. INPUT INFORMATION AND DATA

The QRA is based on information and data strictly associated to the location, the site facilities and surroundings, listed below. For the Delimara project, due to the preliminary stage, most of the data is not yet available, and expert estimation is required in order to carry out the QRA. In these cases, the data is commented on the list below.

Facility

- Plot plan with :
  - Fence/border
  - Entry
  - Pipe routing (estimation according to minimum length, influence on calculation is limited)
  - Production facilities (estimated lay out, based on logical process flow, any mayor change can affect the final curves)
  - Storage facilities (estimated lay out, no changes expected for Option A)
  - (un-)loading facilities (estimated lay out, the position may considerably vary depending on risk limitation, port availability, draft and others parameters. Final position recommended in conclusions)
  - Offices and administrative buildings (estimated lay out, not relevant for preliminary QRA purposes)

- Installations with respect to natural gas (LNG, CNG) :
  - Location on the site (estimated lay out, final position of each equipment and vessel may vary in the same area, no relevant influence on final risk is expected)
  - Dimensions (estimated based on annual consumption, any variation exceeding 30% could affect the result of QRA)
  - volume (m^3) (estimated based on annual consumption, any variation exceeding 30% could affect the result of QRA)
  - filling degree (estimated according to normal operation for this plants)
  - Content in metric tonnes (estimated based on annual consumption, any variation exceeding 30% could affect the result of QRA)
  - Bunds (area and volume) (estimated presence of bunds in onshore facilities, with a maximum area similar to tank surface for tank area or limited to 1,500 m^2 for regasification area)
  - Pressure and temperature (operating and design) (estimated by comparison with similar facilities, any variation exceeding 30% could affect the result of QRA)
  - Connections (size – phase) (estimated by comparison with similar facilities, any variation exceeding 30% could affect the result of QRA)

- Unloading/loading facilities

- number of transfers per year (estimated based on annual consumption, any variation exceeding 30% could affect the result of QRA)
- transfer volume per delivery (estimated based on annual consumption, any variation exceeding 30% could affect the result of QRA)
- unloading rate (m^3/h) (estimated by comparison with similar facilities, any variation exceeding 30% could affect the result of QRA)
- unloading arm (diameter) (estimated by comparison with similar facilities, any variation exceeding 30% could affect the result of QRA)
- Pressure and temperature (operating and design) (estimated by comparison with similar facilities, any variation exceeding 30% could affect the result of QRA)

- Piping (>10 m)
  - Diameter (estimated by comparison with similar facilities, any variation exceeding 30% could affect the result of QRA)
  - Pressure and temperature (estimated by comparison with similar facilities, any variation exceeding 30% could affect the result of QRA)
  - Flow (m^3/h) (estimated by comparison with similar facilities, any variation exceeding 30% could affect the result of QRA)

- Description of normal operation (not available at this stage, regasification operation estimated in comparison with other facilities)

- PFD's (not available at this stage, regasification operation estimated in comparison with other facilities, no details available nor considered for auxiliary equipments)

Surroundings

- Population grid day/night (estimated using official population data according to 2011 census, no major changes expected)

- Neighbouring
  - Residential areas including:
    - Individual houses (population in scattered houses estimated considering presence of three persons each, any important difference regarding this parameter can affect the calculated societal risk)
    - Vulnerable objects such as schools, hospitals, homes for elderly:
      - Name and location (no vulnerable objects identified in the area of concern according to Land use Map)
      - Presence of people (day, night) (not required according to previous point)
    - Public locations
      - Touristic areas (camping sites, museums, hotels, etc.)
        - Name and location (shown in Land Use Map)
        - Presence of people (day, night) (population during daytime estimated according with space availability in each car park lot)

- Environmental information
  - Average temperature of subsoil, air, water (annual) (available from Meteorological Service)
  - Average humidity (%) (annual) (available from Meteorological Service)
  - Meteorological information (annual) (available from Meteorological Service)
    - Stability classes (pasquil) vs. wind direction and wind speed at 10 m (not available for Malta, estimated using data from other similar port)

6.2. MODELLING SOFTWARE

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 examine 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 [23].

EFFECTS contain 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.[24]

6.3. 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. 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.

In the case of Malta, any similar port area in Mediterranean would present similar conditions, thus the decision to look for another port of the Mediterranean Sea, open to the South and surrounded by hills and for which data is available. The final decision was the Port of Cartagena, Spain, only 2º North of Marxaslokk. Data from this reference is shown in the following table.

	Stability class					
Wind velocity m/s	A	B	C	D	E	F
0 – 1	128	0.23	0.05	0.19	0.03	4.36
1 – 3	4.55	1.95	2.08	11.26	0.78	8.85
3 – 5	--	6.11	7.31	21.99	1.34	--
5 – 7	--	--	8.15	12.46	0.12	--
7 – 9	--	--	1.84	3.97	--	--
> 9	--	--	0.36	0.74	--	--

Using this data, 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.

Stability class and wind speed scenario	Total Percentage	Daytime percentage	Night-time percentage
D3	57	36	21
D9	27.52	18	9.52
E5	2.27	0	2.27
F2	13.21	0	13.21
Total	100	54	46

It's important to explain the relevance of this decision, and to highlight the scarce 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. For the case of Malta, the only practical relevance is to give the corresponding weight to the daytime, larger than the nigh time, due to the latitude, and to the stable weather conditions, due to the Mediterranean climate. Thus, Spanish data seems to be the best choice to simulate the Maltese conditions, introducing a minimum error, completely negligible in comparison to other general assumptions necessary for the study.

Fraction of day and night time

The fraction of time considered to be 'day' was calculated by assigning day and night hours to different months of the year, then calculating the number of daytime hours. Note that 'day' and 'night' were defined according to hypothetical resident behaviour (i.e. on when people may typically get up and go to bed, and not sunrise and sunset). Within the weather calculation, this has been defined as a 14 hour period during summer (defined as the period from April to the end of October, when daylight saving time operates) from 07:00 GMT (06:00 DST) until 21:00 GMT (20:00 DST); and a 12 hour period during winter (all months not defined as summer) from 06:00 GMT to 18:00 GMT. Thus, medium daytime is considered to be 13 hours over 24 hours, or 54% of total time.

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 [14][23][20]:

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 jetty and on land. All the leaks from the unloading arms are assumed to fall onto the water. All the leaks in the pipeline are assumed to fall onto the jetty or on land, so the calculation is done in both locations.

Effect of dikes, drainage channels and impounding basins

Most of the process areas would be provided with impounding basins for containment of incidental releases proceeding from equipment or vessels such as pumps, liquefier / absorber and roof top connections for tanks, according to recommendations of norm EN 1473 [25]. Any spillage is contained by walls and physical limitations around the equipment and transported by gravity to the basin by open drainage channels, in a way that ensures the possibility to cover the spillage with foam and to minimize the contact surface of the LGN, or, in other words, to minimize the generation of vapours from the basin.

In general for onshore terminal such as that described for Option A, up to three impounding basins are expected, covering the following zones: jetty, tanks roofs, secondary pumps and other equipments. For Option B, one basin is expected on the jetty and another in the location of the Regasification Unit. Also, any spillage in the LNG tanker deck is expected to be collected in the same way and conducted up to a basin. For Option C, no basin out of the tanker is expected, not being possible any spillage of LNG out of the tanker deck.

For the purposes of the QRA the final effect of the impoundment basins have not been considered, but the effects of the walls and barriers against spillages has been considered generically limiting the spillages to 1,500 m^2[23][20].

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. A general criterion is to limit the extension to 10,000 m^2 [23], [19],[20].

Effects of Topography

At the proposed location, heading in any direction except West, the land rises to a height of approximately 30-40 m up to the top of the hills configuring the Delimara peninsula. This difference in elevation and the slope between the platform and jetty where the process equipment is located will provide effective mitigation of any cold cloud formed on LNG spills, as well as limitation to thermal effect of large pool fire. The limitation in the extension of the cloud has been shown in drawing #13.

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 [23].

The classification provided here is based on table 3.1 from the Yellow Book [23]:

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

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.

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 [23].

Thermal Radiation

The probit most commonly used to determine the risk from thermal radiation is the Eisenberg et al (1975) probit. [20][26]

Probit = -14.9 + 2.56 ln ($I^{1.33t}$) with I in Kw/m^2 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 [23] is 18.75 s. But, according to the HSA criteria [14], the value proposed for long duration fires is 75 s.

It is sometimes necessary to make some further refinement and assumptions for people indoors, based on Crosthwaite et al (1988) [27]. 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 [28] and takes into account that the people are fully clothed.

For some types of major hazard installation, damage contours associated with various levels of harm to property and buildings will be produced and provided to the Malta Environment and Planning Authority, showing the maximum possible extent of any particular level of damage.

Estimation of likelihood

There are two reference manuals [14][19] 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 [19] and [22]. 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.

HSE [29] has defined the boundaries of the inner, middle and outer LUP zones as:

- 10^{-5} / year: risk of fatality for Inner Zone (Zone 1) boundary.
- 10^{-6} / year: risk of fatality for Middle Zone (Zone 2) boundary.
- 1×10^{-7} / year: risk of fatality for Outer Zone (Zone 3) boundary.

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.[29]

The methodology for calculating the Societal Risk Index (SRI) is described by Carter (1995) [30] and Hirst and Carter (2000) [31] 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

7. IDENTIFICATION OF MAJOR ACCIDENT 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 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.

According to the few data available in the preliminary stage of the projects, the preparation of the Hazardous and Operability Analysis (HAZOP) is not yet possible. The redaction of the Front – End Design is generally required for this stage. Front – End Design includes detailed process description, mass and energy balances, list of equipment and instruments, list of safety interlocks and alarms, piping and instrumentation diagrams, etc.

Nevertheless, in the current stage, the elaboration of a preliminary Hazardous Identification (HAZID) can be elaborated and based on the general knowledge of any LNG unloading, storage, regasification process and on the analysis of the layout. The information resulting from the HAZID includes a list of the major scenarios, as well as basic recommendation to be taken into account during the engineering.

The list of proposed scenarios for each option is shown in the following tables, together with the input data for each one. Data definitions as follows:

ITEM is referred to the code of the scenarios and allows data crossing between tables;
EQUIPMENT is referred to the vessel / pipe / pump / tanker;
REFERENCE is the bibliographic source according to which the scenario is proposed;
DEFINITION is the complete name of the scenario;
PHASE is liquid or gas phase of the vessel content;
DENSITY may vary according to phase;
BUND is referred to the presence or not of physical limitations to the extension of liquid releases;
PIPELINE DIAMETER is referred to the considered pipeline diameter;
HOLE DIAMETER is referred to the diameter which must be chosen for the leakage calculation according to the bibliographic source;
DISCHARGE COEFFICIENT is a hydraulic factor to be considered depending on phase;
PIPELINE LENGTH is the estimated length for the leaking pipeline;
VOLUME is the total volume for a vessel, when present;
FILLING DEGREE is the percentage of fill in the volume;
H, L and D are the dimensions of the vessel;
OPERATION TEMPERATURE is the temperature at which the release is expected;
OPERATION PRESSURE is the pressure at which the release is expected;
PUMP NOMINAL RATE is the flow delivered by a pump, when present;
RELEASE TIME is the total time during which the release take place, before the action of emergency shut down systems.

LIST OF SCENARIO'S INPUTS																			
ITEM	EQUIPMENT	REFERENCE	SCENARIO DEFINITION	GAS / LIQ / LNG	DENSITY	BUND	PIPELINE DIAMETER (inch)	HOLE DIAMETER (M)	DISCHARGE COEFFICIENT	PIPELINE LENGTH (m)	VOLUME (m^3)	FILLING DEGREE	H (m)	L(m)	D (m)	OPERATION TEMPERATURE (ºC)	OPERATION PRESSURE (bar)	PUMP NOMINAL RATE (m^3/h)	RELEASE TIME (s)
Consultant layout																			
B01.a	GAS TANKER (RELEASE ON WATER)	See paragraph 10.1 [33] [20]	Rupture of one tank of the Gas tanker due to ship collision	LNG	422	NO	N/A	0.36	N/A	N/A	35,000	95%	N/A	N/A	20.3	-161	1.03	N/A	Until empty vessel
B01.b	GAS TANKER (RELEASE ON WATER)	See paragraph 10.1 [33] [20]	Rupture of one tank of the Gas tanker due to ship collision	LNG	422	NO	N/A	0.5	N/A	N/A	35,000	95%	N/A	N/A	20.3	-161	1.03	N/A	Until empty vessel
B02.a	GAS TANKER TO FSU UNLOADING ARM - LNG (RELEASE ON WATER)	FR 3.3.1 Ship Hardarms	GUILLOTINE BREAK Total failure rate when two arms used	LNG	422	NO	12	0.30	1	N/A	100	99	N/A	N/A	N/A	-161	4	8,000	120
B02.b	GAS TANKER TO FSU UNLOADING ARM - LNG (RELEASE ON WATER)	FR 3.3.1 Ship Hardarms	Hole = 0.1 cross sectional area of pipe	LNG	422	NO	12	0.03	0.62	N/A	100	99	N/A	N/A	N/A	-161	4	8,000	120
B03.a	FSU UNLOADING ARM - LNG (RELEASE ON WATER)	FR 3.3.1 Ship Hardarms	GUILLOTINE BREAK Total failure rate when two arms used	LNG	422	NO	12	0.15	1	N/A	100	99	N/A	N/A	N/A	-161	4	200	120
B03.b	FSU UNLOADING ARM - LNG (RELEASE ON WATER)	FR 3.3.1 Ship Hardarms	Hole = 0.1 cross sectional area of pipe	LNG	422	NO	12	0.01	0.62	N/A	100	99	N/A	N/A	N/A	-161	4	200	120
B04.a	GAS TANKER UNLOADING ARM - GAS RETURN TO GAS TANKER	FR 1.2.3 Ship Hardarms	Release limited according to ERC max content – total	GAS	1.66	N/A	12	0.30	1	N/A	N/A	N/A	0	N/A	N/A	-151	1.03	N/A	Until empty vessel
B04.b	GAS TANKER UNLOADING ARM - GAS RETURN TO GAS TANKER	FR 3.3.1 Ship Hardarms	Release limited according to ERC max content – partial	GAS	1.66	N/A	12	0.030	1	N/A	N/A	N/A	0	N/A	N/A	-151	1.03	N/A	Until empty vessel
B05	PIPELINE FROM FSU TANK TO SECONDARY PUMP - SUCTION (RELEASE ON WATER)	Item FR 3.1.2 Above Ground Pipelines	Total rupture in the pipeline	LNG	422	YES	4	0.10	1	304	N/A	99	N/A	N/A	N/A	-161	1.03	1,860	1,800
B06	SECONDARY PUMP	Item FR 1.2.2 Pumps	Failure of casing	LNG	422	YES	4	0.10	1	N/A	N/A	99	N/A	N/A	N/A	-161	28	1,855	1,800
B07	PIPELINE FROM SECONDARY PUMP TO RU - DISCHARGE	Item FR 3.1.2 Above Ground Pipelines	Total rupture in the pipeline	LNG	422	YES	6	0.15	1	26.5	N/A	99	N/A	N/A	N/A	-161	28	4,600	1,800
B08	REGASIFICATION UNIT (RU)	BEVI	Rupture of 10 pipes at the same time	GAS	1.66	N/A	1.5	0.04	1	N/A	N/A	N/A	N/A	N/A	N/A	5	25	N/A	120

LIST OF SCENARIO'S INPUTS																			
ITEM	EQUIPMENT	REFERENCE	SCENARIO DEFINITION	GAS / LIQ / LNG	DENSITY	BUND	PIPELINE DIAMETER (inch)	HOLE DIAMETER (M)	DISCHARGE COEFFICIENT	PIPELINE LENGTH (m)	VOLUME (m^3)	FILLING DEGREE	H (m)	L(m)	D (m)	OPERATION TEMPERATURE (ºC)	OPERATION PRESSURE (bar)	PUMP NOMINAL RATE (m^3/h)	RELEASE TIME (s)
B09	PIPELINE FROM RU TO GAS METERING STATION	Item FR 3.1.2 Above Ground Pipelines	Total rupture in the pipeline	GAS	1.66	N/A	10	0.25	1	26.5	N/A	N/A	N/A	N/A	N/A	-5	25	N/A	120
B10	PIPELINE FROM FSU TANK TO COMPRESSOR	Item FR 3.1.2 Above Ground Pipelines	Total rupture in the pipeline	GAS	1.66	N/A	6	0.15	1	849	N/A	N/A	N/A	N/A	N/A	19	15	N/A	120
B11	COMPRESSOR	Item FR 3.1.3 Compressors	Rupture (>110mm diameter)	GAS	1.66	N/A	6	0.15	1	N/A	N/A	N/A	N/A	N/A	N/A	19	15	3,011	N/A
B12	PIPELINE FROM COMPRESSOR TO FSU LIQUIFIER - DISCHARGE	Item FR 3.1.2 Above Ground Pipelines	Total rupture in the pipeline	GAS	1.66	N/A	6	0.15	1	22	N/A	N/A	N/A	N/A	N/A	19	15	3,011	N/A
B12	PIPELINE FROM FSU BOC TO FSU LIQUIFIER - DISCHARGE	Item FR 3.1.2 Above Ground Pipelines	Total rupture in the pipeline	GAS	1.66	N/A	6	0.15	1	22	N/A	N/A	N/A	N/A	N/A	19	15	3,011	N/A
B13	PIPELINE FROM FSU LIQUIFIER TO FSU TANK	Item FR 3.1.2 Above Ground Pipelines	Total rupture in the pipeline	LNG	422	YES	4	0.10	1	849	50	50	N/A	N/A	N/A	161	6	n/a	Until empty vessel
ElectroGas layout																			
B01.a	GAS TANKER (RELEASE ON WATER)	See paragraph 10.1 [33] [20]	Rupture of one tank of the Gas tanker due to ship collision	LNG	422	NO	N/A	0.36	N/A	N/A	35,000	95%	N/A	N/A	20.3	-161	1.03	N/A	Until empty vessel
B01.b	GAS TANKER (RELEASE ON WATER)	See paragraph 10.1 [33] [20]	Rupture of one tank of the Gas tanker due to ship collision	LNG	422	NO	N/A	0.5	N/A	N/A	35,000	95%	N/A	N/A	20.3	-161	1.03	N/A	Until empty vessel
B02.a	GAS TANKER TO FSU UNLOADING ARM - LNG (RELEASE ON WATER)	FR 3.3.1 Ship Hardarms admitted for hoses according to Annex C – used as representative of failure in dry disconnection	Total failure rate when three arms (hoses) used	LNG	422	NO	10	0.25	1	15	1	99	N/A	N/A	N/A	-161	4	8,000	Instantaneous
B02.b	GAS TANKER TO FSU UNLOADING HOSE - LNG (RELEASE ON WATER)	FR 3.3.1 Ship Hardarms admitted for hoses according to Annex C – multiplied 0.1 – used as representative of failure in emergency valves closure	Hole = 0.1 cross sectional area of pipe	LNG	422	NO	10	0.03	0.62	15	66.67	99	N/A	N/A	N/A	-161	4	8,000	120

LIST OF SCENARIO'S INPUTS																			
ITEM	EQUIPMENT	REFERENCE	SCENARIO DEFINITION	GAS / LIQ / LNG	DENSITY	BUND	PIPELINE DIAMETER (inch)	HOLE DIAMETER (M)	DISCHARGE COEFFICIENT	PIPELINE LENGTH (m)	VOLUME (m^3)	FILLING DEGREE	H (m)	L(m)	D (m)	OPERATION TEMPERATURE (ºC)	OPERATION PRESSURE (bar)	PUMP NOMINAL RATE (m^3/h)	RELEASE TIME (s)
B03.a	FSU UNLOADING ARM - LNG (RELEASE ON WATER)	FR 3.3.1 Ship Hardarms – used as representative of failure in dry disconnection	GUILLOTINE BREAK Total failure rate when one arm used	LNG	422	NO	12	0.3	1	15	1	99	N/A	N/A	N/A	-161	4	200	Instantaneous
B03.b	FSU UNLOADING ARM - LNG (RELEASE ON WATER)	FR 3.3.1 Ship Hardarms C – multiplied 0.1 – used as representative of failure in emergency valves closure	Hole = 0.1 cross sectional area of pipe	LNG	422	NO	12	0.03	0.62	15	10	99	N/A	N/A	N/A	-161	4	200	120
B04.a	GAS TANKER UNLOADING ARM - GAS RETURN TO GAS TANKER	FR 1.2.3 Ship Hardarms	Release limited according to ERC max content – total	GAS	1.66	N/A	10	0.25	1	15	1	N/A	0	N/A	N/A	-151	1.03	N/A	120
B04.b	GAS TANKER UNLOADING ARM - GAS RETURN TO GAS TANKER	FR 3.3.1 Ship Hardarms	Release limited according to ERC max content – partial	GAS	1.66	N/A	10	0.03	1	15	0.1	N/A	0	N/A	N/A	-151	1.03	N/A	120
B05	PIPELINE FROM FSU TANK TO SECONDARY PUMP - SUCTION (RELEASE ON WATER)	Item FR 3.1.2 Above Ground Pipelines	Total rupture in the pipeline	LNG	422	YES	4	0.10	1	304	N/A	99	N/A	N/A	N/A	-161	1.03	1,860	1,800
B06	SECONDARY PUMP	Item FR 1.2.2 Pumps	Failure of casing	LNG	422	YES	4	0.10	1	N/A	N/A	99	N/A	N/A	N/A	-161	47,5	1,855	1,800
B07	PIPELINE FROM SECONDARY PUMP TO RU - DISCHARGE	Item FR 3.1.2 Above Ground Pipelines	Total rupture in the pipeline	LNG	422	YES	6	0.15	1	26.5	N/A	99	N/A	N/A	N/A	-161	47,5	4,600	1,800
B08	REGASIFICATION UNIT (RU)	BEVI	Rupture of 10 pipes at the same time	GAS	1.66	N/A	1.5	0.04	1	N/A	N/A	N/A	N/A	N/A	N/A	5	45	N/A	120
B09	PIPELINE FROM RU TO GAS METERING STATION	Item FR 3.1.2 Above Ground Pipelines	Total rupture in the pipeline	GAS	1.66	N/A	10	0.25	1	26.5	N/A	N/A	N/A	N/A	N/A	-5	45	N/A	120
B10	PIPELINE FROM FSU TANK TO COMPRESSOR	Item FR 3.1.2 Above Ground Pipelines	Total rupture in the pipeline	GAS	1.66	N/A	6	0.15	1	849	N/A	N/A	N/A	N/A	N/A	19	15	N/A	120
B11	COMPRESSOR	Item FR 3.1.3 Compressors	Rupture (>110mm diameter)	GAS	1.66	N/A	6	0.15	1	N/A	N/A	N/A	N/A	N/A	N/A	19	15	3,011	N/A
B12	PIPELINE FROM COMPRESSOR TO FSU LIQUIFIER - DISCHARGE	Item FR 3.1.2 Above Ground Pipelines	Total rupture in the pipeline	GAS	1.66	N/A	6	0.15	1	22	N/A	N/A	N/A	N/A	N/A	19	15	3,011	N/A

LIST OF SCENARIO'S INPUTS																				
ITEM	EQUIPMENT	REFERENCE	SCENARIO DEFINITION	GAS / LIQ / LNG	DENSITY	BUND	PIPELINE DIAMETER (inch)	HOLE DIAMETER (M)	DISCHARGE COEFFICIENT	PIPELINE LENGTH (m)	VOLUME (m^3)	FILLING DEGREE	H (m)	L(m)	D (m)	OPERATION TEMPERATURE (ºC)	OPERATION PRESSURE (bar)	PUMP NOMINAL RATE (m^3/h)	RELEASE TIME (s)
B12	PIPELINE FROM FSU BOC TO FSU LIQUIFIER - DISCHARGE	Item FR 3.1.2 Above Ground Pipelines	Total rupture in the pipeline	GAS	1.66	N/A	6	0.15	1	22	N/A	N/A	N/A	N/A	N/A	19	15	3,011	N/A
B13	PIPELINE FROM FSU LIQUIFIER TO FSU TANK	Item FR 3.1.2 Above Ground Pipelines	Total rupture in the pipeline	LNG	422	YES	4	0.10	1	849	50	50	N/A	N/A	N/A	161	6	n/a	Until empty vessel
B14	BLEVE OF A PROPANE TANK	BEVI	BLEVE OF A STATIONARY TANK OF PROPANE	LPG	500	NO	N/A	N/A	N/A	N/A	30	85	N/A	N/A	N/A	19	20	N/A	N/A

8. DEVELOPMENT OF ESCALATION SCENARIOS

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.

