CYNERGY PROJECT

FSRU Terminal Risk Assessment

Preliminary Quantitative Risk Analysis

Our ref. 1708-0011

Rev.1

August, 2017
Summary

This report details the results of the Preliminary Quantitative risk assessment study of the proposed FSRU jetty terminal at Vassilkos Port, Cyprus. This study focussed on the assessment of major accident hazards with the potential to affect people at the facility or site and the verification that all identified risks remain at acceptable levels.
The proposed FSRU jetty terminal at Vassilikos Port has been subjected to a preliminary Quantitative Risk Assessment (QRA) in order to verify and quantify potential Major Accident Hazards (MAH) associated with the aspects of the design, the systems and operation of the proposed facility at conceptual engineering level. The objective of the QRA is to identify any critical drawbacks and/or Regulatory non compliances and provide appropriate recommendations required as part of the Environmental Impact Assessment (EIA) for the terminal permitting process.

The results of the QRA have confirmed that:

- All generated risks have been identified to be within tolerable and acceptable levels.
- The terminal generated risk zones do not have any detrimental impact neither would affect future passing ship traffic or cargo fuel loading operations at the nearby buoy.
- The potential risk to third party operations and the public at Vassilikos bay area is considered extremely low or insignificant.
- The overall societal risks are also within the ‘tolerable ALARP’ region and are dominated only by risks to personnel on-site.

It is noted that at this stage, prior to the selection of a specific FSRU, the QRA has used LNG/NG inventories and process system data based on similar FSRU operations at global locations. All data used were conservative and the QRA study is expected to be further developed and optimised during the project’s Front End Engineering Design (FEED) phase.
Glossary of Terms & Abbreviations

ALARP As Low As Reasonably Practicable
EGiG European Gas Pipeline Incident Data Group
ESD Emergency Shut Down
ESDV Emergency Shut Down Valve
ERS Emergency Release System
FMEA Failure Modes and Effect Analysis
FRED Failure Rate and Event Data
FSRU Floating Storage and Re-gasification Unit
GR Geographical Risk
HAZID Hazard Identification
HAZOP Hazard and Operability
HRD Hydrocarbon Release Database
HSE Health and Safety Executive
IRPA Individual Risk per Annum
LFL Lower Flammability Limit
LNG Liquefied Natural Gas
LNGC LNG Carrier
LSIR Location Specific Individual Risk
MAH Major Accident Hazard
MEM Multi Energy Method
NG Natural Gas
PCAG Planning Case Assessment Guide
P&ID Process Instrumentation Diagram
PHA Process Hazard Analysis
PLL Potential Loss of Life
QRA Quantitative Risk Assessment
RPT Rapid Phase Transition
SDV Shut Down Valve
SIS Safety Instrumented System
SIL Safety Integrity Level
SSL Ship-Shore Link
STS Ship to Ship
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1. **INTRODUCTION**

1.1 **General**

Lloyd’s Register EMEA (LR) has been engaged by the Natural Gas Company of Cyprus DEFA (CYGAS) as part of its Synergy Partners group to address the Risk Assessment scope of the detailed Concept Definition Study of the LNG terminal site selection which will enable the award of the permit for the future development of Front-End Engineering Design phase with a single, well-defined concept study.

1.2 **Facility Description**

It is proposed that the development of the facility will involve construction of a trestle/jetty for the permanent berthing of a Floating Storage Regasification Unit (FSRU) which would be able to regasify LNG and export gas over the jetty pipeline to shore. Continuous FSRU operations will be achieved by LNG carriers (LNGC) suppling LNG to the FSRU by Ship-to-Ship (STS) cargo transfer. The FSRU is a strategic project for Cyprus as it would enable the creation of a gas supply chain to the island flexible to accommodate future expansion of the gas consumers market on the island.

The jetty will be located west of the main breakwater of Limassol Port – Terminal 2 (Vassilikos), at a distance of about 1.3km. The trestle runs offshore in a North–South direction for about 750m before turning south-west 430m to form the FSRU berth. A further extension of the jetty by another 310m, in order to accommodate an LNGC is foreseen.