8.1. FINAL EVENTS

In general, the most common effects are well known, typified and modelled. 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 in the following paragraphs.

<u>Pool Fire</u>

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.

<u>Flammable Gas Cloud</u>

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

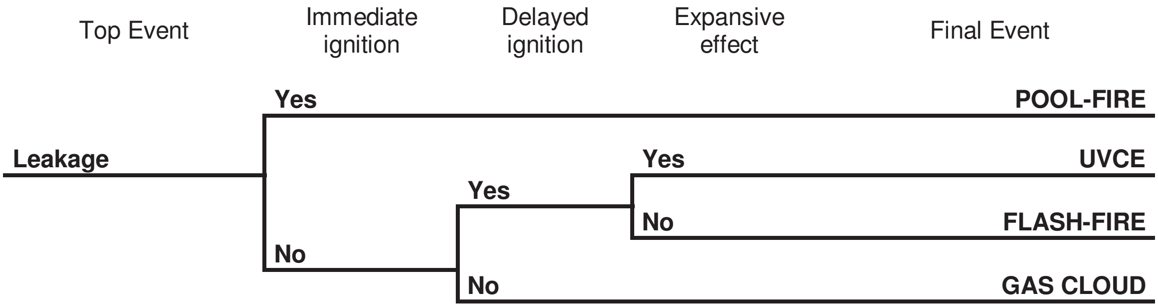
A jet-fire is the direct combustion of a substance leaking from a pressurized vessel. The leakage can be in vapour or in a liquid phase. In this last case, the liquid is spread at high pressure forming fine drops which can be ignited.

8.2. EVENT TREES

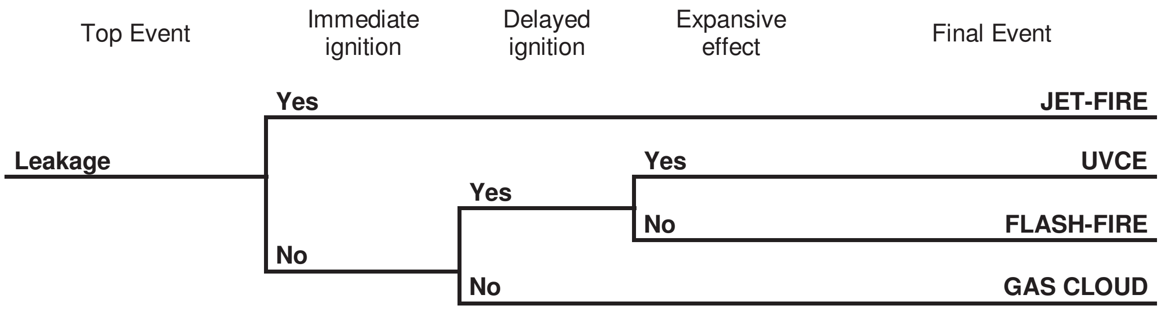
The final effects described in the previous chapter are related to the LOC event by the so-called Event Trees. An event tree is a graphical representation which helps the study of chronological and subsequent events or consequences.

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)



9. ESTIMATION OF CONSEQUENCES

The list of consequences for each scenario, and for each option, is shown in the following tables, together with the output data for each one. Data definitions as follows:

ITEM is referred to the code of the scenarios and allows data crossing between tables;
EQUIPMENT is referred to the vessel / pipe / pump / tanker;
VAPORIZATION (%) is the calculated percentage of liquid which vaporizes after leakage;
MASS FLOW RELEASE (kg/s) is the mass flow rate at which the release takes place;
MASS (kg) is the weight of the quantity released;
VOLUME (m3) is the volume of the quantity released;
PIPELINE SECTION MASS (m3) is the inventory contained in the considered section of the pipe;
TOTAL VOLUME RELEASED (M3) is the volume of the total quantity released;
POOL FIRE AREA (m2) is the surface covered by the extension of the pool fire;
REMARKS is reserved to comments and remarks on the previous data;
POOL FIRE AREA (m2) is referred to the maximum extension on which the pool fire is burning;
EVAPORATION AREA(m2) is referred to the maximum extension on which the gas is evaporating;
EVAPORATION TIME(s) is referred to the minimum duration of the evaporation considered in the calculation;
FLAMMABLE DISPERSION (kg/s) is the flow rate proceeding from the leakage.

LIST OF SCENARIO'S CONSEQUENCES													
ITEM	EQUIPMENT	VAPORIZATION (%)	MASS FLOW RELEASE (kg/s)	MASS (kg)	VOLUME (m^3)	PIPELINE SECTION MASS (m^3)	TOTAL VOLUME RELEASED (m^3)	POOL FIRE AREA (m^2)	REMARKS	POOL FIRE AREA (m2)	EVAPORATION AREA (m2)	EVAPORATION TIME (s)	FLAMMABLE DISPERSION (kg/s)
Consultant layout													
B01.a	GAS TANKER (RELEASE ON WATER)	99	926	1.09E+07	35,000	N/A	0.00	10,000	Hole height 10.15 m	10,000	10,000	1,800	732
B01.b	GAS TANKER (RELEASE ON WATER)	99	1769	1.09E+07	35,000	N/A	0.00	10,000	Hole height 10.15 m	10,000	10,000	1,800	856
B02.a	GAS TANKER UNLOADING ARM - LNG (RELEASE ON WATER)	100	4,2	500	1,2	0	1,2	Unconfined	Open water	Open water	400	1,800	28
B02.b	GAS TANKER UNLOADING ARM - LNG (RELEASE ON WATER)	100	0,42	50	0,12	0	0,12	Unconfined	Open water	Open water	70	1,800	5
B03.a	FSU UNLOADING ARM - LNG (RELEASE ON WATER)	100	353.00	42360.00	100.38	0.00	100.38	10037.91	Unconfined	Unconfined	10,000	1,800	353
B03.b	FSU UNLOADING ARM - LNG (RELEASE ON WATER)	100	2.18	261.60	0.62	0.00	0.62	62	Unconfined	62	62	1,800	2.18
B04.a	GAS TANKER UNLOADING ARM - GAS RETURN TO GAS TANKER	N/A	1.56	9265	5578.64	N/A	772.52	N/A		N/A	N/A	N/A	1.56
B04.b	GAS TANKER UNLOADING ARM - GAS RETURN TO GAS TANKER	N/A	0.033	1265	761.68	N/A	0.00	N/A		N/A	N/A	N/A	0.033
B05	PIPELINE FROM FSU TANK TO SECONDARY PUMP - SUCTION (RELEASE ON WATER)	100	218.00	122540.00	290.38	N/A	290.38	29037.91		1,500	1,500	1,800	65.94
B06	SECONDARY PUMP	100	217.35	3.64E+06	8.62E+03	N/A	8617.30	861729.86		1,500	1,500	1,800	49
B07	PIPELINE FROM SECONDARY PUMP TO RU - DISCHARGE	100	539.25	970650	2300.12	0	2300.12	230011.84	Limited	1,500	1,500	1,800	53
B08	REGASIFICATION UNIT (RU)	100	12.80	1536	924.86	0	924.86	N/A		1,500	1,500	1,800	1,848

LIST OF SCENARIO'S CONSEQUENCES

ITEM	EQUIPMENT	VAPORIZATION (%)	MASS FLOW RELEASE (kg/s)	MASS (kg)	VOLUME (m^3)	PIPELINE SECTION MASS (m^3)	TOTAL VOLUME RELEASED (m^3)	POOL FIRE AREA (m^2)	REMARKS	POOL FIRE AREA (m2)	EVAPORATION AREA (m2)	EVAPORATION TIME (s)	FLAMMABLE DISPERSION (kg/s)
B09	PIPELINE FROM RU TO GAS METERING STATION	N/A	188.45	22614	13616.33	N/A	13616.33	N/A		N/A	N/A	N/A	189
B10	PIPELINE FROM FSU TANK TO COMPRESSOR	N/A	47.672	5720.64	3444.51	N/A	3444.51	N/A		N/A	N/A	N/A	49
B11	COMPRESSOR	N/A	1.49	N/A	N/A	N/A	N/A	N/A		N/A	N/A	N/A	49
B12	PIPELINE FROM COMPRESSOR TO FSU LIQUIFIER - DISCHARGE	N/A	33.48	N/A	N/A	N/A	N/A	N/A	Pipeline length input data has been modified to be realistic with the compressor operability	N/A	N/A	N/A	33
B12	PIPELINE FROM FSU BOC TO FSU LIQUIFIER - DISCHARGE	N/A	1.49	N/A	N/A	N/A	N/A	N/A	Pipeline length input data has been modified to be realistic with the compressor operability	N/A	N/A	N/A	1.5
B13	PIPELINE FROM FSU LIQUIFIER TO FSU TANK	100	9.15	13,479	31.95	0	31.94	2,206	Pipeline length input data has been modified to be realistic with the compressor operability	Confined	2,206	1,800	9.15
ElectroGas layout													
B01.a	GAS TANKER (RELEASE ON WATER)	99	926	1.09E+07	35,000	N/A	0.00	10,000	Hole height 10.15 m	10,000	10,000	1,800	732
B01.b	GAS TANKER (RELEASE ON WATER)	99	1769	1.09E+07	35,000	N/A	0.00	10,000	Hole height 10.15 m	10,000	10,000	1,800	856
B02.a	GAS TANKER UNLOADING HOSE - LNG (RELEASE ON WATER)	100	Instantaneous	422	1	0	1	200	Release on water	200	200	1,800	28
B02.b	GAS TANKER UNLOADING HOSE - LNG (RELEASE ON WATER)	100	1407	28,133.33	66.67	N/A	66.67	Unconfined	Open water	Open water	Unconfined	1,800	1918
B03.a	FSU UNLOADING ARM - LNG (RELEASE ON WATER)	100	Instantaneous	422	1	0	1	200	Release on water	200	200	1,800	28
B03.b	FSU UNLOADING ARM - LNG (RELEASE ON WATER)	100	35.17	4,220	0.67	N/A	4,220	Unconfined	Open water	Open water	Unconfined	1,800	33.2

LIST OF SCENARIO'S CONSEQUENCES													
ITEM	EQUIPMENT	VAPORIZATION (%)	MASS FLOW RELEASE (kg/s)	MASS (kg)	VOLUME (m^3)	PIPELINE SECTION MASS (m^3)	TOTAL VOLUME RELEASED (m^3)	POOL FIRE AREA (m^2)	REMARKS	POOL FIRE AREA (m2)	EVAPORATION AREA (m2)	EVAPORATION TIME (s)	FLAMMABLE DISPERSION (kg/s)
B04.a	GAS TANKER UNLOADING ARM - GAS RETURN TO GAS TANKER	N/A	61.01	7321.20	4409.83	N/A	4409.83	N/A	N/A	N/A	N/A	N/A	1.56
B04.b	GAS TANKER UNLOADING ARM - GAS RETURN TO GAS TANKER	N/A	0.38	45.60	27.47	N/A	27.47	N/A	N/A	N/A	N/A	N/A	0.033
B05	PIPELINE FROM FSU TANK TO SECONDARY PUMP - SUCTION (RELEASE ON WATER)	100	218.00	122,540.00	290.38	N/A	290.38	29037.91		1,500	1,500	1,800	65.94
B06	SECONDARY PUMP	100	254.91	458,838	1,087.29	N/A	1,087.29	108,729		1,500	1,500	1,800	49
B07	PIPELINE FROM SECONDARY PUMP TO RU - DISCHARGE	100	679,26	1,222,668	2897.32	0	2897.32	289,731.75	Limited	1,500	1,500	1,800	53
B08	REGASIFICATION UNIT (RU)	100	6224,6	746,952	449,754	0	449,754	N/A		1,500	1,500	1,800	6224,6
B09	PIPELINE FROM RU TO GAS METERING STATION	N/A	348,37	41804	25171	N/A	25,171	N/A		N/A	N/A	N/A	348,37
B10	PIPELINE FROM FSU TANK TO COMPRESSOR	N/A	47.672	5,720.64	3444.51	N/A	3,444.51	N/A		N/A	N/A	N/A	49
B11	COMPRESSOR	N/A	1.49	N/A	N/A	N/A	N/A	N/A		N/A	N/A	N/A	49
B12	PIPELINE FROM COMPRESSOR TO FSU LIQUIFIER - DISCHARGE	N/A	33.48	N/A	N/A	N/A	N/A	N/A	Pipeline length input data has been modified to be realistic with the compressor operability	N/A	N/A	N/A	33
B12	PIPELINE FROM FSU BOC TO FSU LIQUIFIER - DISCHARGE	N/A	1.49	N/A	N/A	N/A	N/A	N/A	Pipeline length input data has been modified to be realistic with the compressor operability	N/A	N/A	N/A	1.5
B13	PIPELINE FROM FSU LIQUIFIER TO FSU TANK	100	9.15	13,479	31.95	0	31.94	2,206	Pipeline length input data has been modified to be realistic with the compressor operability	Confined	2,206	1,800	9.15

LIST OF SCENARIO'S CONSEQUENCES													
ITEM	EQUIPMENT	VAPORIZATION (%)	MASS FLOW RELEASE (kg/s)	MASS (kg)	VOLUME (m^3)	PIPELINE SECTION MASS (m^3)	TOTAL VOLUME RELEASED (m^3)	POOL FIRE AREA (m^2)	REMARKS	POOL FIRE AREA (m2)	EVAPORATION AREA (m2)	EVAPORATION TIME (s)	FLAMMABLE DISPERSION (kg/s)
B14	BLEVE OF A PROPANE TANK	N/A	N/A	15,015	30	N/A	30	N/A	N/A	N/A	N/A	N/A	N/A

9.1. DOMINO EFFECT ON EXISTING DPS AND ON PROPOSED CCGT

Domino effects resulting from the proposed regasification plant in the Marsaxlokk Bay and with effects on the existing Delimara Power Station and on proposed CCGT Power Plant, is evaluated in this chapter.

The article no. 8 of the European Communities Council Directive on the Control of mayor hazards involving hazardous substances states:

> *Member States shall ensure that the competent authority, using the information received from the operators in compliance with Article 6 and 9, identifies establishments and groups of establishments or where the likelihood and the possibility of consequences of a mayor accident may be increased because of the location and the proximity of such establishments, and their inventories of dangerous substances.*

In order to address these issues the Health and Safety Executive (HSE) reviewed the previous work on domino effects and edited the document "*Development of methods to assess the significance of domino effects from major hazard sites*[4]" which collects the methodologies for determining the additional risks from domino effects between sites and summarizes the values considered to be most appropriate for use in a Domino Assessment.

In the framework of domino effect analysis, the risk of explosion and fire, characterized by the possibility of an accident in an industrial site may lead to serious consequences for the surrounding process equipment, people, goods and environment. These latter can generate four main events that may affect and/or cause the failure of the surrounding process equipments/units:

- Fire
- Explosion
- Toxic Release
- Other hazardous releases

In ENEMALTA case, the relevant mechanisms by which a potential domino effect could take place are fire and explosion; their main characteristics are described below:

[4] WS Atkins Safety & Reliability for the Health and Safety Executive (HSE) (1998) *Development of methods to assess the significance of domino effects from major hazard sites*.

Fire

Effect of fire depends on:

- Passive fire protection
- Fire walls
- Line of sight effects (blocking by others structures, vessels, walls)
- Active fire protection
- Fire load
- Flaring/dump tanks to reduce the inventory of the escaping material

Careful consideration needs to be deserved to whether "fire spread" events should be classified as domino events. A fire may spread due to a burning liquid flowing from one plant area to another, where it causes further hazardous events, or else a fire could spread via combustion of intervening combustible material.

Fire spread depends on:

- Availability of a route for the fire/burning material/gas/liquid to spread along (such as open ground, roads, natural or manmade drainage channels, drains, etc...
- Proximity of combustible material
- Fire walls
- Ditches, dikes, slopes, bunds, kerbs to prevent spread of burning liquid (topographic effects)
- Flashover effects
- Active fire prevention may possible if fire spread is gradual
- Effect of wind spreading fire
- Communication between plants

Another type of fire is the jet fire event. In this case, the jet flames can arise from pressurized releases of gases and liquids. It is considered that in most cases of a jet fire with large hazard range, the jet fire will only give rise to a transient (short duration) hazard since it will involve a large pressurized release from process or storage plant which have a limited inventory. If the leak is being fed from a pipeline bringing material to the site, then it is expected that this will be isolatable so as to limit the duration of the release.

Finally, the case of a flash fire has to be considered. Flash fire is the ignition of a cloud of flammable vapours. In this case, the phenomenon is transient and the combustion takes place in a few seconds. The increase of temperature associated and the thermal radiation is minimum in comparison with a permanent fire, thus no damage is expected on the equipment and domino effect is detected in real cases, even if injuries to people and impact on environment can be important.

Explosion

Explosion can provide vectors for domino escalation in terms of the effects of blast overpressure and missiles.

Blast overpressure

- Blast walls
- Shielding by structures/vessels
- Blast wave amplification effects
- Vessel supports
- Vessel thickness
- Collapse of material above target
- Orientation of target to blast wave
- Weight of vessel inventory

Missiles

- Minimum mass/velocity required to cause damage
- Missile trajectory
- Missile shape
- Vessel thickness / material of construction / pre-stressing levels
- Shielding by others structures
- Distribution of missile sizes
- Target size/length
- Number of pipes close together

A gas explosion is defined as a process where combustion of a premixed gas cloud is causing rapid increase of pressure. Gas explosions can occur inside process equipment or pipes, in buildings or offshore modules, in open process areas or in unconfined areas.

The pressure generated by the combustion wave will depend on how fast the flame propagates and how the pressure can expand away from the gas cloud (governed by confinement). The consequences of gas explosions range from no damage to total destruction. The pressure wave caused by the gas explosion can damage personnel and material or it can lead to accidents such as fires.

When a cloud is ignited the flame can propagate in two different modes through the flammable parts of the cloud. These modes are:

a) deflagration
b) detonation

The deflagration mode of flame propagation is the most common. A deflagration propagates at subsonic speed relative to the unburnt gas, typical flame speeds (i.e. relative to a stationary observer) are of the order of 1-1000 $m \cdot s^{-1}$. The explosion pressure may reach values of several barg, depending on the flame.

A detonation wave is a supersonic (relative to the speed of sound in the unburnt gas ahead of the wave) combustion wave. The shock wave and the combustion wave are in this case coupled. In a fuel-air cloud a detonation wave will propagate at a velocity of 1500-2000 $m \cdot s^{-1}$ and the peak pressure is typically 15-20 bar.

The consequences of a gas explosion will depend on:

- type of fuel and oxidiser
- size and fuel concentration of the combustible cloud
- location of ignition point
- strength of ignition source
- size, location and type of explosion vent areas
- location and size of structural elements and equipment
- mitigation schemes

Gas explosions may be very sensitive to changes in these factors. Therefore it is not a simple task to estimate the consequences of a gas explosion.

As a result of a violent gas explosion walls or decks may start to move or even break down and fragment. Pipes that are suspended on a moving wall may be sheared off (i.e. guillotine break) as a result of the relative movement of the points of suspension. Piping from one module to another module may have to respond to relative movements of the structure. Cables and control lines may also be damaged by this type of relative movement.

An important aspect of damage to buildings is whether the integrity of buildings survives. Damage to a building in case of an accidental gas explosion is not a serious problem as long as the building is not collapsing or dangerous fragments are generated within or from the building. This is equally important for buildings subjected to blast loads from the outside as well as buildings with possibilities of internal explosions.

DAMAGE CRITERIA

The events previously described can lead to domino effects depending on the resistance of materials. In this chapter, several thresholds for each effects are discussed and final threshold for the project is presented.

Thermal radiation

When considering process plant, most studies in the past have considered only the intensity and neglected the exposure duration. In case of process plant that is subjected to steady thermal radiation intensity, the temperature of the material exposed will increase until a steady state temperature is reached. In order to define an allowable radiation intensity, some criteria are generally used which are derived from avoidance of unacceptable effects which would occur at higher temperature (loss of structural properties of materials,)

In conclusion of the exposed by HSE, the damage criteria for the domino effect derived from thermal radiation scenarios are shown below:

THERMAL RADIATION DAMAGE CRITERIA	
ITEM	**THERMAL RADIATION FLUX (kW / m^2)**
Pressure vessels	37.5
Atmospheric Storage Tanks	37.5
Pipework	37.5
Water deluged pipework and vessels	-
Buildings	12.5
Control Buildings	25
People	1000 tdu

As a conservative approach, domino effects should be studied where the thermal flux can exceed 37.5 kW/m^2.

Overpressure

For the overpressure effects, damage criteria are based on empirical data. An overview of the data in the literature has been undertaken by TNO[5]:

ITEM	OVERPRESSURE (kPa)
Connections between steel and aluminium ondulated plates have failed	7-14
Walls made of concrete blocks have collapsed	15-20

[5] TNO, *Methods for the Determination of Possible Damage to People and Objects Resulting from Releases of Hazardous Materials, 1979*

ITEM	OVERPRESSURE (kPa)
Brickstone walls, 20-30 cm have collapsed	50
Minor damage to steel frames	8-10
Collapse of steel frames and displacement of foundation	20
Industrial steel self-framing structure collapsed	20-30
Cladding of light industry building ripped-off	30
The roof of a storage tank has collapsed	7
The supporting structure of a round storage tank has collapsed	100
Cracking in empty oil-storage tanks	20-30
Displacement of a cylindrical storage tank, failure of connecting pipes	50-100
Damage to a fractionating column	35-80
Slight deformation of a pipe-bridge	20-30
Displacement of a pipe-bridge, breakage of pipes	35-40
Collapse of a pipe bridge	40-55
Plating of cars and trucks pressed inwards	35
Breakage of wooden telephone poles	35
Loaded train carriages turned over	50
Large trees have fallen down	20-40

Additionally, the *Gas Explosion Handbook*[6] notes that an important aspect of damage to buildings is whether the integrity of buildings survives. Damage to a building in case of an accidental gas explosion is not a serious problem as long as the building is not collapsing or dangerous fragments are generated within or from the building. This is equally important for buildings subjected to blast loads from the outside as well as buildings with possibilities of internal explosions.
Buildings made of pre-fabricated walls and roof will often collapse when subjected to explosion loads. As shown in the table, ordinary brick walls are also weak. In case of an internal explosion the brick wall will disintegrate and cause dangerous fragments.

Ordinary window glass will typically fail at 20-70 mbarg and cause dangerous flying fragments. As shown by Harris [9,7] glass fragments can fly more than 20 m when the breaking pressure is about 0.25 barg. The velocity of these fragments will be up to 30 or 40 $m \cdot s^{-1}$ (approx. 100 $km \cdot h^{-1}$). To use ordinary window glass in areas where there is an explosion hazard is not recommended. Use blast resistant glass[8] and make the windows as small as possible. The

[6] D. Bjerketvedt, J.R.Bakke, Gas Explosion Handbook, Journal of Hazardous Materials 52 (1997)
7 R.J. Harris, M.R. Marshall, D.J. Moppett, (1977) The response of glass windows to explosion pressure, Symp. Series No.49, IChemE.
8 G. Mayer, A review of adaptable methodology for development of a design procedure for blast hardened windows, US Naval Civil Engineering Laboratory, 2528 SP, Port Hueneme, CA. (1982).

window frames must be as strong as the window itself. If ordinary windows are replaced by blast resistant windows, the frame also has to be changed. If the frame is weaker than the window, the window will fly out as one piece.

TYPICAL FAILURE PRESSURES OF SOME STRUCTURAL BUILDING ELEMENTS UNDER GAS EXPLOSION CONDITIONS [9]	
STRUCTURAL ELEMENT	**TYPICAL FAILURE PRESSURE (mbarg)**
Glass windows	20-70
Room doors	20-30
Light partition walls	20-50
50 nm thick breezeblock walls	40-50
Unrestrained brickwalls	70-150

In conclusion of the exposed by the Gas Explosion Handbook and by HSE, the damage criteria for the domino effect derived from blast overpressure scenarios are shown below:

BLAST DAMAGE CRITERIA		
ITEM	**OVERPRESSURE RESULTING IN DESTRUCTION (bar)**	**OVERPRESSURE RESULTING IN PARTIAL DAMAGE (bar)**
Pressure vessels	0.48	0.38
Fixed Roof Storage Tanks	0.21	0.07
Floating Roof Storage Tanks	0.45	0.45
Ordinary plant buildings	0.07	0.01
Control Buildings		Depends on design
People - outdoors	0.14	-
People - indoors	0.16	-
Pipework	0.4	0.24

As a result of the values presented in the HSE report and applying a conservative approach, the evaluation limit has been set to 160 mbar.

[9] R.J. Harris, The investigation and control of gas explosions in buildings and heating plants, British Gas and F.N. Spon (1983).

ANALYSIS OF RESULTS

Threshold values of 37.5 kW/m^2 for thermal radiation in case of LNG pool fire and 160 mbar for overpressure in case of gas explosion have been adopted. Thus, pool fires can be easily neglected from the study, being very limited the distance at which the threshold value can be detected. Therefore, analysis is focused on the effects of explosions.

The following table shows the distances achieved by domino effect for the scenarios studied on the preliminary QRA study.

SCENARIO	COORDINATES		METEO STABILITIES			
	X (m)	Y (m)	D3	D9	E5	F2
B01a - VCE	459717	3964826	45	---	37	179
B01b - VCE	459717	3964826	45	23	35	245
B01c - VCE	459717	3964826	36	15	35	45
B02a - VCE	459689	3964808	119	85	123	98
B02b - VCE	459689	3964808	38	16	32	37
B03a - VCE	459691	3964807	75	54	79	54
B03b - VCE	459691	3964807	14	15	14	---
B04a - VCE	459689	3964808	125	71	78	37
B04b - VCE	459689	3964808	38	17	32	37
B05 - VCE	459717 459718 459759 459857 459944 459959	3964821 3964807 3964808 3964911 3965006 3965008	74	68	68	105
B06 - VCE	459960	3965014	28	---	19	40
B07 - VCE	459979 459980 459959	3964993 3965014 3965015	32	15	23	41
B08 - VCE	459978	3964995	17	10	15	25
B09 - VCE	459959 459955 459955 459991 459001 459003	3965015 3965015 3965030 3965030 3965030 3965182	76	57	73	76
B10 - VCE	**---**	**---**	---	---	---	---
B11 - VCE	**---**	**---**	---	---	---	---
B12 - VCE	**---**	**---**	---	---	---	---
B13 - VCE	**---**	**---**	---	---	---	---

The final contour resulting from the overlap of all the selected distances from their release point, is presented for ElectroGas layout in drawing # 12.

It is easy to conclude that, in case of gas release in the proposed regasification station and subsequent ignition, the overpressure generated would not reach values over the 160 mbar on the closest obstacles in the DPS (oil tank walls) and on CCGT Power Station.

Thus, an oil spill out of the containment basin or collapse of the structures of the CCGT Power Station as a result of a domino effect is not expected, even if minor damages on the tanks can appear as a result of the projection of fragments.

9.2. OTHER CRITERIA FOR RISK MINIMISATION

Additionally to the findings shown in the previous chapters, other criteria should be considered in order to choose the suitable option for minimising the risk over the population and the surroundings.

Even if the frequencies for a pipe or vessel failure, and therefore, for an LNG leakage are reduced, and the final risk contour is acceptable, the tremendous difference is between a leakage without damages and the ignition of the same leakage must be considered as a decisive factor. Focusing the attention on the event tree shown in chapter 8.2, it's easy to perceive how significant the difference between the dispersion of the gas cloud without any final effect and the immediate or delayed ignition, which can eventually lead to an explosion.

Thus, in this chapter a selection of the maximum extension of the calculated gas clouds is made, based on the maximum length and the frequency of the top event. Scenarios with a frequency below 1E-09 are discarded. The results are shown in the following tables. Also, the final contour resulting from the overlap of all the selected distances from their release point is presented for consultant and ElectroGas layout in drawings #9 and 10 and compared in drawing # 11.

Gas cloud extensions – Consultant layout					
Scenario	Frequency	UTM (x)	UTM (y)	Flash fire contour	Remarks
B01.a	--	459605	3964999	129	
B01.b	--	459605	3964999	133	
B01.c	--	459605	3964999	138	
B02.a	1.30E-05	459626	3964995	532	
B02.b	1.60E-05	459626	3964995	320	
B03.a	1.30E-05	459693	3965024	962	
B03.b	1.60E-05	459693	3965024	36	
B04.a	7.00E-06	459626	3964995	150	
B04.b	8.00E-06	459626	3964995	13	
B05	6.50E-09	pipeline		--	Discarded
B06	3.00E-05	459799	3965197	192	
B07	6.50E-09				Discarded
B08	1.00E-06	459797	3965217	558	
B09	6.50E-09	pipeline		---	Discarded
B10	6.50E-09	pipeline		--	Discarded
B11	2.90E-06	459799	3965236	32	
B12	6.50E-09	pipeline		--	Discarded
B13	6.50E-09	pipeline		--	Discarded

Gas cloud extensions – ElectroGas layout					
Scenario	Frequency	UTM (x)	UTM (y)	Flash fire contour	Remarks
B01.a	--	459717	3964826	129	
B01.b	--	459717	3964826	133	
B01.c	--	459717	3964826	138	
B02.a.rev	8,00E-07	459689	3964808	38	
B02.b.rev	1,60E-06	459689	3964808	526	
B03.a.rev	8,00E-07	459961	3964807	38	
B03.b.rev	1,60E-06	459961	3964807	221	
B04.a.rev	2,00E-07	459689	3964808	150	
B04.b.rev	4,00E-07	459689	3964808	13	
B05	6.50E-09	pipeline		--	Discarded
B06.rev	3.00E-05	459960	3965014	276	
B07.rev	6.50E-09				Discarded
B08.rev	1.00E-06	459978	3964995	122	
B09.rev	6.50E-09	pipeline		---	Discarded
B10	6.50E-09	pipeline		--	Discarded
B11	2.90E-06	459975	3965036	32	
B12	6.50E-09	pipeline		--	Discarded
B13	6.50E-09	pipeline		--	Discarded

The analysis of the drawing shows that for consultant layout, there is an extremely large gas cloud, which cannot be discarded by frequency. This is associated with the ship to shore unloading arm, permanently connected between the floating unit and the onshore plant. This gas cloud proceeds from a pool of LNG spilled onto the water due to the failure of the unloading arm connecting the FSU to the onshore RU.

This risk can be easily limited adopting special technologies not normally adopted for unloading arms (hence the high frequency), limiting the extension of a pool in the case of LNG spillage or implementing a hydro-shield system around the area which disperses and dilutes the flammable cloud. Thus this extremely large cloud can be discarded for the generation of the final contour.

In the ElectroGas layout, this scenario can be included in the calculation, being the maximum distance lower than 550 meters, due to expected introduction of specific safeguards (ERC) in the ship to ship and ship to shore connections.

With the remaining contours, it's easy to see how a flammable gas cloud can rapidly travel from the release point to some part of the Delimara peninsula or to the existing Delimara Power Station. Specially in the DPS, a large number of different ignition points would be present, so that ignition in this zone is almost certain.

In order to reduce the possibility of an ignition, the part of the plant located on the jetty and involved in the cloud generation, can be relocated and the distance between the release point and the possible ignition point can be increased.

Drawing # 13 shows the position initially proposed by consultant for the unloading arm of the permanently moored FSU. The unloading arm has been chosen as the central point of any FSU installation and the origin of the major spillage of LNG. The red contour is the maximum distance at which a cloud of gas can travel with a concentration higher than the lower flammability limit. The aim of this drawing is to suggest (in green in the drawing) a position for the jetty which ensures that no ignition point is found in the range of the cloud. This can easily be done for the existing facilities, the Freeport and the rest of the bay. The only ignition points which cannot be avoided are those in the Delimara peninsula and passing boats in the harbour. Also, in case of ignition, the flash fire would be limited to the water surface and south of Delimara peninsula, reducing the damage to the population and the DPS, which must be protected against any possible flash-fire, being the main power plant on the island.

ElectroGas layout is follows the suggested layout and seems to increase the safety distances from the coastline, proposing a position of the jetty located a few meters south of the suggested.

Regarding the presence of a dolphin, used for fuel unloading to onshore facilities, it can be kept in place if the jetty is located on east side of the part marked in red, otherwise have to be removed in order to reduce the possibility of a collision or spillage from other tankers affecting the LNG tanker. Also, the unloading operation at existing the dock in DPS is out of the red contour and is not affected nor affecting.

10. ESTIMATION OF LIKELIHOOD

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 [22][19] and have been adapted to the period of use of the facilities, especially in the case of the LNG unloading facilities.

10.1. IMPACT FREQUENCY OF MANOEUVRING SHIPS ON LNG TANKER OR FSU/FSRU

The impact frequency cannot be directly extracted from bibliographical sources, but should be estimated depending on surrounding conditions.

From the data presented in chapter 2.7, and depending on manoeuvring routes, the probability of impact can be estimated, considering the following general topics:

- Impact between two manoeuvring ships
- Impact between a manoeuvring ship and a moored ship
- Impact of a ship due to grounding
- Impact of moored ship with the jetty or dock

Also, the final results of an impact can be associated with the gross weight of the moving ship and its velocity. The higher the weight and the velocity at the moment of the impact, the larger the size of the hole would be in the affected tanker. Generally, operation in a port area can be subdivided by ship classes according to the naval register. Also, manoeuvring velocity is limited by port pilots according to the ship class. Thus, from the general statistic, percentage of each class presence can be extracted. For the Marsaxlokk Bay, the data is not disaggregated and the manoeuvring routes are not available, so that the impact frequency is only a first and overestimated approach to the real impact frequency.

The calculation of the frequency was done on the following basis:

TYPE OF DATA	External impact on moored LNG tanker (all options)	External impact on moored FSU / FSRU
Impact probability per visit [33]	5,00E-05	5,00E-05
Release probability in case of major accident [33], [20]	1,20E-04	1,20E-04
Release probability in case of minor accident [33], [20]	2,50E-02	2,50E-02
Moored ships presence per year	1,11E+02	8,76E+03
Manoeuvring ships per year	2150	2150
Total impact probability (impact probability per number of manoeuvring ships)	1,08E-01	1,08E-01
Total release frequency due to a major impact	1,63E-07	1,29E-05
Total release frequency due to a minor impact	3,41E-05	3,41E-05

The final data must be considered as an overestimation of the frequency, because all passing ships are considered sensitive for an impact, while most of them are manoeuvring close to Freeport and their routes are not compatible with a collision on the moored LNG tanker or FSU/FSRU, even in case of engine failure, propeller failure, mooring rope breakage, etc.

10.2. UNLOADING HOSES AND ARMS FAILURE FREQUENCY

After finding out the initial details of the project from ElectroGas, and specifically, the proposed use of hoses instead of arms, as initially considered in this report, it is necessary to introduce a discussion about the frequencies to be considered.

As a first choice for the whole project, frequencies from HSE guidelines [22] were taken into consideration when available and complemented with frequencies from BEVI guidelines [19] when not. Frequencies for ship unloading arms are specifically tabulated in the HSE Frequency Report. Being necessary to update this frequency to a ship unloading hose, the first thing to do is to check availability of this frequency in the same reference. Unfortunately, the chapter referred to ship unloading does not include any reference to the use of hoses, probably because the use of classic hoses (rubber tube covered and protected by metal coil or wires and supported by cranes) has been discouraged for hazardous materials unloading in the past twenty years. In the meanwhile, the introduction of a new generation of hoses, with higher protection, higher flexibility and improved resistance to thermal shocks, has made hoses an interesting alternative for specific activities again, and a challenging issue for the introduction of hoses in QRAs, the frequency not yet being available in the guidelines.

A second choice may be represented by the frequency calculated for hoses for general purposes in the same HSE guidelines, but the data seems to be too generic and clearly related to truck unloading activities.

A third choice can be represented by the use of hose frequencies from BEVI guidelines, where they are published in contrast with arms frequencies, both for general unloading purposes. In this case the frequency is much higher than expected, non comparable with the frequency from HSE and absolutely out of range for special hoses, provided with dry coupling.

A fourth choice could be the use of the same failure frequency as per arms, but introducing a corrective factor calculated from the comparison of frequencies for arms and hoses published in BEVI. In this case, the result would be highly unrealistic, the calculated factor increasing the frequency by 133 times and making this scenario one of the weakest points in the whole installation.

Additionally, the frequencies tabulated in both sources are presented with different and non comparable units (one over operations in the first case and one over hours in the second case).

In conclusion, none of the options listed above represent a clear solution to the question of updating the frequency, thus the recommendation is to apply to hoses the same frequency as for arms.

For this reason, use of hoses instead of hardarms has been investigated further with consultants from ElectroGas and evidence of the high reliability and safety of the LNG hoses in comparison with generic hardarms have been collected in Annex C.

10.3. 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 chapter 8. In the case of natural gas, the probability of each final event scenario depends on the ignition frequency.

The ignition frequency is considered to be 0.065 for immediate ignition and variable depending on the release rate for delayed ignition and for a low reactivity gas, such as methane, as shown in the following table [20].

Release rate	Frequency	Value
<10 kg/s	Delayed Ignition Small	0.02
10-100 kg/s	Delayed Ignition Medium	0.04
>100 kg/s	Delayed Ignition Large	0.09

10.4. EVENT TREES

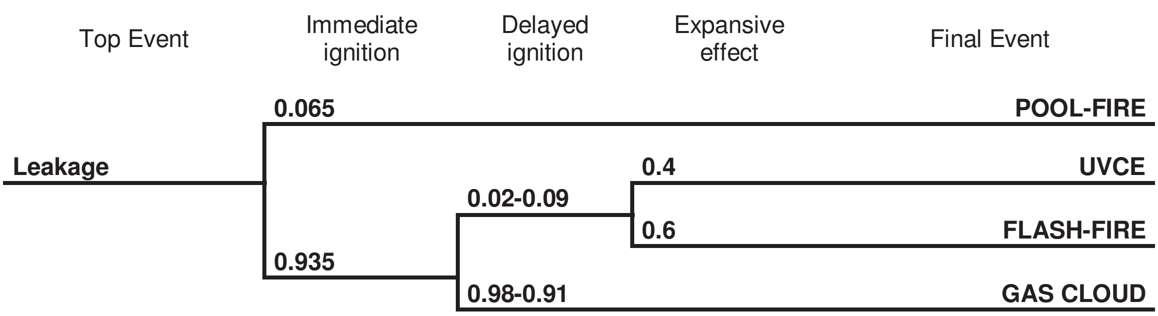
Starting from the literature, the goal is to quantify the probability of events that determine the evolution from the initial event and end up causing damage. This can be done by using the event tree technique.

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.

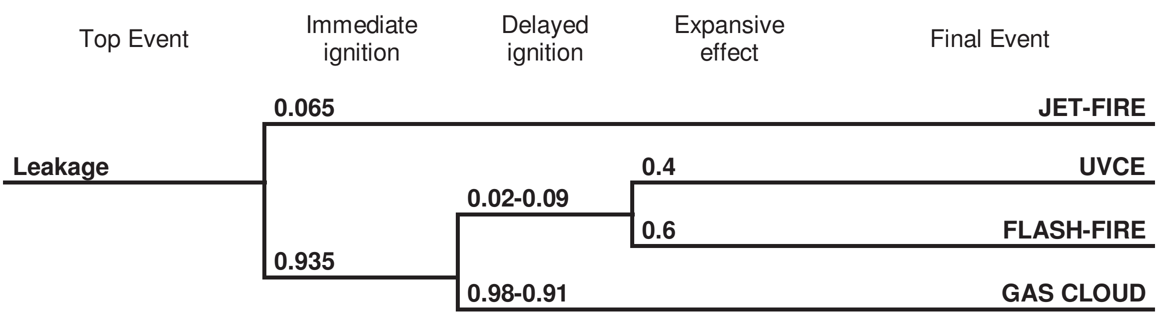
From the initial failure or initiator and considering the conditioning factors involved, the tree describes the accident sequences leading to possible events. The construction and evaluation of the tree begins by identifying the conditions and their probabilities of occurrence of each of them.

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.

Event tree for liquid release (LNG)



Event tree for gas release (GAS PHASE)



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

LIST OF SCENARIO'S FREQUENCIES										
ITEM	EQUIPMENT	FAILURE FREQUENCY	UNITS	OPERATING	UNITS	WEIGHTED FREQUENCY	UNITS	POOL FIRE / JET FIRE FREQUENCY	FLASH FIRE FREQ	REMARKS
Consultant layout										
B01.a	GAS TANKER (RELEASE ON WATER)	1.63E-07	y-1	-	-	1.63E-07	y-1	1.06E-08	1.38E-08	Related: impacts/visits
B01.b	GAS TANKER (RELEASE ON WATER)	3.41E-05	y-1	-	-	3.41E-05	y-1	6.37E-07	2.87E-06	Related: impacts/visits
B02.a	GAS TANKER TO FSU UNLOADING ARM - LNG (RELEASE ON WATER)	1.30E-05	op.-1	111 hours 8 operations	h Op.	2.41E-07	y-1	6.76E-06	8.75E-06	Total failure rate when 2 arms used
B02.b	GAS TANKER TO FSU UNLOADING ARM - LNG (RELEASE ON WATER)	1.60E-05	op.-1	111 hours 8 operations	h Op	3.04E-07	y-1	8.32E-06	4,79E-06	Total failure rate when 2 arms used
B03.a	FSU UNLOADING ARM - LNG (RELEASE ON WATER)	1.30E-05	op.-1	8,760	h	1.30E-05	y-1	8.45E-07	1.09E-06	Total failure rate when 2 arms used
B03.b	FSU UNLOADING ARM - LNG (RELEASE ON WATER)	1.60E-05	op.-1	8,760	h	1.60E-05	y-1	1.46E-06	5.98E-07	Total failure rate when 2 arms used
B04.a	GAS TANKER UNLOADING ARM - GAS RETURN TO GAS TANKER	7.00E-06	op.-1	8,760 hours Continuos operation	h	7.00E-06	y-1	5.77E-09	1.66E-09	Total failure rates when one arm used

LIST OF SCENARIO'S FREQUENCIES										
ITEM	EQUIPMENT	FAILURE FREQUENCY	UNITS	OPERATING	UNITS	WEIGHTED FREQUENCY	UNITS	POOL FIRE / JET FIRE FREQUENCY	FLASH FIRE FREQ	REMARKS
B04.b	GAS TANKER UNLOADING ARM - GAS RETURN TO GAS TANKER	8.00E-06	op.-1	8,760 hours Continuos operation	h	8.00E-06	y-1	6,59E-09	1.90E-09	Total failure rates when one arm used
B05	PIPELINE FROM FSU TANK TO SECONDARY PUMP - SUCTION (RELEASE ON WATER)	6.50E-09	m·y-1	8,760	h	1.98E-06	y-1	1.28E-07	7.39E-08	Pipeline diameter > 110 mm
B06	SECONDARY PUMP	3.00E-05	pump-1·y-1	8,760	h	3.00E-05	y-1	5.85E-06	7.57E-06	
B07	PIPELINE FROM SECONDARY PUMP TO RU - DISCHARGE	6.50E-09	m·y-1	8,760	h	1.72E-07	y-1	1.12E-08	1.45E-08	Pipeline diameter > 110 mm