The orientation of the berth is about 220° North, so that ships are aligned to the prevailing direction of wind and waves. Thus, according to the proposed layout (refer to Figure 1) the depth at the inner berth is between 15m and 18m while the outer berth depth will be approximately 22m.

The berth will consist of a loading platform of dimensions 30 meters by 35 meters. The loading platform substructure and deck is supported by piles. Ships berth against four breasting dolphins. The breasting dolphins will be equipped with fenders and quick release mooring hooks to accommodate the FSRUs spring lines.

There are also six (6) mooring dolphins for each berth, each mooring dolphin is equipped a quick release mooring hook.

The necessary infrastructure for development is expected to include the following as a minimum:

- A jetty for FSRU berthing and LNG transfer activities with an emergency shelter for the FSRU
- A Floating Storage and Regasification Unit (FSRU), permanently berthed at Vassilikos bay
- An offshore pipeline connecting the FSRU to the receiving point onshore
- The development of a local buffer/storage array able to store Natural Gas in gaseous form at the required operational pressure ranges adjacent to Vassilikos power station
- Any other facilities relating to the operational requirements of the system
1.3 Facility Schematic

Figure 2 below is a schematic to coarsely represent the proposed facility, based on the level of information available to Lloyd’s Register at the time of this assessment. It is noted that the regasification process skid will be located forward on-board the FSRU, and the LNG regasification process will required primary equipment such as recondenser, booster pump, and heat exchanger.
2. HAZARDS OF LNG AND NATURAL GAS

2.1 Properties of Natural Gas

Natural gas (NG) is a mixture of methane (the main constituent) and other low molecular weight hydrocarbons (such as ethane and propane). LNG is natural gas that is kept in liquid form at extremely low temperatures and pressures close to atmospheric. The liquefaction process requires that contaminants such as water and carbon dioxide are removed, so that the concentration of such contaminants in LNG, and natural gas produced by vaporising LNG, is extremely low. The physical properties of methane, ethane and propane are summarised in Table 1.

<table>
<thead>
<tr>
<th>Property</th>
<th>Substance</th>
<th>Methane</th>
<th>Ethane</th>
<th>Propane</th>
</tr>
</thead>
<tbody>
<tr>
<td>Chemical Formula</td>
<td></td>
<td>CH₄</td>
<td>C₂H₆</td>
<td>C₃H₈</td>
</tr>
<tr>
<td>Molecular weight</td>
<td></td>
<td>16.04</td>
<td>30.07</td>
<td>44.09</td>
</tr>
<tr>
<td>Atmospheric boiling point (°C)</td>
<td></td>
<td>-161.5</td>
<td>-88.6</td>
<td>-42.1</td>
</tr>
<tr>
<td>Liquid specific gravity</td>
<td></td>
<td>0.422</td>
<td>0.546</td>
<td>0.590</td>
</tr>
<tr>
<td>(relative to water = 1)</td>
<td></td>
<td>(at -160°C)</td>
<td>(at -88.6°C)</td>
<td>(at -50°C)</td>
</tr>
<tr>
<td>Gas specific gravity</td>
<td></td>
<td>0.55</td>
<td>1.1</td>
<td>1.5</td>
</tr>
<tr>
<td>(relative to air = 1)</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Lower Flammable Limit (% v/v)</td>
<td></td>
<td>5</td>
<td>2.9</td>
<td>2.1</td>
</tr>
<tr>
<td>Upper Flammable Limit (% v/v)</td>
<td></td>
<td>15</td>
<td>13</td>
<td>9.5</td>
</tr>
</tbody>
</table>


Table 1: Physical Properties of Natural Gas Constituents

Natural gas’s hazards arise from its flammability and vapour dispersion properties. LNG presents an additional hazard in the form of extreme cold (being held at a temperature of approximately -162°C). Note that natural gas is not toxic (although it may act as an asphyxiant by displacing air).