SGS

LIST OF SCENARIO'S FREQUENCIES										
ITEM	EQUIPMENT	FAILURE FREQUENCY	UNITS	OPERATING	UNITS	WEIGHTED FREQUENCY	UNITS	POOL FIRE / JET FIRE FREQUENCY	FLASH FIRE FREQ	REMARKS
B08	REGASIFICATION UNIT (RU)	1.00E-06	y-1	8,760	h	1.00E-06	y-1	6.50E-08	8.42E-08	BEVI Table 38 Scenarios for pipe heat exchangers where the hazardous substance is located inside the pipes and where the casing has a design pressure that is greater than or equal to the maximum pressure of the hazardous substance occurring in the pipe
B09	PIPELINE FROM RU TO GAS METERING STATION	6.50E-09	m·y-1	8,760	h	1.72E-07	y-1	1.12E-08	1.45E-08	Pipeline diameter > 110 mm
B10	PIPELINE FROM FSU TANK TO COMPRESSOR	6.50E-09	m·y-1	8,760	h	5.52E-06	y-1	3.59E-07	2.06E-07	Pipeline diameter > 110 mm
B11	COMPRESSOR	2.90E-06	compr·y-1	8,760	h	2.90E-06	y-1	1.89E-07	5.42E-08	

LIST OF SCENARIO'S FREQUENCIES										
ITEM	EQUIPMENT	FAILURE FREQUENCY	UNITS	OPERATING	UNITS	WEIGHTED FREQUENCY	UNITS	POOL FIRE / JET FIRE FREQUENCY	FLASH FIRE FREQ	REMARKS
B12	PIPELINE FROM COMPRESSOR TO FSU LIQUIFIER - DISCHARGE	6.50E-09	m·y-1	8,760	h	1.43E-07	y-1	9.30E-09	5.35E-09	Pipeline diameter > 110 mm
B12	PIPELINE FROM FSU BOC TO FSU LIQUIFIER – DISCHARGE	6.50E-09	m·y-1	8,760	h	1.43E-07	y-1	9.30E-09	2.67E-09	Pipeline diameter > 110 mm
B13	PIPELINE FROM FSU LIQUIFIER TO FSU TANK	6.50E-09	m·y-1	8,760	h	5.52E-06	y-1	3.59E-07	1.03E-07	Pipeline diameter > 110 mm
ElectroGas layout										
B01.a	GAS TANKER (RELEASE ON WATER)	1.63E-07	y-1	-	-	1.63E-07	y-1	1.06E-08	1.38E-08	Related: impacts/visits
B01.b	GAS TANKER (RELEASE ON WATER)	3.41E-05	y-1	-	-	3.41E-05	y-1	6.37E-07	2.87E-06	Related: impacts/visits
B02.a	GAS TANKER TO FSU UNLOADING HOSE - LNG (RELEASE ON WATER)	1.90E-05	transf-1	8 operations	Transfers/year	1.52E-04	y-1	9.88E-06	2.84E-06	Total failure rate when 3 arms (hoses) used

LIST OF SCENARIO'S FREQUENCIES										
ITEM	EQUIPMENT	FAILURE FREQUENCY	UNITS	OPERATING	UNITS	WEIGHTED FREQUENCY	UNITS	POOL FIRE / JET FIRE FREQUENCY	FLASH FIRE FREQ	REMARKS
B02.b	GAS TANKER TO FSU UNLOADING HOSE - LNG (RELEASE ON WATER)	1.90E-06	transf-1	8 operations	transfers/year	1.52E-05	y-1	9.88E-07	2.84E-07	Total failure rate when 3 arms (hoses) used – corrected with factor 0.1
B03.a	FSU UNLOADING ARM - LNG (RELEASE ON WATER)	7.00E-06	transf-1	Continuous operation while frequency is referred to 12 hour operation. Frequency adapted considered a 0.1 reduction	transfers/year	5.11E-03	y-1	3.32E-06	9.56E-07	Total failure rate when one arm used
B03.b	FSU UNLOADING ARM - LNG (RELEASE ON WATER)	7.00E-07	transf-1	Continuous operation while frequency is referred to 12 hour operation. Frequency adapted considered a 0.1 reduction	transfers/year	5.11E-04	y-1	3.32E-06	1.91E-07	Total failure rate when one arm used
B04.a	GAS TANKER UNLOADING ARM - GAS RETURN TO GAS TANKER	7.00E-06	transf-1	Continuous operation	transfers/year	5.60E-05	y-1	3.32E-06	2.09E-06	Total failure rates when one arm used
B04.b	GAS TANKER UNLOADING ARM - GAS RETURN TO GAS TANKER	8.00E-06	transf-1	Continuous operation	transfers/year	6.40E-05	y-1	3.80E-06	1.19E-06	Total failure rates when one arm used
B05	PIPELINE FROM FSU TANK TO SECONDARY PUMP - SUCTION (RELEASE ON WATER)	6.50E-09	m·y-1	8,760	h	1.98E-06	y-1	1.28E-07	7.39E-08	PIPELINE DIAMETER > 110 mm

LIST OF SCENARIO'S FREQUENCIES										
ITEM	EQUIPMENT	FAILURE FREQUENCY	UNITS	OPERATING	UNITS	WEIGHTED FREQUENCY	UNITS	POOL FIRE / JET FIRE FREQUENCY	FLASH FIRE FREQ	REMARKS
B06	SECONDARY PUMP	3.00E-05	pump-1·y-1	8,760	h	3.00E-05	y-1	5.85E-06	7.57E-06	
B07	PIPELINE FROM SECONDARY PUMP TO RU - DISCHARGE	6.50E-09	m·y-1	8,760	h	1.72E-07	y-1	1.12E-08	1.45E-08	Pipeline diameter > 110 mm
B08	REGASIFICATION UNIT (RU)	1.00E-06	y-1	8,760	h	1.00E-06	y-1	6.50E-08	8.42E-08	Table 38 Scenarios for pipe heat exchangers where the hazardous substance is located inside the pipes and where the casing has a design pressure that is greater than or equal to the maximum pressure of the hazardous substance occurring in the pipe
B09	PIPELINE FROM RU TO GAS METERING STATION	6.50E-09	m·y-1	8,760	h	1.72E-07	y-1	1.12E-08	1.45E-08	Pipeline diameter > 110 mm
B10	PIPELINE FROM FSU TANK TO COMPRESSOR	6.50E-09	m·y-1	8,760	h	5.52E-06	y-1	3.59E-07	2.06E-07	Pipeline diameter > 110 mm

LIST OF SCENARIO'S FREQUENCIES										
ITEM	EQUIPMENT	FAILURE FREQUENCY	UNITS	OPERATING	UNITS	WEIGHTED FREQUENCY	UNITS	POOL FIRE / JET FIRE FREQUENCY	FLASH FIRE FREQ	REMARKS
B11	COMPRESSOR	2.90E-06	compr·y-1	8,760	h	2.90E-06	y-1	1.89E-07	5.42E-08	
B12	PIPELINE FROM COMPRESSOR TO FSU LIQUIFIER - DISCHARGE	6.50E-09	m·y-1	8,760	h	1.43E-07	y-1	9.30E-09	5.35E-09	Pipeline diameter > 110 mm
B12	PIPELINE FROM FSU BOC TO FSU LIQUIFIER – DISCHARGE	6.50E-09	m·y-1	8,760	h	1.43E-07	y-1	9.30E-09	2.67E-09	Pipeline diameter > 110 mm
B13	PIPELINE FROM FSU LIQUIFIER TO FSU TANK	6.50E-09	m·y-1	8,760	h	5.52E-06	y-1	3.59E-07	1.03E-07	Pipeline diameter > 110 mm
B14	BLEVE OF A PROPANE TANK	5.8E-08	y-1	8,760	h	5.8E-08	y-1	N/A	N/A	N/A

11. PRESENTATION OF RESULTING RISK AND COMPARISON WITH ESTABLISHED TOLERABILITY CRITERIA

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 for consultant and ElectroGas options is shown in drawing #6 and 7 and compared in drawing #8 attached in Annex B.

The risk contours may be drawn in accordance with HSE criteria for the boundaries of the inner, middle and outer LUP zones as [29]:

- 10^{-5} / year: risk of fatality for Inner Zone (Zone 1) boundary.
- 10^{-6} / year: risk of fatality for Middle Zone (Zone 2) boundary.
- 10^{-7} / year: risk of fatality for Outer Zone (Zone 3) boundary.

Other acceptability criteria applied worldwide have been collected in the report attached in the Annex B, with the only purpose of comparison.

As can be easily noticed, none of the vulnerable element is reached by the outer iso-risk contour, thus the project accomplish the acceptability criterion, so far.

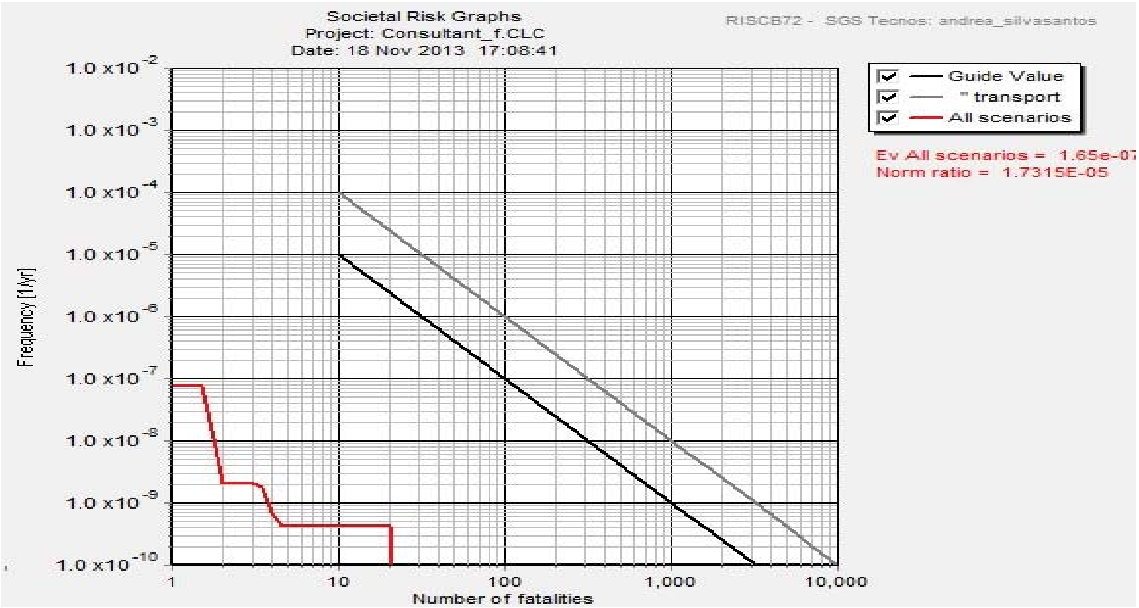
Also, the societal risk calculation has been performed, considering the resident population plus the possible presence of people in touristic zones, such as the Fort Delimara, the beaches, etc.

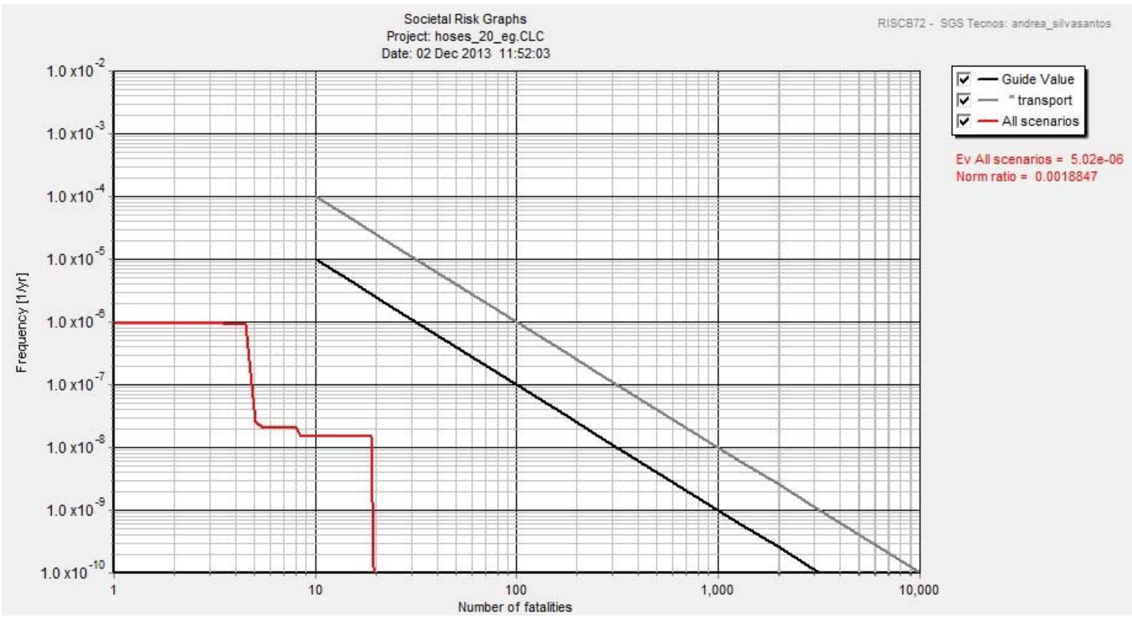
Societal risk is defined [34] [35] as the relationship between frequency and the number of people suffering from a specified level of harm in a given population from the realization of specified hazards [36]. Societal risk evaluation is concerned with estimation of the chances of more than one individual 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 [20], which are plots of the cumulative frequency (F) of various accident scenarios against the number (N) of casualties associated with the modeled 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 curves are shown in the following figures for “Consultant layout” and for “ElectroGas layout”.





In both cases the number of fatalities versus their frequency is acceptable, being well below the limiting curves of acceptability.

Additionally, following Maltese legislation [37], the “applications for new hazardous installations will be approved only if they:

a) will have no harmful or adverse impact on the environment due to the inherent hazardous nature of the installation or on existing or proposed adjoining land uses;
b) are located so as to ensure adequate separation from other uses, including residential areas, areas of public use and areas of particular natural sensitivity or interest, so as to guarantee safety and amenity;
c) are located so as to ensure adequate separation from other hazardous installations, to minimise the likelihood of the exacerbation of the consequences of a major accident;
d) comply with other relevant Structure Plan and Local Plan policies.

Proposals for development at existing hazardous installations which involves the addition of new dangerous substances or an increase in the quantity of existing dangerous substances will be assessed against the criteria set out above."

According to the performed calculations, all requirements can be considered as fulfilled by the consultant and the ElectroGas layout, with the following limitations:

a) environmentally sensitive areas and projects for development of new natural parks should be well defined in order to ensure that they are not reached by the isorisk contour.
b) adequate separation from existing sites is suggested and implemented, and, when not possible, technical measures are introduced in order to minimize the possibility of domino effects.

12. CONCLUSIONS

A preliminary quantitative risk assessment (QRA) of the proposed LNG terminal to be located in the Marsaxlokk Bay has been carried out. In the first issue of the document, the results for the three proposed options have been calculated, in accordance with the current HSE criteria. In the present revision, a comparison has been introduced between the second out of three options and the initial details provided by ElectroGas as the successful bidder.

The following results have been obtained:

- individual risk contours;
- societal risk FN curves;
- maximum extension of the gas clouds.

The findings drawn from the results in the first issue (comparison between there options) are as follows:

- The three options proposed, as well as the three layouts, have been engineered as a first approach specifically for carrying out the quantitative risk assessment. They are based on general and open assumptions. The solution finally adopted could significantly vary according to engineering criteria adopted by the contractor. Obviously, the layout must be decided according to geological and nautical limitations and could be completely different from the proposed one, especially in reference to the position of the jetty and the on-shore regasification unit.
- The comparison between the three options using the risk contours, shows that option A presents the largest individual risk to some of the scattered houses near the Delimara Power Station. Option C seems to be the better option in order to minimize the risk to the population. Option B can also be taken into account if the regasification unit is relocated as far as possible from the Power Station and as close as possible to the unloading facilities.
- The comparison between the three options using the extension of the gas cloud contour, clearly demonstrates that for the three options a flammable gas cloud can travel to the Delimara Power Station and easily find an ignition point, there with devastating effects on the Maltese power system.
- However, it must be considered that the analyzed layouts were designed for a first approach on risk assessment, and are not definitive. The possibility to locate both options B and C in the inner part of the harbour has been taken into account and a suitable location for the jetty is presented in order to remove most of the possible flash-fires which may be generated from the ignition of the flammable gas cloud. Otherwise, technical solution for minimization of flammable gas cloud can be

adopted, as well as solution for the removal of ignition points in the surrounding, such as adoption of ATEX equipment in nearby DPS.

The ultimate conclusion is that a FSRU (Option C) or a FSU plus a RU (Option B), if located in the recommended zone, is the preferred choice in order to minimize the individual risk to the population as well as to minimise the damage to the Delimara Power Station in case of flash-fire. However, the client has to take into account that the suggested position may be not suitable if analysed from a nautical point of view. In fact the FSRU or FSU would be located closer to the mouth of the harbour, increasing the probabilities of a collision with a manoeuvring ship or for damage in the FSRU or FSU itself due to high waves, storms and other atmospheric phenomena, against which the tanker would not be protected. In order to define the optimum location in the harbour, balancing (1) the facilities inherent risk, (2) the nautical collision risk and (3) the meteorological risk, is highly recommended to perform a nautical risk assessment (for #2) as well as a harbour risk assessment (for #3).

Also, the solution finally adopted must be submitted to a detailed quantitative risk assessment, and final risk of the installation must be proven and eventually reduced to meet the conclusions of this preliminary study.

Following the decision of Enemalta Corporation announcing that the ElectroGas Malta Consortium is the preferred bidder, an updated version of this document is issued, after discarding the proposed options A and C and introducing a comparison between the data and layout estimated by the consultant (hereafter called the consultant layout) and the ones proposed by ElectroGas Malta Consortium (ElectroGas layout).

The new findings derived from the revision of the document are listed below:

- The preliminary data and layout provided by ElectroGas suggests that the projected plant mostly fits into the preliminary data and layout proposed by the consultant.
- The location of the jetty and FSU proposed by ElectroGas fits in the recommended area in order to minimize ignition of gas cloud in the existing DPS.
- Recalculation of scenarios has been carried out when required with negligible impact on the result of the risk contour estimation.
- Introduction of hoses instead of arms is not quantifiable in the risk contour due to lack of evidence in the comparison of frequencies in their respective sources of information. Extension to hoses of the frequencies originally published for hardarms has been discussed in a dedicated Annex.
- None of the vulnerable element is reached by the outer iso-risk contour, thus ElectroGas project accomplish the acceptability criterion.

- In case of accident, the number of fatalities is acceptable, if compared with acceptance criteria used in other European Countries with a large tradition of quantitative risk assessment;

The main conclusion so far, is that the ElectroGas plant project is compatible with acceptability criteria proposed, in agreement with the set of criteria adopted in the calculation, provided that safeguards and leakage limitations considered in the calculations are set in place.

In addition, the consultant recalls the importance of completing the safety case for the project, once the preliminary QRA is accepted and permit is given by the competent authority. Safety case should include the following:

- HAZOP according to IEC/BS 61882, once Front End Design is completed
- Complete and definitive Safety report, before commissioning
- Emergency planning, before commissioning
- Functional Safety Report according to IEC 61511, before commissioning
- Fulfillment report for EN/BS 1473, before commissioning

Also, recommendations presented in the HAZID are expected to be studied and applied during the evolution of the project engineering.

13. REFERENCES

[1] Process Description Statement.

[2] C. Galdies, The climate of Malta: statistics, trends and analysis 1951-2011, National Statistics Office, Malta.

[3] "Malta National Focal Point," EMWIS: Euro-Mediterranean Information System on know-how in the Water sector, [Online]. Available: http://www.emwis-mt.org/documentation/context/physical%20factors_files/Geology.htm. [Accessed June 2013].

[4] P. Galea, "Seismic history of the Maltese islands and considerations on seismic risk," *Annals of Geophysics,* vol. 50, no. 6, pp. 725-740, December 2007.

[5] "Wikipedia," [Online]. Available: http://en.wikipedia.org/wiki/Q-Flex. [Accessed June 2013].

[6] "Ship Technology," [Online]. Available: http://www.ship-technology.com/projects/tembek/. [Accessed Juny 2013].

[7] "Oil & Gas Journal," June 2013. [Online]. Available: http://www.ogj.com/articles/2008/07/new-q-max-lng-vessel-is-worlds-largest.html.

[8] «Maritime Connector,» June 2013. [En línea]. Available: http://maritime-connector.com/wiki/q-max/.

[9] "Wikipedia," [Online]. Available: http://en.wikipedia.org/wiki/Q-Max. [Accessed June 2013].

[10] (Ph. D.) Vianello, Chiara, "Risk analysis of gas distribution network".

[11] P. Michele Michot Foss, "LNG Safety and Security," Sugar Land, Texas, 2006.

[12] Health & Safety Executive (HSE), «LNG source term models for hazard analysis "A review of the state-of-the-art and an approach to model assessment",» 2010.

[13] VROM, Publication Series on Dangerous Substances (PGS 1) - Methods for the determination of possible damage "Green Book" CPR 16E.

[14] Health and Safety Authority (HSA), Policy & Approach of the Health & Safety Authority to COMAH Risk-based Land-use Planning, 07 September 2009.

[15] A. Franks, «A Review of HSE's Risk Analysis and Protection - Based Analysis Approaches for Land-Use Planning,» Health and Safety Executive (HSE), 2004.

[16] Health And Safety Executive (HSE), "Offshore Installations (Safety Case) Regulations 2005 Regulation 12 Demonstrating compliance with the relevant statutory provisions".