2.2 Fire and Explosion Hazards

Natural gas, when released from containment as a gas, or when generated by vaporisation of a release of LNG, forms flammable mixtures in air between concentrations of 5 and 15 % vol/vol. Although natural gas at ambient temperature is less dense than air, the natural gas vapour generated by LNG at -162°C is approximately 1.5 times denser than air at 25°C. Hence natural gas as a gas under pressure at ambient temperature rapidly becomes buoyant upon release. However, the cold vapour generated by vaporisation of LNG behaves as a dense cloud. Although as the cold vapour mixes with air it becomes warmer and less dense, the cloud will tend to remain negatively buoyant until after it has dispersed below its lower flammability limit (LFL).

Different types of fire hazard may arise, depending on whether it is gaseous natural gas or LNG that is released. These fire hazards include jet fires, flash fires and pool fires. In certain circumstances, vapour cloud explosions (VCEs) may also occur.

2.2.1 Jet Fires

A jet fire is a strongly directional flame caused by burning of a continuous release of pressurised flammable gas (in this case natural gas) close to the point of release. Ignition may occur soon after the release begins; or may be delayed, with the flame burning back through the cloud (i.e.
as a flash fire, see below) to the source. Jet fires may result from ignited leaks from process equipment (vessels, pipes, gaskets etc.) and pipelines.

A jet fire may be directed horizontally or vertically (or at some angle in between). A jet fire may impinge on structures or other process equipment, giving a potential for escalation of the incident. The intensity of thermal radiation emitted by jet fires can be sufficient to cause harm to exposed persons.

### 2.2.2 Flash Fires

Flash fires result from ignition of a cloud of flammable gas or vapour, when the concentration of gas within the cloud is within the flammable limits. In this case, the flammable cloud may be generated by:

- A release of pressurised flammable gas (i.e. natural gas); or,
- Vaporisation of a pool of volatile flammable liquid (i.e., LNG).

Typically a flash fire occurs as a result of delayed ignition, once the flammable cloud has had time to grow and reach an ignition source. In the absence of confinement or congestion, burning within the cloud takes place relatively slowly, without significant over-pressure. It is assumed that thermal effects are generally limited to within the flame envelope where there is a very high probability of death.

### 2.2.3 Pool Fires

Ignited releases of flammable liquids (including LNG) tend to give rise to pool fires. As with jet fires, ignition of the liquid pool may occur soon after the release begins, or may occur as a result of flashback from a remote ignition source, if the liquid is sufficiently volatile to generate a cloud of flammable vapour.

### 2.2.4 Vapour Cloud Explosions

When a cloud of flammable gas occupies a region which is confined or congested, and is ignited, a vapour cloud explosion results. The presence of confinement (in the form of walls, floors and / or a roof) or congestion (such as the pipes, vessels and other items associated with process plant) in and around the flammable cloud results in acceleration of the flame upon ignition. This flame acceleration generates blast over-pressure. The strength of the blast depends on a number of factors, including:

- The reactivity of the fuel
- The degree of confinement or congestion
- The size of the congested/confined region occupied by the flammable cloud
- The strength of the ignition source

It should be noted that a variety of objects may act as confinement/congestion, in addition to those normally encountered on process plant. This includes areas of dense vegetation bordering the site.

### 2.2.5 Cryogenic Burns

The extremely low (cryogenic) temperature of LNG means that it can cause burns if it comes into contact with exposed skin. Furthermore, inhalation of the cold vapours generated by LNG can cause damage to the lungs (so-called ‘frosting of the lungs’).

### 2.2.6 Rapid Phase Transition

If LNG is spilt on to water it usually forms a boiling pool on the water surface. However, under certain circumstances, LNG released on to water can change from liquid to vapour virtually instantaneously. The effect has been observed in some experiments involving LNG but is not well understood. A Rapid Phase Transition (RPT) can generate overpressure and a ‘puff’ of
dispersing vapour. Any damage from the overpressure generated tends to be quite localised. Rapid phase changes have not resulted in any known major incidents involving LNG.
3. HAZARD IDENTIFICATION AND SCENARIO DEFINITION

3.1 Site Evaluation HAZID Study

A Site Evaluation Study including Hazard Identification (HAZID) workshop was undertaken as part of the Risk Assessment activities in order to verify the safety and integrity of the proposed terminal jetty installation. Based on similar FSRU installations the HAZID identified operations and involved systems and areas where potential LNG/gas releases may occur.

The objectives of the study were to:

- Undertake a preliminary examination of the terminal, gas pipeline system, operation during gas export, in compliance with the formal HAZID process.
- Identify potential hazards associated with the aspects of the design, installation and operation of the proposed jetty terminal and provide recommendations for the Preliminary QRA study required as part of the Environmental Impact Assessment (EIA) for the terminal permitting process.
- Assess the adequacy of the proposed marine facilities, layout design for ensuring the integrity and safety of the maritime operations and gas export to the pipeline.
- Perform a round table discussion of potential failure mode scenarios and emergency response procedures and update lay-out design (if required) in order to further reduce any potential hazards and minimise risks.

3.2 Scenario Definition

For the purposes of hazardous scenario definition, the following terminal areas / operations were addressed:

- LNG STS transfer headers, manifolds, hoses
- LNG feed to HP pumps/Heat exchangers
- Regasification header to Gas export manifold
- Gas piping to jetty ESDV

The first step in definition of scenarios for the preliminary QRA was to sub-divide the overall operation into ‘systems’, on the basis of the early process information available. Systems are groups of connected equipment items (pipes, vessels, etc.) containing process materials at similar conditions of temperature, pressure and composition. System boundaries may also be defined by isolation points (such as emergency shut-off valves).

Based on the previously undertaken FSRU risk assessment studies and the findings of the Site Evaluation HAZID, a set of major accident hazard scenarios were developed for risk assessment. The scenarios related to leaks from equipment of either gaseous natural gas or LNG, arising from a variety of causes.

A summary of the scenarios is presented in Section 4, Table 2.
4. MAJOR ACCIDENT HAZARD SCENARIOS

4.1 Scenario Definition

Having determined which hazards will be included in the assessment, and the level of detail that should be applied, it is then necessary to develop the list of hazards into modelling scenarios. This involves describing the scenario in sufficient detail to proceed with the modelling. For example, the hazard identification may identify the following hazard:

‘Leak of gas from pipe due to impact by object.’

The scenario definition step adds further detail to this, including:

- The process conditions (temperature, pressure) within the pipe
- The composition of the gas
- The size(s) of the leak that may occur
- The location(s) at which the leak might occur
- The volume of gas available to feed the leak

It is also common practice to group similar hazards together for the purposes of the subsequent analysis. Using the example above, the hazard identification study may identify a number of ways in which a leak of gas from a pipe could result (internal corrosion, external corrosion). All of those could be grouped together into a single ‘pipe leak’ scenario. The scenarios related to leaks from equipment of either gaseous natural gas or LNG is presented below:

<table>
<thead>
<tr>
<th>System</th>
<th>Node Reference</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>FSRU</td>
<td>L01</td>
<td>LNG release from pipework between the FSRU storage tank (Tank 4) and Recondenser</td>
</tr>
<tr>
<td>FSRU</td>
<td>L02</td>
<td>LNG release from Recondenser to the HP Booster Pumps</td>
</tr>
<tr>
<td>FSRU</td>
<td>L03</td>
<td>LNG release from HP Booster Pumps discharge pipework up to LNG-Seawater Heat exchanger</td>
</tr>
<tr>
<td>FSRU</td>
<td>L04</td>
<td>LNG release from cargo distribution header line (longest pipe length from Tank 4)</td>
</tr>
<tr>
<td>LNGC</td>
<td>L05</td>
<td>LNG release from liquid unloading hoses (STS Operations)</td>
</tr>
<tr>
<td>LNGC</td>
<td>L06</td>
<td>LNG release from cargo distribution header between the LNGC tanks (longest pipe length Tank 4) to the cargo manifold (STS Ops)</td>
</tr>
<tr>
<td>LNGC</td>
<td>G06</td>
<td>NG release from cargo vapour return header to LNGC storage tanks (Tank 4) (STS Operations)</td>
</tr>
<tr>
<td>LNGC</td>
<td>G05</td>
<td>NG release from vapour return hoses (STS Operations)</td>
</tr>
<tr>
<td>FSRU/LNGC</td>
<td>L05</td>
<td>LNG release from liquid unloading hoses (STS Operations)</td>
</tr>
<tr>
<td>FSRU/LNGC</td>
<td>G05</td>
<td>NG release from vapour return hoses (STS Operations)</td>
</tr>
<tr>
<td>FSRU/LNGC</td>
<td>L06</td>
<td>LNG release from cargo distribution header between the LNGC tanks (longest pipe length Tank 4) to the cargo manifold (STS Ops)</td>
</tr>
<tr>
<td>FSRU/LNGC</td>
<td>G06</td>
<td>NG release from cargo vapour return header to LNGC storage tanks (Tank 4) (STS Operations)</td>
</tr>
</tbody>
</table>