[17] Health and Safety Executive (HSE), «Fire, Explosion and Risk

Assessment,» February 2003.
[18] Health and Safety Executive (HSE), «Application of QRA in operational safety issues,» 2002.
[19] RIVM, Reference Manual Bevi Risk Assessment version 3.2, 2009.
[20] VROM, Publication Series on Dangerous Substances (PGS 3) - Guideline for quantitative risk assessment 'Purple book' CPR 18E., 2005.
[21] Flemish Government, LNE Department, Environment, Nature and Energy Policy Unit, Safety Reporting Division, «Handbook Failure Frequencies,» 2009.
[22] HSE, Failure Rate and Event Data for use within Risk Assessment.
[23] VROM, Publication Series on Dangerous Substances (PGS 2) - Methods for the calculation of physical effects - due to releases of hazardous materials (liquids and gases)- "Yellow Book, CPR 14E".
[24] TNO, "TNO innovation for life," [Online]. Available: http://www.tno.nl/index.cfm?Taal=2.
[25] EN 1473 (2007): Installation and Equipment for Liquefied Natural Gas - Design of Onshore Installations, 2007.
[26] Eisenberg N A, et al. 1975, "Vulnerability model. A simulation system for assessing damage resulting from marine spills," US DoT, US coast guard, 1975.
[27] Crosswaite, P. J.; Fitzpatrick, R. D.; Hurst, N. W.;, "Risk Assessment for the Siting of Developments Near Liquefied Petroleum Gas Installations," in *IChemE Symposium Series 110, Preventing Major Chemical and Related Process Accidents*, London, May 1988.
[28] Building Regulations, "Technical Guidance Document B. Fire Safety," Stationary Office, Dublin, 2006.
[29] Health and Safety Executive (HSE) , "An independent review of HSE methodology for assessing societal risk," January 2006.
[30] Carter, D.A., "The Scaled Risk Integral - A Simple Numerical Representation of Case Societal Risk for Land Use Planning in the Vicinity of Major Accident Hazards," in *Loss Prevention and Safety Promotion in the Process Industries*, vol. II, Elsevier, 1995.
[31] Hirst, I. L.; Carter, D. A.;, "A “Worst Case” Methodology for Risk Assessment of Major Accident Installations," *Process Safety Progress,* vol. 19, no. 2, Summer 2000.
[32] Health and Safety Laboratory (HSL), «Review of Hazard Identification Techniques,» 2005.
[33] Health and Safety Executive (HSE), "Canvey - An Investigation of Potential Hazards from Operations in the Canvey Island/Thurrock Area," HMSO, London, 1978.
[34] Malta Environment & Planning Authority (MEPA) , Supplementary Planning Policy Guidance, November 2004.
[35] COMAH Regulations. Policy & Approach of the Health & Safety Authority

to COMAH Risk-based Land-use Planning.
[36] H. &. S. E. (HSE), «Societal Risk: Initial briefing to Societal Risk Technical Advisory Group,» Buxton, 2009.
[37] D. Jones, Nomenclature for hazard and risk assessment in the process industries. 2nd Edition, IChemE, 1985.
[38] Supplementary Planning Policy Guidance - Major Accident Hazards and Hazardous Substances, HAZARDOUS SUBSTANCES, 2004.
[39] Center for Chemical Process Safety (CCPS), Guidelines for Chemical Process Quantitative Risk Analysis, Second Edition, New York, 2000.
[40] H. M. S. Office, The Control of Major Hazards, Advisory Committee on Major Hazards, First Report, London, 1976.
[41] Health and Safety Executive (HSE), QuantiJied Risk Assessment: Its Input to Decision Making, London: Her Majesty's Stationery Office, 1989.
[42] Health and Safety Executive (HSE), The Tolerability of Risk from Nuclear Power Stations, London: Her Majesty's Stationery Office, 1988.
[43] Health and Safety Executive (HSE), Reducing Risks, Protecting People - HSE 's Decision-making Process, London: Her Majesty's Stationery Office, 2001.
[44] Health and Safety Executive (HSE), Risk Criteria for Land-use Planning in the Vicinity of Major Industrial Hazards, London: Her Majesty's Stationery Office, 1989.
[45] PADHI- HSE's land use planning methodology, http://www.hse.gov.uk/landuseplanning/padhi.pdf, 2008.
[46] Health and Safety Executive (HSE), HSE'S current approach to land use planning (LUP), http://www.hse.gov.uk/landuseplanning/lupcurrent.pdf, 2008.
[47] Health and Safety Executive (HSE), Revised land use planning arrangements around large scale petroleum depots, UK: http:l/www.hse.gov.uk/researchlrrpdf/rr5 1 1 .pdf, 2007.
[48] Health and Safety Executive (HSE), Guidance on 'as low as reasonablypracticable ' (ALARP) decisions in control of major accident hazards (COMAH), http : //www.hse.gov.uk/comah/circular/perm12.htm, 2008.
[49] VROM, Besluit Externe Veiligheid Inrichtingen (External Safety (Establishments) Decree) Staatscourant Sept. 23, The Netherlands, 2004, p. nt.183.
[50] VROM, Summary of the advice on external safetypublished by the Advisory Council for Transport and Wuter Management and the Advisory Council for Housing, Spatial Planning and the Environment, http://international.vrom.nl/docs/internationaal/030601%20Summary%20RadenadviesEVH_engels.pdf, 2003.
[51] VROM, Guidance on the Accountability for Societal Risk, The Hague: http://www2.vrom.nl/docs/internationaal/Accountabilitity.pdf, 2004.

[52] B. Ale, Tolerable Or Acceptable: A Comparison Of Risk Regulation In The United Kingdom And In The Netherlands. Risk Analysis, vol. 25, 2005.

[53] R. e. a. Kolluru, Risk assessment and management handbook for environmental, health and safety professionals, New York: McGraw-Hill, 1996.

[54] D. J. B. a. P. J. Floyd, Societal Risks, Final Report, 1998.

[55] Boult, «Risk management of LPG transport activities in Hong Kong,» *Journal of Hazardous Materials,* nº 71, pp. 85-100, 2000.

[56] «Hong Kong Planning Standards and Guidelines, Chapter 12: Miscellaneous Planning Standards and Guidelines,» nº http://www.pland.gov.hk/tech_doc/hkpsg/english/chl2/chl2_text.htm, 2002.

[57] Technical Memorandum to Environmental Impact Assessment Ordinance, Section 4, Hong Kong: http://www.epd.gov.hk/eia/english/legis/memorandum/text4.html, 2008.

[58] Environmental Impact Assessment Ordinance, Hong Kong: http://www.epd.gov.hk/eia/english/legis/index1.htmll, 2008.

[59] Hong Kong Planning Standards and Guidelines, Chapter 12:Miscellaneous Planning Standards and Guidelines, 2002.

[60] Landslide Risk Management and the Role of Quantitative Risk Assessment Techniques Information Note 121200.

[61] Companhia de Technologia de Saneamento Ambiental (CETESB), Manual De Orientaça'o Para A Elaboraçao De Estudos De Análise De Riscos, 2003.

[62] Governo do Estado Do Rio De Janeiro, Znstrupjo Tkcnica Para ElaboraqEo De Estudo De Zmpacto Ambiental- Eia E Seu Respectivo Relatorio De Impacto Ambiental-Rima Para 0 Complexo Petroquimico Do Rio de Janeiro - Comperj Instru@o Tecnica Decon No 0112007, Rio De Janeiro, 2007.

[63] F. E. d. P. Ambiental, Manual de Analise de Riscos Industriais, FEPAM N."01/01, Brazil: www.fepam.rs.gov.br/central/formularios/arq/manual-risco.pdf, 2001.

[64] Loi no 2003-699 du 30 juillet 2003 relative a la prevention des risques technologiques et naturels et a la reparation des dommages,, Paris, 2003.

[65] Arrêté du 29 septembre 2005 relatif à l'évaluation et à la prise en compte de la probabilité d'occurrence, de la cinètique, de l'intensité des effets et de la gravité des conséquences des accidents potentiels dans les études de dangers des installations.., Paris, 2005.

[66] S. o. E. N. SEN-35-91, Nuclear Safety Policy, http://www.directives.doe.gov/pdfs/doe/doetext/senord/35/n3591.html, September 9, 1991.

[67] U. D. o. Energy, Guidance for Preparation ofDOE 5480.22 (TSR) and 5480.23 (SAR) Implementation Plans, DOE-STD-3011-94, http://www osti.gov/bridge/servlets/purl/10194808-

mY7ZJM/webviewable/10194808.pdf, November 1994.

[68] U.S. Department of Energy, DOE Regulatory Unit Evaluation Report of the BNFL Inc. Safety Requirements Document, REG-98-01, Richland Operations Office, 1998.

[69] U.S.Department of Energy, Top-Level Radiological, Nuclear, And Process Safety Standards And Principles For The RPP Waste Treatment Plant Contractor, 2004.

[70] U.S. Department of Energy, Office Of Safety Regulation Position On Conformance With Risk Goals In DOE/RL-96-0006, RLIREG-2000-08, 2002.

[71] L. R. Rhomberg, Survey of Methods for Chemical Health Risk Assessment Among Federal Regulatory Agencies, a report made to The Presidential/Congressional Commission on Risk Assessment and Risk Management, http://www.riskworld.cominreports/1996/risk-rpt/pdf/rhomberg.: Harvard Center for Risk Analysis, 1996.

[72] The Presidential/Congressional Commission on Risk Assessment and Risk Management, Risk Assessment and Risk Management in Regulatory Decision-Making, http://www.riskworld.com/nreports/nr7me001.htm, 1997.

[73] International Maritime Organization (IMO), Interim Guidelines For The Application Of Formal Safety Assessment (FSA) To The IMO Rule-Making Process, MSC/Circ. 829 & MEPC/Circ. 335, London, 1997.

[74] International Maritime Organisation (IMO), Guidelines for Formal Safety Assessment (FSA) for use in the IMO rule-making process, MSCICirc. 1023, London, 2002.

[75] International Maritime Organization (IMO), Formal safety assessment - decision parameters including risk acceptance criteria, MSC 7211 6, submitted by Norway, 2000.

[76] International Maritime Organisation (IMO, Risk Evaluation Criteria, D.4.5.2, 2005.

[77] Land Use Planning Guidelines in the context of directives 96/82/EC and 105/2003/EC, Christou et al, 2006. ISBN 978-92-79-09182-7.

[78] Lees' Loss Prevention in the Process Industries. Hazard identification, assessment and control, Elsevier Butterworth Heimann, 2004.

[79] A. Ronza, «A quantitative risk analysis approach to port hydrocarbon logistics,» *Journal of hazardous materials,* 2005.

[80] "NFPA 59AS: Standard for the Production, Storage, and Handling of Liquefied Natural Gas (LNG)," March 27, 2013.

[81] International Association of Oil & Gas Producers (OGP), "Guidance on performing risk assessment in the design of onshore LNG installations including the ship/shore interface," February 12, 2006.

[82] B. M. I. I. Board, “The Buncefield Incident, 11 December 2005 - The final report of the Major Incident Investigation Board,” *http://www .buncefieldinvestigation.gov.uk/reports/index.htm,* 2008.

[83] Health and Safety Executive (HSE), Murray, PADHI Rule 4c (Existing Use Rule), http://www.hse.gov.uk/landuseplanning/rule4cletter.pdf, 2008.

ANNEX A. HAZID

Project:	**Proposed LNG floating storage and onshore regasification unit**			
System:	**Supplying LNG Ship**			
HAZARDS RELATED TO	**CAUSES**	**CONSEQUENCES**	**SAFEGUARDS**	**RECOMMENDATION**
LNG transfer	n.a. (Not applicable)	n.a.	n.a.	n.a.
Heat transfer	Continuous regasification of LNG due to heat transfer from the outside of the tanks, effect known as "boil off" during ship manoeuvre	Possible emission of gas in case is required to keep pressure low. Possible flammable cloud in safe place	Ships are provided with compressor and liquefier in order to avoid any possible emission to atmosphere. In the unlikely event of an emission, this is vent in safe place	n.a.
Failure of rotating equipment	Out of scope	n.a.	n.a.	n.a.
Failure of instrumentation and control loops	Out of scope	n.a.	n.a.	n.a.
Failure of utilities	Out of scope	n.a.	n.a.	n.a.
Lay-out	Difficulties in the manoeuvre and mooring operations due to lay-out	Possible collision or domino effect in case of accident	Not present	Ensure safety distance is kept from LNG passing ships and traffic is regulated in the port.
External impacts	Possible collision with other ship and or breakwaters, seashore, etc.	Possible damage to the tanks if the speed and tonnage of impacting ships is high, which is highly improbable. → Major accident included in QRA → scenario # 1	Layout has been optimized in order to minimize manoeuvring and presence of obstacles	n.a.
Extreme meteorological conditions	Ship approaching to port in extreme weather and sea conditions	Less manoeuvrability, possible mooring break, possible collision as previously stated	n.a.	Consider the possibility to limit the manoeuvre according to weather forecast

Project:	**Proposed LNG floating storage and onshore regasification unit**			
System:	**Supplying LNG Ship**			
HAZARDS RELATED TO	**CAUSES**	**CONSEQUENCES**	**SAFEGUARDS**	**RECOMMENDATION**
Domino effects	Possible domino effect in case of explosion or pool fire proceeding from others facilities in the port area	Possibility to generate an impact on the ship due to the explosion or projection of fragments. In the worst case, expected effect is an external impact with major spillage from tanks, already considered	n.a.	n.a.

Project:	Proposed LNG floating storage and onshore regasification unit			
System:	**Ship to ship transfer by hoses**			
HAZARDS RELATED TO	**CAUSES**	**CONSEQUENCES**	**SAFEGUARDS**	**RECOMMENDATION**
LNG transfer	Unexpected movement of the ship or mooring break during unloading operation	Possible disconnection or rupture of hoses	Hoses provided with Emergency Release System and specific safeguards described in dedicated Annex	
	Human error in the connection and / or cooling, blowing, etc.	Same as previous	Same as previous	
	Failure of Emergency Release System	Possible spillage to the sea up to the activation of other emergency systems → Major accident included in the QRA → scenario # 2	Both ships provided with gas detection, Emergency Shutdown System and automatic valves	
Heat transfer	Continuous regasification of LNG due to heat transfer from the outside, effect known as “boil off” when ship is moored and unloading operation is suddenly shut down	Possible overpressure in the pressurized parts, possible leakage of LNG	All parts are insulated and provided with liquid release valve to reduce pressure when LNG is trapped.	
		Possible overpressure within the hose if unloading operation is shutdown	LNG is removed and hose blown in case of long shutdown	
Failure of rotating equipment	Mechanical or electrical failure in primary pumps in the ship tanks	Possible unexpected shutdown of the process, with the effect cited above. Possible minor leakages	Ship tank pumps are usually submerged in the LNG. At least one pump is permanently in stand by and used as backup of others.	

Project:	**Proposed LNG floating storage and onshore regasification unit**			
System:	**Ship to ship transfer by hoses**			
HAZARDS RELATED TO	**CAUSES**	**CONSEQUENCES**	**SAFEGUARDS**	**RECOMMENDATION**
Failure of instrumentation and control loops	Failure of temperature, pressure, flow, level detection, field communication, control system, control valves, etc.	Possibility to create a condition not suitable for the process and to produce damages to the installations. Possible spillage of LNG. Effects is not expected to be huger than spillage in case of disconnection	Safeguards are generally present and redundant for each possible failure	Study detailed effect of failure of each control loop and corresponding safeguards in a complete HAZOP to be carried out after front-end-design is completed
Failure of utilities	Failure of power, instrument air, nitrogen, control signals, etc.	Possibility to create a condition not suitable for the process and to produce damages to the installations. Possible spillage of LNG. Effects is not expected to be huger than spillage in case of disconnection	Safeguards are generally present and redundant for each possible failure	Study detailed effect of failure of each utility and corresponding safeguards in a complete HAZOP to be carried out after front-end-design is completed
Lay-out	Major accident in the jetty area due to causes already studied	Possible domino effects to onshore installation. Possible additional damages and effects	Jetty position in the bay has been proposed according to minimization of ignition probability in the existing DPS. Gas detection, emergency shut down system and fire fighting system would be implemented on the jetty	

Project:	Proposed LNG floating storage and onshore regasification unit			
System:	**Ship to ship transfer by hoses**			
HAZARDS RELATED TO	**CAUSES**	**CONSEQUENCES**	**SAFEGUARDS**	**RECOMMENDATION**
External impacts	Impact of other manoeuvring ship on the unloading ship	Possible damage to the tanks if the speed and tonnage of impacting ships is high, which is highly improbable. → Major accident included in the QRA (already mentioned in previous node) → scenario # 2		Ensure manoeuvring speed is low enough to minimize consequences of impacts
Extreme meteorological conditions	Extreme weather and sea conditions when ship is moored and unloading	Possible mooring break, possible collision as previously stated	LNG ships usually leave port in case of adverse weather conditions	
Domino effects	Possible domino effect in case of explosion or pool fire proceeding from others facilities in the port area	Possibility to generate an impact on the ship due to the explosion or projection of fragments. In the worst case, expected effect is an external impact with major spillage from tanks, already considered	n.a.	n.a.

Project:	**Proposed LNG floating storage and onshore regasification unit**			
System:	**Floating storage unit (permanently moored)**			
HAZARDS RELATED TO	**CAUSES**	**CONSEQUENCES**	**SAFEGUARDS**	**RECOMMENDATION**
LNG transfer	Failure of instrumentation or human error during operation on the deck (maintenance, start / stop of pumps, process changes, flow regulation, etc.)	Possible spillage of LNG on top of the FSU deck in the worst case scenario. No spillage to the water is expected. Any spillage onboard the FSU is recovered and minimized	Control system, pressure safety valves, relief valves, vents, nitrogen blow and others safeguards prevent, control or minimize any possible failure in the process facilities.	
Heat transfer	Continuous regasification of LNG due to heat transfer from the outside, effect known as “boil off” when ship is moored and unloading operation is suddenly shut down	Already studied in previous node	Already studied in previous node	
Failure of rotating equipment	Mechanical or electrical failure in primary pumps in the ship tanks	Already studied in previous node	Already studied in previous node	
Failure of instrumentation and control loops	Failure of temperature, pressure, flow, level detection, field communication, control system, control valves, etc.	Possibility to create a condition not suitable for the process and to produce damages to the installations. Possible spillage of LNG. Effects is not expected to produce spillage in the water	Safeguards are generally present and redundant for each possible failure	Study detailed effect of failure of each control loop and corresponding safeguards in a complete HAZOP to be carried out after front-end-design is completed

Project:	**Proposed LNG floating storage and onshore regasification unit**			
System:	**Floating storage unit (permanently moored)**			
HAZARDS RELATED TO	**CAUSES**	**CONSEQUENCES**	**SAFEGUARDS**	**RECOMMENDATION**
Failure of utilities	Failure of power, instrument air, nitrogen, control signals, etc.	Possibility to create a condition not suitable for the process and to produce damages to the installations. Possible spillage of LNG. Effects is not expected to produce spillage in the water	Safeguards are generally present and redundant for each possible failure	Study detailed effect of failure of each utility and corresponding safeguards in a complete HAZOP to be carried out after front-end-design is completed
Lay-out	Major accident on top of the FSU deck due to causes cited in other rows	Possible generation of gas cloud travelling in the direction of the DPS, the middle of the port bay or the south of Delimara peninsula depending on wind direction and speed. Possible ignition of the cloud if ignition point is present (permanent in DPS due to high voltage connections, low probability in the port bay due to passing ship and low probability in the peninsulas road and cultivated land due to presence of motor vehicles).	FSU position in the bay has been proposed according to minimization of ignition probability in the existing DPS. Maximum length of the cloud has been taken into account according to credible causes. Gas detection, emergency shut down system, spillage containment and fire fighting system are implemented on top of the FSU	

Project:	Proposed LNG floating storage and onshore regasification unit			
System:	Floating storage unit (permanently moored)			
HAZARDS RELATED TO	**CAUSES**	**CONSEQUENCES**	**SAFEGUARDS**	**RECOMMENDATION**
External impacts	Impact of other manoeuvring ship on the permanently moored FSU	Possible damage to the tanks if the speed and tonnage of impacting ships is high, which is highly improbable. → Major accident included in the QRA (already mentioned in previous node) → scenario # 1		Ensure manoeuvring speed is low enough to minimize consequences of impacts
Extreme meteorological conditions	Extreme weather and sea conditions	Possible mooring break, possible collision as previously stated	Mooring are expected to be adequate to permanent mooring	Ensure FSU position is suitable for extreme conditions
Domino effects	Possible domino effect in case of explosion or pool fire proceeding from others facilities in the port area	Possibility to generate an impact on the FSU due to the explosion or projection of fragments. In the worst case, expected effect is an external impact with major spillage from tanks, already considered	n.a.	n.a.

SGS

Project:	**Proposed LNG floating storage and onshore regasification unit**			
System:	**Ship to shore transfer by hardarm**			
HAZARDS RELATED TO	**CAUSES**	**CONSEQUENCES**	**SAFEGUARDS**	**RECOMMENDATION**
LNG transfer	Unexpected movement of the FSU or mooring break when permanently unloading	Possible disconnection or rupture of hardarms	Hardarms provided with Emergency Release System and specific safeguards described in dedicated Annex	
	Aging, ice formation and other effects reducing life expectancy of the hardarm	Same as previous	Redundant hardarm in standby allows optimization of maintenance	
	Failure of Emergency Release System	Possible spillage to the sea up to the activation of other emergency systems → Major accident included in the QRA→ scenario # 3	Both FSU and jetty provided with gas detection, Emergency Shutdown System and automatic valves	
Heat transfer	Continuous regasification of LNG due to heat transfer from the outside, effect known as "boil off" when FSU is moored and regasification is suddenly shut down	Possible overpressure in the pressurized parts, possible leakage of LNG	All parts are insulated and provided with liquid release valve to reduce pressure when LNG is trapped.	
		Possible overpressure within the hardarm if unloading operation is shutdown	LNG is removed and hardarm blown in case of long shutdown	
		Possible accumulation of boil off in the FSU tanks. Possible emission of gas in case is required to keep pressure low. Possible flammable cloud in safe place	FSU is provided with compressor and liquefier in order to avoid any possible emission to atmosphere. In the unlikely event of an emission, this is vent in safe place	

Project:	**Proposed LNG floating storage and onshore regasification unit**			
System:	**Ship to shore transfer by hardarm**			
HAZARDS RELATED TO	**CAUSES**	**CONSEQUENCES**	**SAFEGUARDS**	**RECOMMENDATION**
Failure of rotating equipment	Mechanical or electrical failure in primary pumps in the FSU tanks	Possible unexpected shutdown of the process, with the effect cited above. Possible minor leakages	FSU tank pumps are usually submerged in the LNG. At least one pump is permanently in stand by and used as backup of others.	
Failure of instrumentation and control loops	Failure of temperature, pressure, flow, level detection, field communication, control system, control valves, etc.	Possibility to create a condition not suitable for the process and to produce damages to the installations. Possible spillage of LNG on the water or the jetty. Effects is not expected to be huger than spillage in case of disconnection	Safeguards are generally present and redundant for each possible failure Gas detection, emergency shut down system, spillage collection and drainage system and fire fighting system would be implemented on the jetty and the FSU	Study detailed effect of failure of each control loop and corresponding safeguards in a complete HAZOP to be carried out after front-end-design is completed
Failure of utilities	Failure of power, instrument air, nitrogen, control signals, etc.	Possibility to create a condition not suitable for the process and to produce damages to the installations. Possible spillage of LNG. Effects is not expected to be huger than spillage in case of disconnection	Safeguards are generally present and redundant for each possible failure	Study detailed effect of failure of each utility and corresponding safeguards in a complete HAZOP to be carried out after front-end-design is completed

Project:	**Proposed LNG floating storage and onshore regasification unit**			
System:	**Ship to shore transfer by hardarm**			
HAZARDS RELATED TO	**CAUSES**	**CONSEQUENCES**	**SAFEGUARDS**	**RECOMMENDATION**
Lay-out	Major accident in the jetty area due to causes already studied	Possible domino effects to onshore installation. Possible additional damages and effects	Jetty position in the bay has been proposed according to minimization of ignition probability in the existing DPS. Gas detection, emergency shut down system and fire fighting system would be implemented on the jetty	Requirement of standard EN 1473 must be fulfilled and evidence produced in the corresponding report
External impacts	Already analyzed in previous node			
Extreme meteorological conditions	Already analyzed in previous node			
Domino effects	Already analyzed in previous node			

Project:	Proposed LNG floating storage and onshore regasification unit			
System:	**Booster pump**			
HAZARDS RELATED TO	**CAUSES**	**CONSEQUENCES**	**SAFEGUARDS**	**RECOMMENDATION**
LNG transfer	Sudden closure of vaporizer inlet in case of gas detection or emergency shut down	Possible hammering. Possible damages to the pipes	Recirculation valves or minimum flow protection are usually implemented in order to avoid hammering.	
Heat transfer	Pumps stopped over a long period.	Vaporization of LNG trapped in the pumps and pipes and consequent increase of pressure. Possible leakage of LNG. → major accident included in the QRA → scenario # 5, 6	All parts are insulated and provided with liquid release valve to reduce pressure when LNG is trapped.	
Failure of rotating equipment	Malfunctioning of high pressure pumps due to mechanical problems, lack of lubrication, ice formation, etc.	Spillage of LNG in the worst case, if seals of the pump are broken.	High pressure LNG pumps are provided with extremely sophisticated internal protection, continuously monitoring the temperature, vibration, power consumption and other parameters and tripping the motor to safe stop when required	
Failure of instrumentation and control loops	Failure of temperature, pressure, flow detection, field communication, control system, control valves, etc.	Possibility to create a condition not suitable for the process and to produce damages to the vaporizer, i.e sudden closure of vaporizer outlet and pressure increase due to thermal inertia. Possible high pressure gas leakage or LNG spillage→ Major	Safeguards are generally present and redundant for each possible failure All pressurized equipments provided with PSV Gas detection, emergency shut down system, and fire fighting system would be	Study detailed effect of failure of each control loop and corresponding safeguards in a complete HAZOP to be carried out after front-end-design is completed

Project:	Proposed LNG floating storage and onshore regasification unit			
System:	**Booster pump**			
HAZARDS RELATED TO	**CAUSES**	**CONSEQUENCES**	**SAFEGUARDS**	**RECOMMENDATION**
		accident included in the QRA	implemented and cover the whole onshore area.	
Failure of utilities	Failure of power, instrument air, nitrogen, control signals, etc.	Possibility to create a condition not suitable for the process and to produce damages to the vaporizer (pipe vibration and breaking). Scenario already detected in the previous row	Safeguards are generally present and redundant for each possible failure	Study detailed effect of failure of each utility and corresponding safeguards in a complete HAZOP to be carried out after front-end-design is completed
Lay-out	Possible damages in the onshore area during maintenance due to equipment congestion	Possible major leakage in a high pressure gas or LNG pipe → Major accident included in the QRA → scenario # 5, 6		Separation between equipments must be respected. Requirement of standard EN 1473 must be fulfilled and evidence produced in the corresponding report
External impacts	Impact of road vehicle	Possible major leakage in a high pressure LNG pipe → Major accident included in the QRA	Circulation of vehicles would be limited, speed minimized and equipment protected by concrete walls, barriers	
Extreme meteorological conditions	n.a.			
Domino effects	Possible domino effect in case of explosion or pool fire proceeding from other equipment in the plant	Possible major leakage in vaporizer outlet or LNG spillage in vaporizer inlet → Major accident included in the QRA	Onshore plant would be protected by fire fighting system including deluge system in order to reduce fire radiation. Also, emergency shutdown system and eventually the emergency vent would	

SGS

Project:	**Proposed LNG floating storage and onshore regasification unit**			
System:	**Booster pump**			
HAZARDS RELATED TO	**CAUSES**	**CONSEQUENCES**	**SAFEGUARDS**	**RECOMMENDATION**
			reduce the amount of gas exposed to the heat radiation	

Project:	Proposed LNG floating storage and onshore regasification unit			
System:	**LNG Vaporization**			
HAZARDS RELATED TO	**CAUSES**	**CONSEQUENCES**	**SAFEGUARDS**	**RECOMMENDATION**
LNG transfer	Already studied in previous node	Already studied in previous node	Already studied in previous node	
Heat transfer	Thermal inertia in case of sudden closure of outlet valves or gas turbine trip in the CCGT	Pressure increase downstream booster pumps. Possible leakage.	Process control and emergency shutdown system would drive the process to safe condition	
Failure of rotating equipment	n.a.	n.a.	n.a.	
Failure of instrumentation and control loops	Failure of temperature, pressure, flow detection, field communication, control system, control valves, etc.	Possibility to create a condition not suitable for the process and to produce damages to the vaporizer, i.e sudden closure of vaporizer outlet and pressure increase due to thermal inertia. Possible high pressure gas leakage or LNG spillage→ Major accident included in the QRA → scenario # 7, 8	Safeguards are generally present and redundant for each possible failure All pressurized equipments provided with PSV Gas detection, emergency shut down system, and fire fighting system would be implemented and cover the whole onshore area.	Study detailed effect of failure of each control loop and corresponding safeguards in a complete HAZOP to be carried out after front-end-design is completed
Failure of utilities	Failure of power, instrument air, nitrogen, control signals, etc.	Possibility to create a condition not suitable for the process and to produce damages to the vaporizer (pipe vibration and breaking). Scenario already detected in the previous row	Safeguards are generally present and redundant for each possible failure	Study detailed effect of failure of each utility and corresponding safeguards in a complete HAZOP to be carried out after front-end-design is completed
Lay-out	Possible damages in the onshore area during maintenance due to equipment congestion	Possible major leakage in a high pressure gas or LNG pipe → Major accident included in the QRA →		Separation between equipments must be respected. Requirement of standard EN 1473 must be

Project:	**Proposed LNG floating storage and onshore regasification unit**			
System:	**LNG Vaporization**			
HAZARDS RELATED TO	**CAUSES**	**CONSEQUENCES**	**SAFEGUARDS**	**RECOMMENDATION**
		scenario # 7,8		fulfilled and evidence produced in the corresponding report
External impacts	Impact of road vehicle	Possible major leakage in a high pressure gas or LNG pipe → Major accident included in the QRA → scenario # 7, 8	Circulation of vehicles would be limited, speed minimized and equipment protected by concrete walls, barriers	
Extreme meteorological conditions	n.a.			
Domino effects	Possible domino effect in case of explosion or pool fire proceeding from other equipment in the plant	Possible major leakage in vaporizer outlet or LNG spillage in vaporizer inlet → Major accident included in the QRA → scenario # 7, 8	Onshore plant would be protected by fire fighting system including deluge system in order to reduce fire radiation. Also, emergency shutdown system and eventually the emergency vent would reduce the amount of gas exposed to the heat radiation	

Project:	**Proposed LNG floating storage and onshore regasification unit**			
System:	**High Pressure Equipment (Metering and Regulation Station, gas transfer and Compressor)**			
HAZARDS RELATED TO	**CAUSES**	**CONSEQUENCES**	**SAFEGUARDS**	**RECOMMENDATION**
LNG transfer	n.a.	n.a.	n.a.	
Heat transfer	n.a.	n.a.	n.a.	
Failure of rotating equipment	Malfunctioning of compressor due to mechanical problems, lack of lubrication, lack of cooling, internal corrosion, presence of humidity, etc.	Leakage of compressed gas in the worst case, if seals of the compressor or flexible connections are broken.	High pressure gas compressors are provided with extremely sophisticated internal protection, continuously monitoring the temperature, vibration, power consumption, oil pressure and other parameters and tripping the motor to safe stop when required	
Failure of instrumentation and control loops	Failure of temperature, pressure, flow detection, field communication, control system, control valves, etc.	Possibility to create a condition not suitable for the process and to produce damages to the installations, i.e. blockage of valve, unexpected flow reduction, etc. Possible high pressure gas leakage → Major accident included in the QRA → scenarios # 9, 10, 11, 12, 13, 14	Safeguards are generally present and redundant for each possible failure All pressurized equipments provided with PSV Gas detection, emergency shut down system, and fire fighting system would be implemented and cover the whole onshore area.	Study detailed effect of failure of each control loop and corresponding safeguards in a complete HAZOP to be carried out after front-end-design is completed
Failure of utilities	Failure of power, instrument air, nitrogen, control signals, etc.	Possibility to create a condition not suitable for the process and to produce damages to the compressor. Scenario already detected in the	Safeguards are generally present and redundant for each possible failure	Study detailed effect of failure of each utility and corresponding safeguards in a complete HAZOP to be carried out after front-end-design is completed

Project:	Proposed LNG floating storage and onshore regasification unit			
System:	**High Pressure Equipment (Metering and Regulation Station, gas transfer and Compressor)**			
HAZARDS RELATED TO	**CAUSES**	**CONSEQUENCES**	**SAFEGUARDS**	**RECOMMENDATION**
		previous row		
Lay-out	Possible damages in the onshore area during maintenance due to equipment congestion	Possible major leakage in a high pressure gas pipe → Major accident included in the QRA scenarios # 9, 10, 11, 12, 13, 14		Separation between equipments must be respected. Requirement of standard EN 1473 must be fulfilled and evidence produced in the corresponding report
External impacts	Impact of road vehicle	Possible major leakage in a high pressure gas pipe → Major accident included in the QRA scenarios # 9, 10, 11, 12, 13, 14	Circulation of vehicles would be limited, speed minimized and equipment protected by concrete walls, barriers	
Extreme meteorological conditions	n.a.	n.a.	n.a.	
Domino effects	Possible domino effect in case of explosion or pool fire proceeding from other equipment in the plant	Possible major leakage in a high pressure gas pipe → Major accident included in the QRA scenarios # 9, 10, 11, 12, 13, 14	Onshore plant would be protected by fire fighting system including deluge system in order to reduce fire radiation. Also, emergency shutdown system and eventually the emergency vent would reduce the amount of gas exposed to the heat radiation	
		Possible BLEVE in the propane tank if exposed to fire over a large period		Ensure fire fighting protection to the propane gas tank

ANNEX B. DRAWINGS

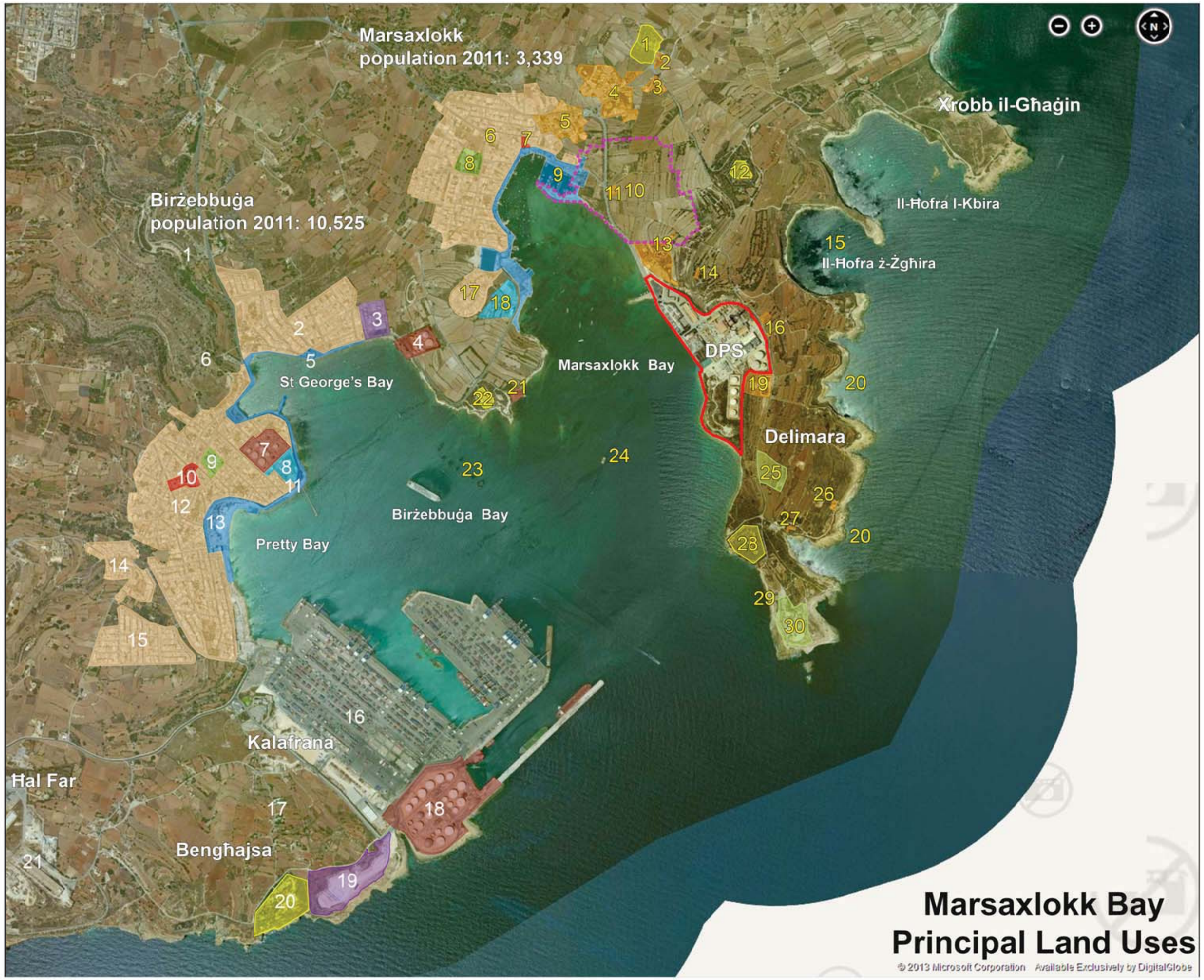
The following drawings are attached in the present Annex:

1. Area of concern (scale 1/10,000)
2. Land use (no scale)
3. Population estimation (scale 1/10,000)
4. Preliminary plot plan – consultant layout (scale 1/10,000)
5. Preliminary plot plan – ElectroGas layout (scale 1/10,000)
6. Individual risk curve – consultant layout (scale 1/10,000)
7. Individual risk curve – ElectroGas layout (scale 1/10,000)
8. Individual risk curve – comparison (scale 1/10,000)
9. Gas cloud extension – consultant layout (scale 1/10,000)
10. Gas cloud extension – ElectroGas layout (scale 1/10,000)
11. Gas cloud extension – comparison (scale 1/10,000)
12. Global domino effect – Blast Overpressure (scale 1/10,000)
13. Suggested position for offshore options (scale 1/10,000)

SGS	PROJECT: DELIMARA LNG PLANT QRA	SCALE: A3 : 1/10000	DRAWING NAME: AREA OF CONCERN	DATE: November 2013	DRAWING: 1

Birżebbuġa

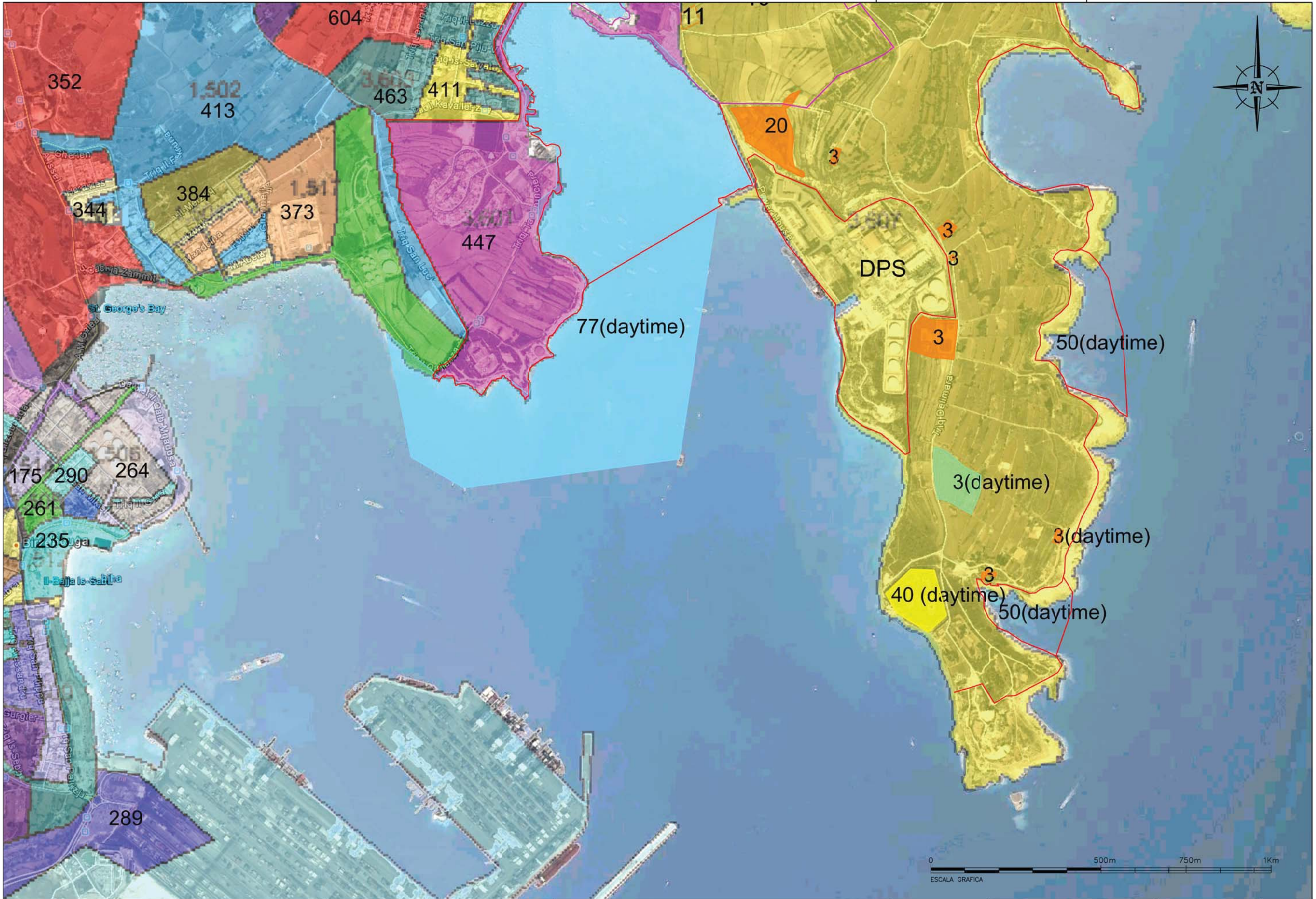
1 Important archaeological find
2 Predominantly residential
3 Unused LPG storage depot
4 Petroleum storage tanks
5 Historic redoubt
6 Important archaeological find
7 Petroleum storage tanks
8 Importer of petroleum products
9 Primary school
10 Parish Church and square
11 Historic redoubt
12 Predominantly residential
13 Recreation & tourism (along coast)
14 Predominantly residential
15 Predominantly residential
16 Malta Freeport (transshipment)
17 Small residential hamlet
18 Active petroleum storage depot
19 Active LPG storage facility
20 Historic fort
21 East of Industrial Estate



Marsaxlokk

1 Important archaeological find
2 Low density residential
3 Convent/Chapel
4 Low density residential
5 Low density residential
6 Predoiminantly residential
7 Parish Church and square
8 Primary school
9 Fishing, recreation, and tourism
10 Site of Community Importance
11 Low density residential
12 Historic fort (used as dog sanctuary)
13 Low density residential
14 Low density residential
15 Fish farm
16 Low density residential
17 Medium density residential
18 Light industry
19 Low density residential
20 Coastal ecology/swimming
21 Petroleum tank
22 Historic fort/research centre (fish)
23 Fish cages
24 Dolphin
25 Horse farm
26 Low density residential
27 Low density residential
28 Historic fort
29 Light house
30 Farm

	SGS	PROJECT: DELIMARA LNG PLANT QRA	SCALE: A3 : NOT SCALE	DRAWING NAME: LAND USE	DATE: November 2013	DRAWING: 2



		PROJECT:	SCALE:	DRAWING NAME:	DATE:	DRAWING:
	SGS	DELIMARA LNG PLANT QRA	A3 : 1/10000	POPULATION ESTIMATION	November 2013	3

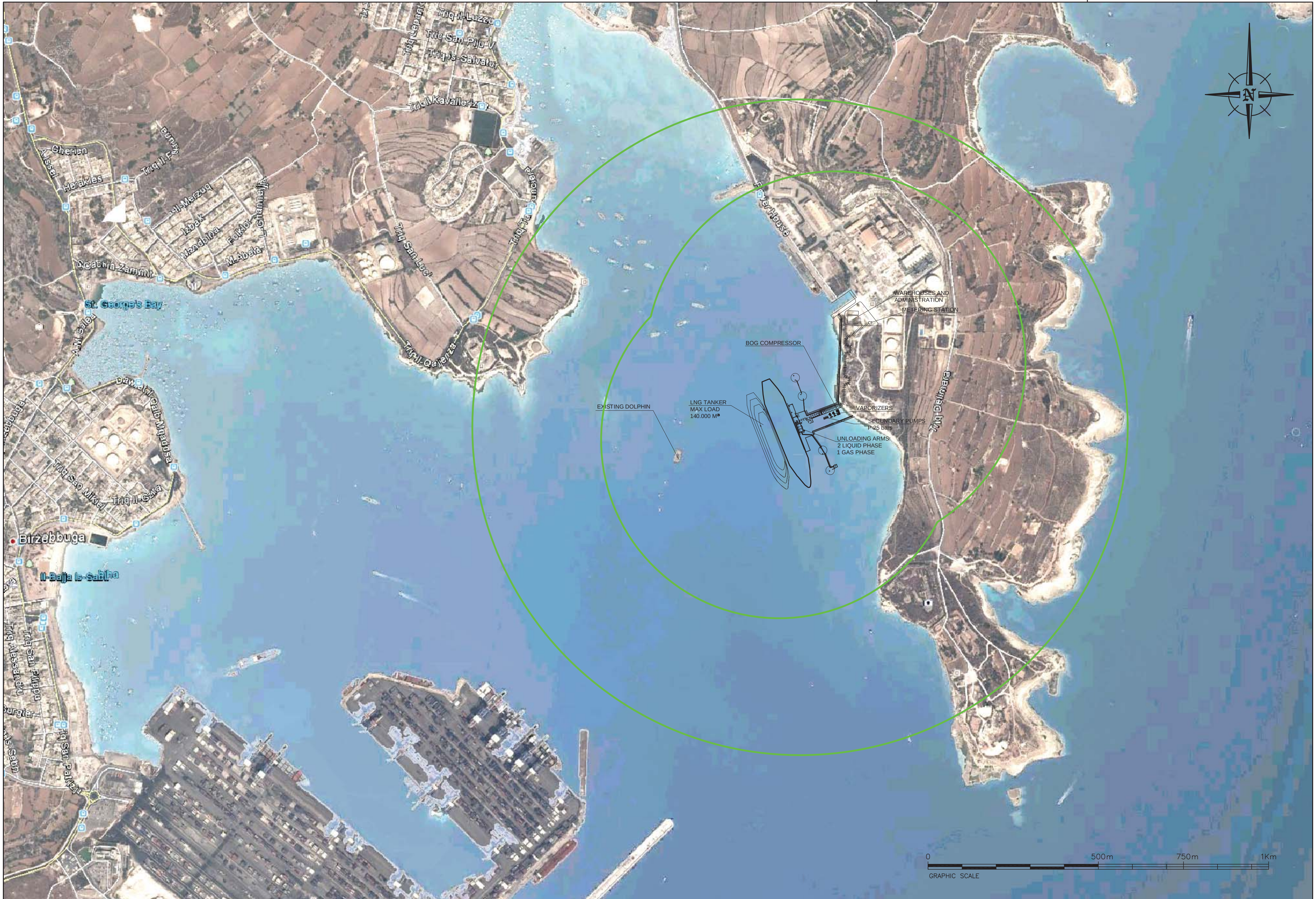
	SGS	PROJECT: DELIMARA LNG PLANT QRA	SCALE: A3 : 1/10000	DRAWING NAME: PRELIMINARY PLOT PLAN_CONSULTANT LAYOUT	DATE: November 2013	DRAWING: 4