Table 2: Major Accident Hazard (MAH) Scenarios
5. RISK ASSESSMENT METHODOLOGY

5.1 Data Gathering

Depending on the purpose of the analysis and the size of the system under consideration, the quantity of data required to perform a QRA can be substantial. Typically, the data required include:

- Information about the system (engineering drawings, process data, equipment specifications, maps etc.);
- Information on potential ignition sources (on and off-site);
- Population data (for people on-site and/or off-site, depending on the purpose of the study); and,
- Meteorological data.

5.2 Consequence Analysis

The purpose of consequence analysis is to determine the potential outcome (or outcomes) of the various scenarios comprising the QRA. Consequence analysis may be broken down into the following steps:

- Source term modelling
- Physical effects modelling
- Impact modelling

Depending on the tools used by the analyst to perform the QRA, these steps may be performed using separate models, or in a single model that automatically proceeds from one step to the next.

5.2.1 Source Term Modelling

Source term modelling determines the behaviour of the material upon leakage, in terms of:

- Release rate and/or quantity;
- The velocity of the material;
- The phase of the material (liquid, gas / vapour or two-phase); and,
- The conditions within the material upon release (temperature, density, etc.).

Where the material forms a pool of liquid, it will also be necessary to model the pool spreading and rate of vaporisation of material from the pool.

5.2.2 Physical Effects Modelling

Modelling of physical effects predicts the behaviour of the material once it has been released, using the source term modelling results as inputs. The types of physical effects considered may include:

- Gas or vapour dispersion
- Fire dimensions and heat output (for ignited releases of flammable material)
- Size and strength of explosions (for ignited flammable clouds in congested/confined regions)

Since some of the calculations performed can be quite complex, and the number of calculations required in a QRA study can be large, software packages are usually employed to perform the modelling.
5.2.3 Impact Modelling

Impact modelling determines the impact that the various physical phenomena have upon receptors of interest (i.e. people, environmental features or assets, depending on the objectives of the study). For people, the relationship between exposure to a potentially harmful agent (such as toxic gas, thermal radiation or blast overpressure) and the probability of fatality is often expressed using a probit equation. Probit relationships take the form:

\[ Y = A + B \ln(D) \]

Where:

- \( Y \) = Probit value
- \( A \) and \( B \) are constants that are specific to the harmful agent.
- \( D \) is the harmful dose received by the receptor. This is a function of the concentration (or intensity) of the harmful agent and the exposure duration. In the case of thermal radiation:
  \[ D = Q^{\frac{4}{3}} \cdot t \]

Where:

- \( Q \) = incident thermal radiation flux (W.m\(^{-2}\))
- \( t \) = exposure duration (s)

The probit value is related to the probability of fatality by the following expression:

\[ P = 0.5 \times \left[ 1 + \text{erf} \left( \frac{Y - 5}{\sqrt{2}} \right) \right] \]

Where:

- \( P \) = probability of fatality

Probit values are available in standard tables and are incorporated into the PHAST Risk software. For example, a fatality probability of 0.1 corresponds to a probit value of 4.16.

5.3 Frequency Analysis

In general terms, frequency analysis is used to calculate:

- The likelihood of a given release of dangerous material occurring – this is usually expressed as a frequency (e.g. \( 1 \times 10^{-3} \) per year, or once in a thousand years);
- Given that a release has occurred, the probability that a given type of physical effect follows – for example, for releases of flammable material, the type of effect may depend on whether the material is ignited soon after the release begins, or at some time later; and,
- Given that a certain type of physical effect results, the probability of an undesired outcome – this may depend on the wind direction, the probability that a person is present within the hazard range, and the probability of successful emergency action.

Frequency analysis approaches fall into three categories:

- Use of relevant historical data
- Use of analytical or simulation techniques (such as fault tree analysis or event tree analysis)
- Use of expert judgment
Historical data may relate to the frequency of releases of varying sizes from different types of equipment (e.g., the frequency of small leaks from flanges), or to the frequency of accidents on facilities of interest (e.g., the frequency of spills during transfer of cargoes of dangerous substances from ships).

5.4 **Risk Analysis**

In simple terms, risk is the chance of an undesired outcome. The chance is usually expressed as a frequency; the undesired outcome may be fatality, environmental damage or financial loss. In terms of risks to people, there are different types of risk outputs that may be calculated using QRA.

- Risk indices (such as Fatal Accident Rate)
- Individual risk, usually expressed as the risk of harming a hypothetical person with a defined set of characteristics. Individual risk results may be expressed as a point value (the individual risk to a hypothetical person at a given geographical location), as a graph of individual risk versus distance (a risk transect) or as contours overlaid on a map
- Societal risk, which expresses the frequency with which different numbers of people could be affected by an accident.

5.5 **Risk Assessment and Risk Reduction**

Once the risk analysis results have been obtained, it is necessary to assess their significance. This often involves comparison of the results with criteria. Risk criteria may be established by regulators, or set internally by the company. Risk criteria usually define the level of risk which is deemed unacceptable (except perhaps in extraordinary circumstances); and the level of risk which is considered so low that further efforts to reduce the risk are unnecessary.

Between these two levels is a region in which the risk may be considered tolerable, on condition that all appropriate measures have been taken to control the risk.

The risk analysis results may indicate a need to consider the implementation of further measures to reduce the risk. The analysis outputs may then be interrogated to determine whether there are any particular scenarios which dominate the risk profile. Where such key risk contributors can be identified, it is prudent to focus efforts to reduce the risk on these scenarios.

Once potential risk reduction measures have been postulated, their effectiveness may be evaluated by modifying the analysis inputs to include them, and re-calculating the results. The final decision about whether or not to implement a given risk reduction option depends on:

- The magnitude of the initial risk – if the risk is high relative to the relevant criteria, this will provide a stronger driver for taking action;
- The size of the risk reduction that would be achieved if the measure were to be introduced; and,
- The cost of implementing the measure.

It should be noted that consideration of the costs and benefits of implementing a risk reduction measure is usually weighted in favour of safety, such that the costs have to be much greater than the benefits before a measure can be ruled out.
5.6 HSE Risk Criteria

For the purposes of assessing the QRA results, the risk criteria used in the UK has been adopted. These criteria are also adopted by Cyprus Regulations as specified by the Cyprus Department of Labour Inspection.

The UK Health and Safety Executive (“HSE”) has published general risk criteria applicable to major industrial hazards and these criteria are presented below.

5.6.1 Risk Criteria for Individual Risk

The UK HSE divide levels of individual risk into three bands, as illustrated in Figure 3.

![Figure 3: UK HSE Individual Risk Criteria](image)

Risks that are within the highest band are considered unacceptable. Where this is the case, action should be taken to reduce the risk, or the activity giving rise to the risk should be stopped. Conversely, risks falling within the lowest band are ‘broadly acceptable’. Such risks are considered to be insignificant and adequately controlled.

Between the broadly acceptable and unacceptable levels is a region in which the risk is tolerable as long as it is ‘as low as reasonably practicable’ (ALARP). The risk is ALARP when the cost of any further risk reduction measures would be grossly disproportionate to (i.e. much greater than) the benefits gained.