SGS	PROJECT: DELIMARA LNG PLANT QRA	SCALE: A3 : 1/10000	DRAWING NAME: PRELIMINARY PLOT PLAN_ELECTROGAS LAYOUT	DATE: November 2013	DRAWING: 5

SGS	PROJECT: DELIMARA LNG PLANT QRA	SCALE: A3 : 1/10000	DRAWING NAME: INDIVIDUAL RISK CURVE_Consultant_layout	DATE: November 2013	DRAWING: 6

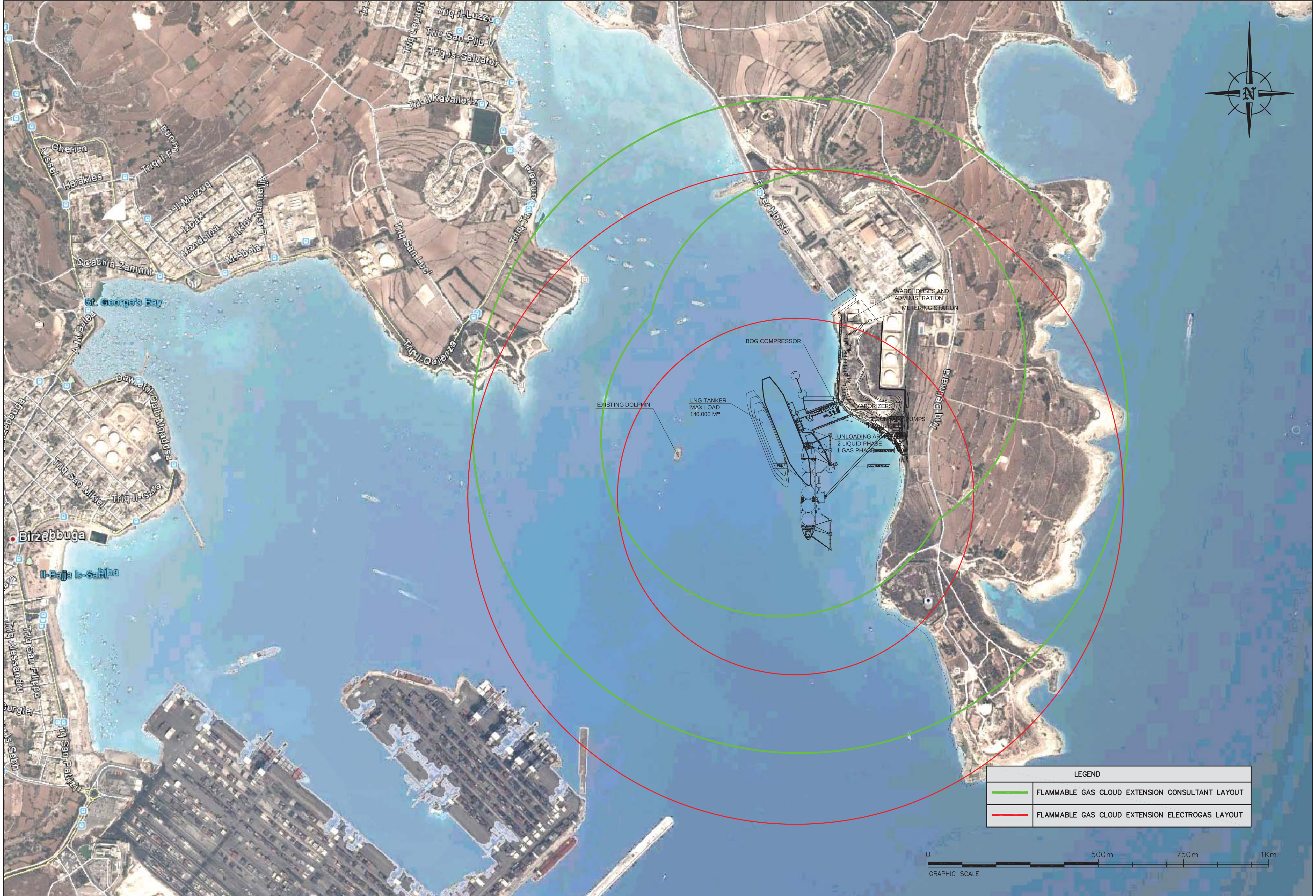
SGS	PROJECT: DELIMARA LNG PLANT QRA	SCALE: A3 : 1/10000	DRAWING NAME: INDIVIDUAL RISK CURVE_ELECTROGAS_layout	DATE: November 2013	DRAWING: 7

SGS	PROJECT: DELIMARA LNG PLANT QRA	SCALE: A3 : 1/10000	DRAWING NAME: COMPARISON INDIVIDUAL RISK CURVES	DATE: November 2013	DRAWING: 8



	PROJECT:	SCALE:	DRAWING NAME:	DATE:	DRAWING:
SGS	DELIMARA LNG PLANT QRA	A3 : 1/10000	GAS CLOUD EXTENSION_Consultant_layout	November 2013	9

SGS	PROJECT: DELIMARA LNG PLANT QRA	SCALE: A3 : 1/10000	DRAWING NAME: GAS CLOUD EXTENSION_ELECTROGAS_layout	DATE: November 2013	DRAWING: 10



	PROJECT:	SCALE:	DRAWING NAME:	DATE:	DRAWING:
SGS	DELIMARA LNG PLANT QRA	A3 : 1/10000	COMPARISON GAS CLOUD EXTENSION_OPTION B	November 2013	11

SGS	PROJECT: DELIMARA LNG PLANT QRA	SCALE: A3 : 1/10000	DRAWING NAME: GLOBAL DOMINO EFFECT - BLAST OVERPRESSURE	DATE: November 2013	DRAWING: 12

SGS	PROJECT: DELIMARA LNG PLANT QRA	SCALE: A3 : 1/10000	DRAWING NAME: SUGGESTED POSITION FOR OFFSHORE OPTIONS	DATE: JUNE 2013	DRAWING: 13

ANNEX C. REQUIREMENT FOR USE OF THE FREQUENCY AND CALCULATION OF HARDARMS AND HOSES SCENARIOS

INTRODUCTION

This annex has been prepared to extend to hoses the use of frequency data originally published by HSE for hardarms, due to the lack of specific data for hoses from the same source.

ANALYSIS

In the following table, the requirements associated with the use of the frequency, as they are listed in the original source, are commented in comparison with characteristics of the hardarms included in the analysis of the frequency itself and in comparison with characteristic of LNG transfer hoses.

REQUIREMENT FOR USE OF THE FREQUENCY AND CALCULATION OF SCENARIO	CHARACTERISTIC OF HARDARM FOR LNG	CHARACTERISTICS OF THE HOSES PROPOSED BY ElectroGas	REMARKS
Frequency is specific for loading / unloading ship connection, based on data collected in several port areas and for liquefied gases (FRED)	Hard arms are designed to withstand temperatures up to minus-165 degrees all equipment is designed for use with cryogenic substances up to minus 165 degrees. LNG hardarms are designed to withstand cryogenic operations according to industry standards, regulations and guidelines. Which exceed other product guidelines.	Any hose has to pass more than 20 specific test according to EN 1474-2 requirements in order to obtain class approval. Hoses are tested down to -196ºC. Even if thermal shock is avoided with gradual cooling at the beginning of each connection, hoses withstand thermal shock better than hardarms, thanks to the ductile material used for construction instead of metallic alloys.	LNG standards for both hoses and hardarms suggest that general failure frequency may be corrected, but no alternative data is published because no accidents have been reported so far.

REQUIREMENT FOR USE OF THE FREQUENCY AND CALCULATION OF SCENARIO	CHARACTERISTIC OF HARDARM FOR LNG	CHARACTERISTICS OF THE HOSES PROPOSED BY ElectroGas	REMARKS
Failure may lead to flow from both ends of the disconnected coupling (FRED)	In general, in case of disconnection, and apart from the presence of the PERC (powered emergency release coupling), both ship and jetty pipeline are provided with a emergency shut down valve (ESD) and relieve valve (RV) in order to isolate the transfer system and to minimize the quantity trapped in the same system.	Hose based system utilizes ERC which mimic the functionality provided by the PERC. The inventory content within the hose is depends on the size of the hose, however it is estimated to be less than the one calculated for an arm with same diameter. Also, in case of the unexpected event of a leakage not protected by the ERC, the spillage from a hose would fall directly into the sea between ship and jetty, rather than being released into the atmosphere as would be the case with the hardarm.	Presence of shut down valves is not considered in the FRED frequency, making not credible the scenario of total failure associated with the frequency.
Facilities are provided with emergency release coupling (ERC), which is a guarantee of immediate closure of valves from both sides of the coupling and minimum spillage of the quantity of liquefied gas trapped inside the coupling itself (FRED)	Following standards for LNG industry, all terminals utilize hardarms provided with PERC systems specifically developed for LNG operations. Due to the nature of their construction, hardarms are limited in the movements to within specific range of positions.	Hoses replicates the protections offered by hardarms, but the operational envelope of the hose based system is greater than that of the hardarms, resulting in a greater flexibility and greater range of vessel movement, thus reducing the likelihood of a release.	Protection is implemented in both cases, but hoses result in a lower probability of disconnection due to vessel movement, thus frequency seems overestimated.
Frequency includes not making a connection correctly, opening the wrong valve or at the wrong time, or spilling cargo when disconnecting or venting (FRED)	In order to ensure that the whole procedure for connection and disconnections are followed, interlocks are in place to prevent inadvertently operating valves. Interlocks are removed following a sequence implemented in the DCS (distributed control system) in the control room.	Protection is exactly the same as in hardarms	Operational failures and human errors included in the estimation of the frequency are minimized in the LNG industry, being any human operated installation supervised by the control system

REQUIREMENT FOR USE OF THE FREQUENCY AND CALCULATION OF SCENARIO	CHARACTERISTIC OF HARDARM FOR LNG	CHARACTERISTICS OF THE HOSES PROPOSED BY ElectroGas	REMARKS
Failure includes gross movement of the ship at the jetty. It is assumed that the unloading system is fitted with ranging alarms. (FRED)	Should the vessel move outside of the operation envelope then an ESD 1 follow by ESD 2 will occur. All LNG ships are provided with emergency systems: ESD 1 is the shut down of operation, while ESD 2 is the complete disconnection.	Protection is exactly the same as in hardarms, but envelope guaranteed by hoses is greater than for arms.	System is exactly the same for both solutions.
failure frequency due to passing ships assumes 10 passing ships during offloading (FRED)	Issue is not expected to be considered due to low traffic in Marsaxlokk bay.	Issue is not expected to be considered due to low traffic in Marsaxlokk bay.	Traffic in Malta is lower, resulting the adoption of the frequency in an overestimation of risk
Ranging failures may simultaneously affect more than one connection where multiple hard arms are in use (i.e. the ship moves and more than one hard arm becomes disconnected). (FRED)	Due to the nature of their construction, hardarms are limited in the movements to within specific range of positions.	Hoses replicates the protections offered by hardarms, but the operational envelope of the hose based system is greater than that of the hardarms, resulting in a greater flexibility and greater range of vessel movement	System is exactly the same for both solutions.
Release duration time less than two minutes (TNO) when an automatic detection and acting system are installed	Automatic detection of any spillage and corresponding pump stop, closure of shut down valves and disconnections are carried out in the minimum time in order to guarantee no damages to the installations due to hammering. Normal disconnections time in LNG industry is below 30 seconds, according to best industry practices and EN1474-1.	Shut down and disconnection time is guaranteed by the vendor of the ERC and is tested and certified by classifications societies such as DNV, BV, Lloys etc. To EN 1474-1 which is the same standard for hard arms.	Minimum release duration has been already considered in the calculation.
Quantity of LNG released was limited to the amount trapped in the coupling	A generic figure is approximately 5 liters per arm of LNG spilled in case of proper functioning of the PERC. For a 12” hardarm the inventory than can be spilled is estimated in 4 m3.	A generic figure is approximately 0.3 liters per arm of LNG spilled in case of proper functioning of the ERC. For a 12” hose the inventory than can be spilled is estimated in 1.8 m3.	Release was estimated in 1 cubic meter.

FRED: Failure Rate and Event Data
TNO: Netherlands Organisation for Applied Scientific Research

CONCLUSION

In conclusion, safeguards implemented by hardarms and hose in the LNG industry not only completely fulfill the requirements from HSE, but also exceed these requirements, introducing specific solutions not available in the market for other products, guaranteeing to the LNG industry one of the highest safety records in the shipping and energy industry. Use of modern hoses provided with the same level of protection as hardarms guarantees better protections against unexpected movements, while carrying all the protections and safeguards of the hardarms.

As usual for leading technologies, historical data takes time to be collected, thus a specific frequency for the LNG industry is not available at this time, making necessary the adoption of the general frequency published by HSE, well knowing that the resulting risk would be overestimated.

The ultimate conclusion is that extension to hoses of frequency published for hardarms, should be acceptable in the LNG industry.

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

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 [38]:

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.

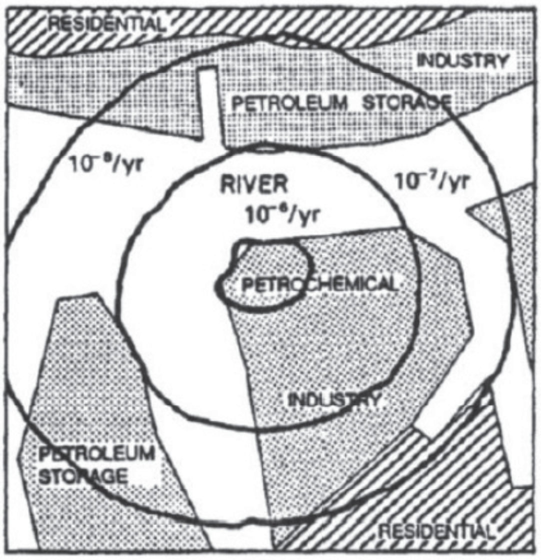


Figure 2.- Example Individual Risk Contour [38]

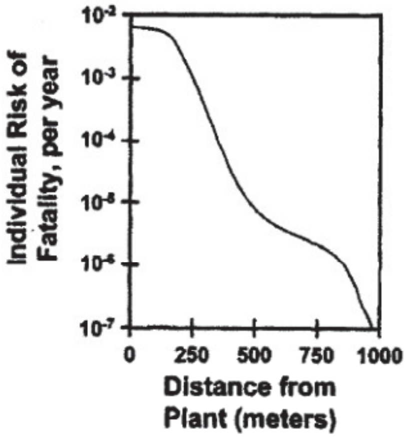


Figure 3.- Example Individual Risk Profile [38]

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.

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).

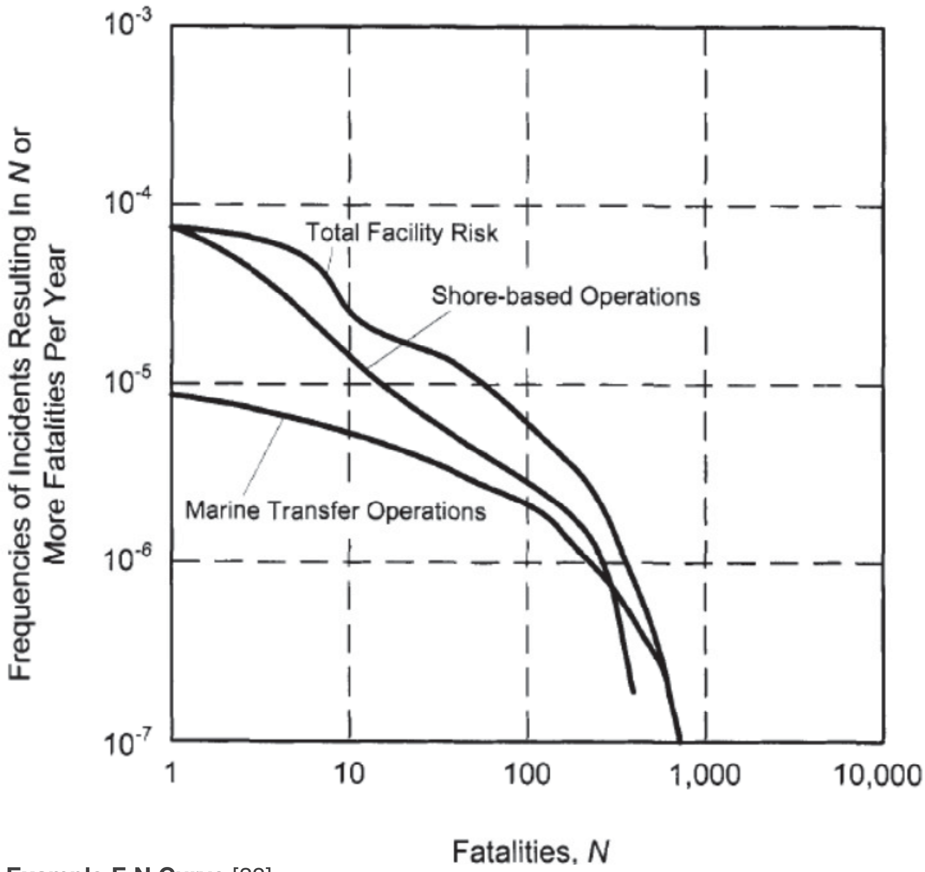


Figure 4.- Example F-N Curve [38]

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.

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.

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**. [39]

> "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 [40]:

> "[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})[10] which is still used in some risk criteria (e.g., Hong Kong; Sao Paulo, Brazil; and Victoria and New South Wales, Australia).

[10] 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.

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.

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: [41]

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.

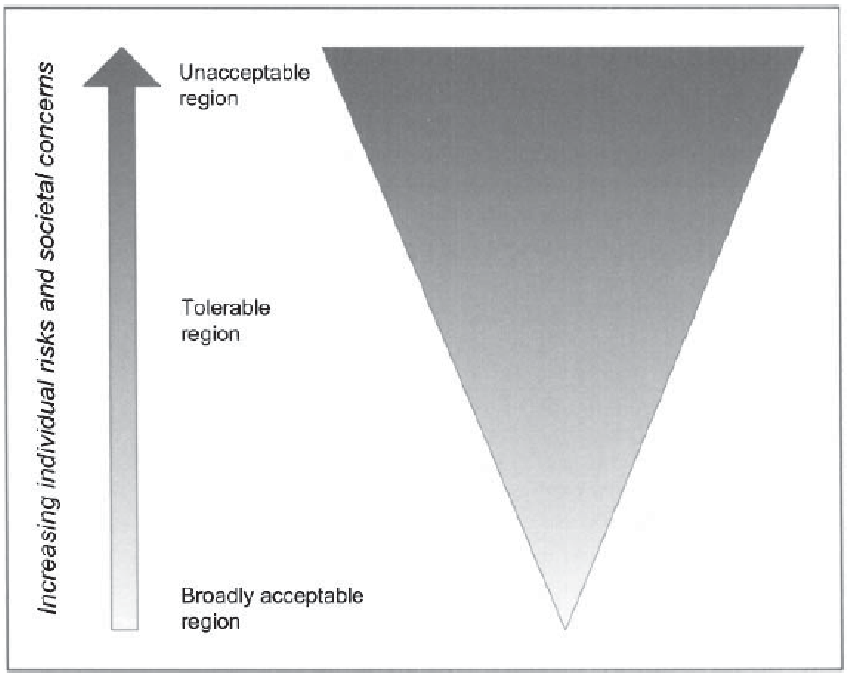


Figure 5.- HSE Tolerability of Risk Diagram [42]

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.

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*[43]. 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 [42] 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.

Health and Safety Executive (HSE) - 2008[11]

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*[44]. The updated methodology is similar to, but more detailed than, that described above. In addition, the scope has been expanded to

[11] 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.

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 6. 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 $\mathbf{10x10^{-6}}$/year, $\mathbf{1x10^{-6}}$/year, and $\mathbf{0,3x10^{-6}}$/years, respectively [45]. For other facilities handling large amounts of flammable hydrocarbons, the zones values, without considering the likelihood of a release occurring. [46] A database of consultation distance information is maintained for use by the planning authority.

New criteria have been established for categorizing developments by sensitivity levels that, similar to the precedent set in [47], 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. [44]

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).

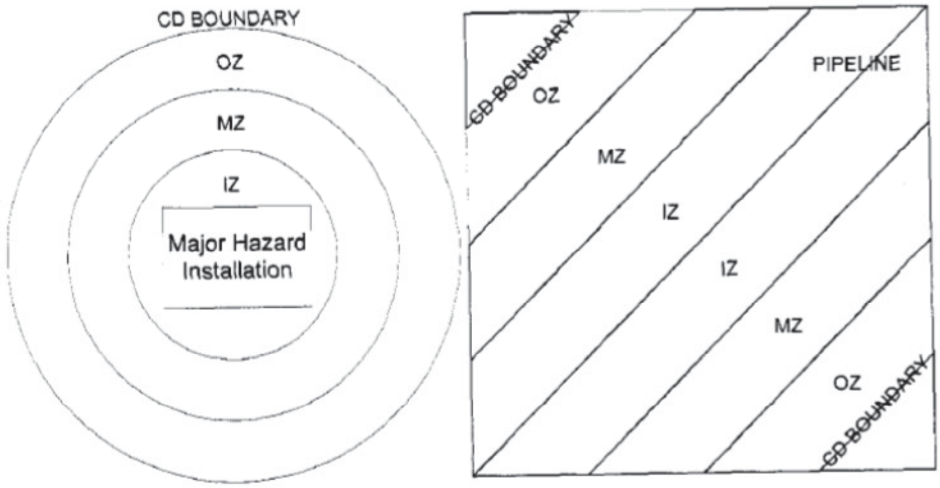


Figure 6.- Illustration of HSE's Consultation Distance Around Fixed Facilities and Pipelines [44]

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 [44]

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[12]

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.

[12] 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]

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* [48], 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 **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., [49], [50], [51]) with some noting that, of the two processes, compliance with the requirements of the environmental permitting requirements is the more rigorous.

LAND USE PLANNING CRITERIA IN HONG KONG

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. [52] This and subsequent studies prompted the government to formulate preliminary risk criteria in the mid 1980s. [53] 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. [53] and [54]. The risk criteria were formalized and added to the *Hong Kong Planning Standards and Guidelines* [55] in 1993.

The individual risk and societal risk criteria are presented in Table 2 and Figure 7. 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

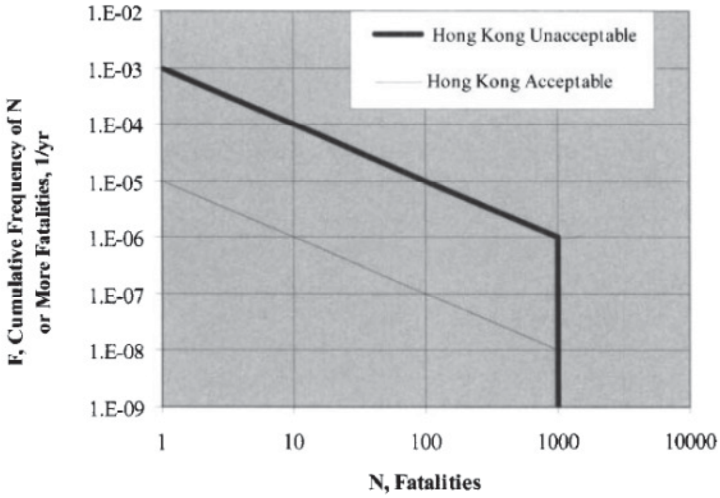


Figure 7.- Hong Kong Societal Risk Criteria

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). [56] 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.” [57]

Examples of facilities that require environmental permits, and are therefore subject to requiring an environmental impact assessment, include but are not limited to: [57]

- 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 [53], 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. [39] 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. [58]

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: [55]

> "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. [59]

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[13]. The individual risk and societal risk criteria for the three states are provided in Table 3 and Figure 8. Omitted from Figure 8, 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.

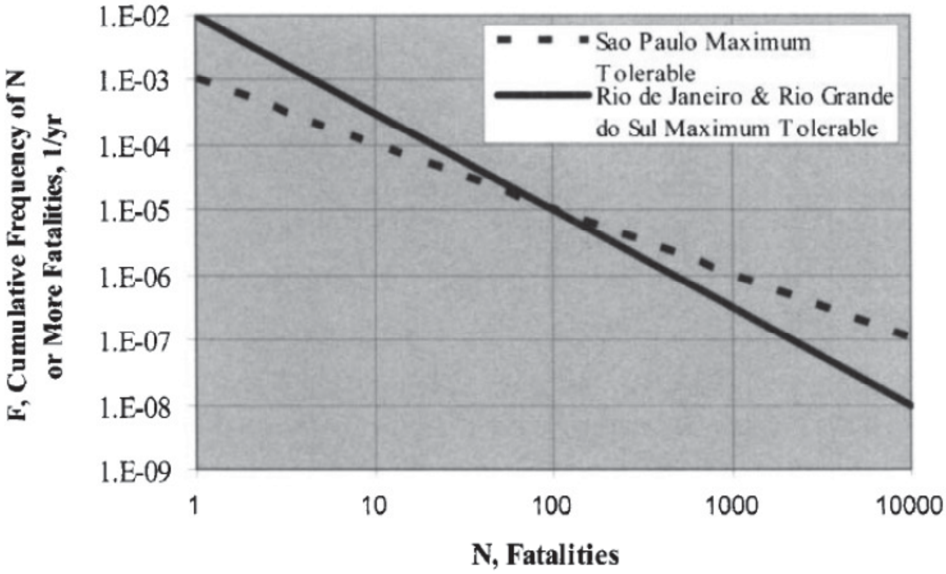


Figure 8.- Societal Risk Criteria for Three States in Brazil

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.

---

[13] 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.

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
Maximum tolerable risk to the public Existing situations	Plants: 10^{-6} Pipelines: 10^{-4}	Plants: 10^{-5} Pipelines: 10^{-5}
New situations	Plants: 10^{-6} 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[14] [60] may, for fixed facilities, allow individual risk to exceed $\mathbf{10^{-5}}$ 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 [61]

The state environmental agency, FEEMA[15] 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 [62]

QRA guidelines, including risk tolerance criteria, have been issued by the state environmental licensing agency, FEPAM.27[16]

[14] Companhia de Tecnologia de Saneamento Ambiental
[15] Fundação Estadual de Engenharia do Meio Ambiente
[16] Fundação Estadual de Proteção ambiental

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.

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[63]. 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 [64]. 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
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.

LAND USE PLANNING CRITERIA IN UNITED STATES FEDERAL COVERNMENT AGENCIES

Department of Energy (DOE)

DOE'S standards and guidance for the preparation of nuclear safety analysis reports [65] and [66] 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 [65]:

> "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 [67] and [68]:

- 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).[17]

At least one DOE field office has identified the need to fully evaluate the risk spectrum [69]:

> "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)."

<u>Environmental Protection Agency (EPA)</u>

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 [70]:

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

[17] 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.

REGULATION	TYPICAL ACCEPTABLE RESIDUAL RISK, FATALITY / LIFETIME	COMMENTS
		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: [71]

> "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}**)."

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: [70]

> "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.

INTERNATIONAL MARITIME ORGANIZATION (IMO)

In 1997, IMO published interim guidelines for the conduct of formal safety assessments (FSA)s [72]. 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 [73], were criteria for evaluating the risk.

Norway proposed individual risk and societal risk criteria for use in the FSA process in 2000. [74] While not yet formally adopted by IMO, these criteria were discussed extensively in a recent IMO publication on Risk Evaluation Criteria. [75] 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 [42]. 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: [75]

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 [75].
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[75].

SUMMARY

Table 10 and Table 11 summarize relevant information from this report for individual risk criteria for the public and for workers, respectively. Figure 9 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		
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

REGULATION	ENTITIES / APPLICATIONS	COMMENTS
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
1×10^{-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
$1{,}4 \times 10^{-8}$	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		
1×10^{-3}	UK HSE	
	International Maritime Organization (IMO) / Existing Ships	For crew members on existing ships
1×10^{-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		
1×10^{-6}	UK HSE	
	International Maritime Organization (IMO)	For crew members on new or existing ships

REGULATION	ENTITIES / APPLICATIONS	COMMENTS
$2,2 \times 10^{-5}$	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		
$2,5 \times 10^{-6}$	Various US OHSA Regulations	Upper range value for cancer risk to workers (10^{-4} cancer fatality/lifetime) divided by assumed lifetime of 40 years
$2,5 \times 10^{-7}$	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

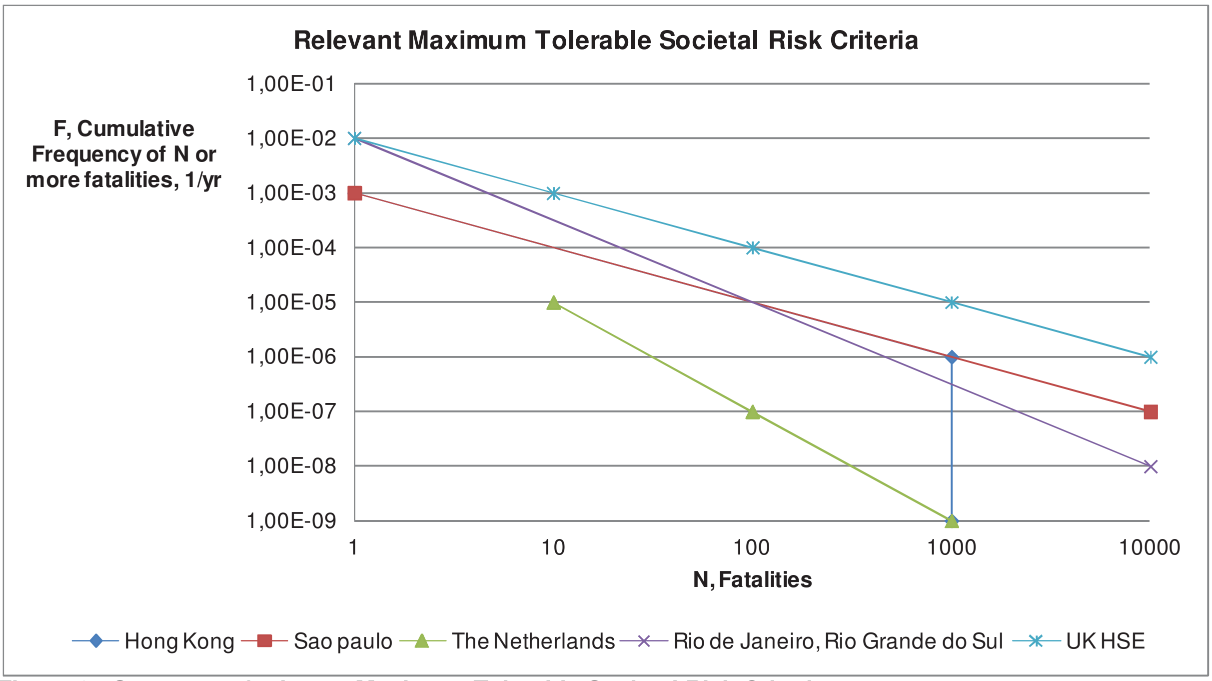


Figure 9.- Summary of relevant Maximum Tolerable Societal Risk Criteria

REFERENCES

[1] Process Description Statement.

[2] C. Galdies, The climate of Malta: statistics, trends and analysis 1951-2011, National Statistics Office, Malta.

[3] "Malta National Focal Point," EMWIS: Euro-Mediterranean Information System on know-how in the Water sector, [Online]. Available: http://www.emwis-mt.org/documentation/context/physical%20factors_files/Geology.htm. [Accessed June 2013].

[4] P. Galea, "Seismic history of the Maltese islands and considerations on seismic risk," *Annals of Geophysics,* vol. 50, no. 6, pp. 725-740, December 2007.

[5] "Wikipedia," [Online]. Available: http://en.wikipedia.org/wiki/Q-Flex. [Accessed June 2013].

[6] "Ship Technology," [Online]. Available: http://www.ship-technology.com/projects/tembek/. [Accessed Juny 2013].

[7] "Oil & Gas Journal," June 2013. [Online]. Available: http://www.ogj.com/articles/2008/07/new-q-max-lng-vessel-is-worlds-largest.html.

[8] “Maritime Connector,” June 2013. [Online]. Available: http://maritime-connector.com/wiki/q-max/.

[9] "Wikipedia," [Online]. Available: http://en.wikipedia.org/wiki/Q-Max. [Accessed June 2013].

[10] (Ph. D.) Vianello, Chiara, "Risk analysis of gas distribution network".

[11] P. Michele Michot Foss, "LNG Safety and Security," Sugar Land, Texas, 2006.

[12] Health & Safety Executive (HSE), “LNG source term models for hazard analysis "A review of the state-of-the-art and an approach to model assessment",” 2010.

[13] VROM, Publication Series on Dangerous Substances (PGS 1) - Methods for the determination of possible damage "Green Book" CPR 16E.

[14] Health and Safety Authority (HSA), Policy & Approach of the Health & Safety Authority to COMAH Risk-based Land-use Planning, 07 September 2009.

[15] A. Franks, “A Review of HSE's Risk Analysis and Protection - Based Analysis Approaches for Land-Use Planning,” Health and Safety Executive (HSE), 2004.

[16] Health And Safety Executive (HSE), "Offshore Installations (Safety Case) Regulations 2005 Regulation 12 Demonstrating compliance with the relevant statutory provisions".

[17] Health and Safety Executive (HSE), “Fire, Explosion and Risk

Assessment," February 2003.

[18] Health and Safety Executive (HSE), "Application of QRA in operational safety issues," 2002.

[19] RIVM, Reference Manual Bevi Risk Assessment version 3.2, 2009.

[20] VROM, Publication Series on Dangerous Substances (PGS 3) - Guideline for quantitative risk assessment 'Purple book' CPR 18E., 2005.

[21] Flemish Government, LNE Department, Environment, Nature and Energy Policy Unit, Safety Reporting Division, "Handbook Failure Frequencies," 2009.

[22] HSE, Failure Rate and Event Data for use within Risk Assessment.

[23] VROM, Publication Series on Dangerous Substances (PGS 2) - Methods for the calculation of physical effects - due to releases of hazardous materials (liquids and gases)- "Yellow Book, CPR 14E".

[24] TNO, "TNO innovation for life," [Online]. Available: http://www.tno.nl/index.cfm?Taal=2.

[25] EN 1473 (2007): Installation and Equipment for Liquefied Natural Gas - Design of Onshore Installations, 2007.

[26] Eisenberg N A, et al. 1975, "Vulnerability model. A simulation system for assessing damage resulting from marine spills," US DoT, US coast guard, 1975.

[27] Crosswaite, P. J.; Fitzpatrick, R. D.; Hurst, N. W.;, "Risk Assessment for the Siting of Developments Near Liquefied Petroleum Gas Installations," in *IChemE Symposium Series 110, Preventing Major Chemical and Related Process Accidents*, London, May 1988.

[28] Building Regulations, "Technical Guidance Document B. Fire Safety," Stationary Office, Dublin, 2006.

[29] Health and Safety Executive (HSE) , "An independent review of HSE methodology for assessing societal risk," January 2006.

[30] Carter, D.A., "The Scaled Risk Integral - A Simple Numerical Representation of Case Societal Risk for Land Use Planning in the Vicinity of Major Accident Hazards," in *Loss Prevention and Safety Promotion in the Process Industries*, vol. II, Elsevier, 1995.

[31] Hirst, I. L.; Carter, D. A.;, "A "Worst Case" Methodology for Risk Assessment of Major Accident Installations," *Process Safety Progress,* vol. 19, no. 2, Summer 2000.

[32] Health and Safety Laboratory (HSL), "Review of Hazard Identification Techniques," 2005.

[33] Health and Safety Executive (HSE), "Canvey - An Investigation of Potential Hazards from Operations in the Canvey Island/Thurrock Area," HMSO, London, 1978.

[34] COMAH Regulations. Policy & Approach of the Health & Safety Authority to COMAH Risk-based Land-use Planning.

[35] H. &. S. E. (HSE), "Societal Risk: Initial briefing to Societal Risk Technical

Advisory Group," Buxton, 2009.
[36] D. Jones, Nomenclature for hazard and risk assessment in the process industries. 2nd Edition, IChemE, 1985.
[37] Supplementary Planning Policy Guidance - Major Accident Hazards and Hazardous Substances, HAZARDOUS SUBSTANCES, 2004.
[38] Center for Chemical Process Safety (CCPS), Guidelines for Chemical Process Quantitative Risk Analysis, Second Edition, New York, 2000.
[39] H. M. S. Office, The Control of Major Hazards, Advisory Committee on Major Hazards, First Report, London, 1976.
[40] Health and Safety Executive (HSE), QuantiJied Risk Assessment: Its Input to Decision Making, London: Her Majesty's Stationery Office, 1989.
[41] Health and Safety Executive (HSE), The Tolerability of Risk from Nuclear Power Stations, London: Her Majesty's Stationery Office, 1988.
[42] Health and Safety Executive (HSE), Reducing Risks, Protecting People - HSE 's Decision-making Process, London: Her Majesty's Stationery Office, 2001.
[43] Health and Safety Executive (HSE), Risk Criteria for Land-use Planning in the Vicinity of Major Industrial Hazards, London: Her Majesty's Stationery Office, 1989.
[44] PADHI- HSE's land use planning methodology, http://www.hse.gov.uk/landuseplanning/padhi.pdf, 2008.
[45] Health and Safety Executive (HSE), HSE'S current approach to land use planning (LUP), http://www.hse.gov.uk/landuseplanning/lupcurrent.pdf, 2008.
[46] Health and Safety Executive (HSE), Revised land use planning arrangements around large scale petroleum depots, UK: http:l/www.hse.gov.uk/researchlrrpdf/rr5 1 1 .pdf, 2007.
[47] Health and Safety Executive (HSE), Guidance on 'as low as reasonablypracticable ' (ALARP) decisions in control of major accident hazards (COMAH), http : //www.hse.gov.uk/comah/circular/perm12.htm, 2008.
[48] VROM, Besluit Externe Veiligheid Inrichtingen (External Safety (Establishments) Decree) Staatscourant Sept. 23, The Netherlands, 2004, p. nt.183.
[49] VROM, Summary of the advice on external safetypublished by the Advisory Council for Transport and Wuter Management and the Advisory Council for Housing, Spatial Planning and the Environment, http://international.vrom.nl/docs/internationaal/030601%20Summary%20RadenadviesEVH_engels.pdf, 2003.
[50] VROM, Guidance on the Accountability for Societal Risk, The Hague: http://www2.vrom.nl/docs/internationaal/Accountabilitity.pdf, 2004.
[51] B. Ale, Tolerable Or Acceptable: A Comparison Of Risk Regulation In The United Kingdom And In The Netherlands. Risk Analysis, vol. 25, 2005.

[52] R. e. a. Kolluru, Risk assessment and management handbook for environmental, health and safety professionals, New York: McGraw-Hill, 1996.

[53] D. J. B. a. P. J. Floyd, Societal Risks, Final Report, 1998.

[54] Boult, “Risk management of LPG transport activities in Hong Kong,” *Journal of Hazardous Materials,* no. 71, pp. 85-100, 2000.

[55] “Hong Kong Planning Standards and Guidelines, Chapter 12: Miscellaneous Planning Standards and Guidelines,” no. http://www.pland.gov.hk/tech_doc/hkpsg/english/chl2/chl2_text.htm, 2002.

[56] Technical Memorandum to Environmental Impact Assessment Ordinance, Section 4, Hong Kong: http://www.epd.gov.hk/eia/english/legis/memorandum/text4.html, 2008.

[57] Environmental Impact Assessment Ordinance, Hong Kong: http://www.epd.gov.hk/eia/english/legis/index1.htmll, 2008.

[58] Hong Kong Planning Standards and Guidelines, Chapter 12:Miscellaneous Planning Standards and Guidelines, 2002.

[59] Landslide Risk Management and the Role of Quantitative Risk Assessment Techniques Information Note 121200.

[60] Companhia de Technologia de Saneamento Ambiental (CETESB), Manual De Orientaça'o Para A Elaboraçao De Estudos De Análise De Riscos, 2003.

[61] Governo do Estado Do Rio De Janeiro, Znstrupjo Tkcnica Para ElaboraqEo De Estudo De Zmpacto Ambiental- Eia E Seu Respectivo Relatorio De Impacto Ambiental-Rima Para 0 Complexo Petroquimico Do Rio de Janeiro - Comperj Instru@o Tecnica Decon No 0112007, Rio De Janeiro, 2007.

[62] F. E. d. P. Ambiental, Manual de Analise de Riscos Industriais, FEPAM N."01/01, Brazil: www.fepam.rs.gov.br/central/formularios/arq/manual-risco.pdf, 2001.

[63] Loi no 2003-699 du 30 juillet 2003 relative a la prevention des risques technologiques et naturels et a la reparation des dommages,, Paris, 2003.

[64] Arrêté du 29 septembre 2005 relatif à l'évaluation et à la prise en compte de la probabilité d'occurrence, de la cinètique, de l'intensité des effets et de la gravité des conséquences des accidents potentiels dans les études de dangers des installations.., Paris, 2005.

[65] S. o. E. N. SEN-35-91, Nuclear Safety Policy, http://www.directives.doe.gov/pdfs/doe/doetext/senord/35/n3591.html, September 9, 1991.

[66] U. D. o. Energy, Guidance for Preparation ofDOE 5480.22 (TSR) and 5480.23 (SAR) Implementation Plans, DOE-STD-3011-94, http://www osti.gov/bridge/servlets/purl/10194808-mY7ZJM/webviewable/10194808.pdf, November 1994.

[67] U.S. Department of Energy, DOE Regulatory Unit Evaluation Report of the

BNFL Inc. Safety Requirements Document, REG-98-01, Richland Operations Office, 1998.

[68] U.S.Department of Energy, Top-Level Radiological, Nuclear, And Process Safety Standards And Principles For The RPP Waste Treatment Plant Contractor, 2004.

[69] U.S. Department of Energy, Office Of Safety Regulation Position On Conformance With Risk Goals In DOE/RL-96-0006, RLIREG-2000-08, 2002.

[70] L. R. Rhomberg, Survey of Methods for Chemical Health Risk Assessment Among Federal Regulatory Agencies, a report made to The Presidential/Congressional Commission on Risk Assessment and Risk Management, http://www.riskworld.cominreports/1996/risk-rpt/pdf/rhomberg.: Harvard Center for Risk Analysis, 1996.

[71] The Presidential/Congressional Commission on Risk Assessment and Risk Management, Risk Assessment and Risk Management in Regulatory Decision-Making, http://www.riskworld.com/nreports/nr7me001.htm, 1997.

[72] International Maritime Organization (IMO), Interim Guidelines For The Application Of Formal Safety Assessment (FSA) To The IMO Rule-Making Process, MSC/Circ. 829 & MEPC/Circ. 335, London, 1997.

[73] International Maritime Organisation (IMO), Guidelines for Formal Safety Assessment (FSA) for use in the IMO rule-making process, MSCICirc. 1023, London, 2002.

[74] International Maritime Organization (IMO), Formal safety assessment - decision parameters including risk acceptance criteria, MSC 7211 6, submitted by Norway, 2000.

[75] International Maritime Organisation (IMO, Risk Evaluation Criteria, D.4.5.2, 2005.

[76] Land Use Planning Guidelines in the context of directives 96/82/EC and 105/2003/EC, Christou et al, 2006. ISBN 978-92-79-09182-7.

[77] Lees' Loss Prevention in the Process Industries. Hazard identification, assessment and control, Elsevier Butterworth Heimann, 2004.

[78] A. Ronza, “A quantitative risk analysis approach to port hydrocarbon logistics,” *Journal of hazardous materials,* 2005.

[79] "NFPA 59AS: Standard for the Production, Storage, and Handling of Liquefied Natural Gas (LNG)," March 27, 2013.

[80] International Association of Oil & Gas Producers (OGP), "Guidance on performing risk assessment in the design of onshore LNG installations including the ship/shore interface," February 12, 2006.

[81] B. M. I. I. Board, “The Buncefield Incident, 11 December 2005 - The final report of the Major Incident Investigation Board,” *http://www .buncefieldinvestigation.gov.uk/reports/index.htm,* 2008.

[82] Health and Safety Executive (HSE), Murray, PADHI Rule 4c (Existing Use Rule), http://www.hse.gov.uk/landuseplanning/rule4cletter.pdf, 2008.

ANNEX E. CALCULATION OUTPUT

Calculation outputs are presented in a separate file in the electronic version only.