The HSE has provided individual risk values corresponding to the boundaries between the different regions. These are shown in Figure 3 and summarised in Table 3 below. It should be noted that the HSE criteria are stated as Individual Risk per Annum (“IRPA”) and take into account the time for which an individual may be present at a given location, together with other factors such as whether the individual is located indoors or outdoors.
5.6.2 Risk Criteria for Societal Risk

With regard to societal risk (of fatality), the HSE publication states that:

“...the risk of an accident causing the death of 50 people or more in a single event should be regarded as intolerable if the frequency is estimated to be more than one in five thousand per annum.”

This criterion point is based on an examination of the levels of risk that society was prepared to tolerate from a major accident affecting the population surrounding a group of industrial installations at Canvey Island in the UK.

Unacceptable, tolerable and broadly acceptable regions can be extrapolated from the criterion point, when using an approach analogous to that used for individual risk criteria. It should be noted that:

- Taken in context, the criterion refers to fatalities among members of the public from accidents at a ‘single major industrial activity’; and,
- The criterion appears to be referring to a cumulative frequency (since it refers to ‘50 people or more’) rather than the single value associated with a single release outcome.

With this in mind, the broadly acceptable region is taken to be two orders of magnitude lower than the criterion point, i.e. – the risk of an accident causing the death of 50 people or more is taken to be broadly acceptable if the estimated frequency is less than one in 500,000 per annum. The threshold for unacceptable societal risk to employees is taken to be an order of magnitude above that for members of the public.

Furthermore, each individual point is plotted on a graph and criterion lines extrapolated through them, to give the Cumulative Frequency (F) – Number of Fatality (N) criteria lines shown in Figure 4.

![Figure 4: Societal Risk FN Lines](image-url)
6. CONSEQUENCE ANALYSIS

6.1 Introduction

The consequence analysis has been performed within the DNV PHAST Risk software, version 6.7. The Phast Risk software is internationally recognised as one of the ‘industry standard’ packages for this purpose. The programme automatically performs all of the required source term, physical effects and impact modelling calculations for each scenario defined by the user. In addition to the information gathered at the Scenario Definition stage, the analyst is also required to enter other parameters used in the study. These include:

- Meteorological data; and,
- Data required for vapour cloud explosion calculations.

These are discussed in more detail below, together with other assumptions made.

6.2 Meteorological Data

Within a QRA, weather conditions are usually described as a combination of a letter with a number, such as ‘F2’. 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.

Wind speeds range from light (1-2 m/s) through moderate (around 5 m/s) to strong (10 m/s or more). The probability of the wind blowing from a particular direction is displayed graphically in the ‘wind rose’ Figure 4.

![Figure 4: Annual Wind Rose at Larnaca (1996-2012)](image-url)
6.3 Study Assumptions

6.3.1 STS Transfer Philosophy
During STS transfer of LNG in the ‘double banked’ arrangement all non-essential personnel will stay in the ship’s superstructure. A minimum number of personnel (approximately 2, one on each vessel) will be around the transfer area supervising the operation.

6.3.2 Maximum Flowrates
Where material is released from a system downstream of a pump it has been assumed that the maximum flowrate is limited to the normal pumping rate plus 20%. This accounts for pump operation at over speed with reduced discharge head.

Where a PHAST ‘modelled case’ result gave a flowrate in excess of the assumed maximum, the case was converted to a ‘user-defined’ case at the assumed maximum rate.

6.3.3 Release Elevation and Orientation
Release elevations used are based on elevations that are typical for the FSRU, associated offloading systems and jetty i.e.

- FSRU Deck: 15m above water level
- FSRU topside process: 15m above water level
- Jetty: 5m above water level
- Holes in LNG storage tanks (due to ship collision): 1m above water level

All releases of LNG and natural gas have been modelled as horizontal releases over water. The surface roughness parameter of 0.1 has been used in Phast to account for the mangroves.

6.3.4 Bunding
It has been assumed that releases of LNG on the tanker deck are unconfined and are therefore likely to flow overboard towards the water surface.

6.3.5 Release Composition
LNG/natural gas has been assumed to be 100% methane for the purposes of modelling.

6.3.6 Flammable Clouds
Flammability has been assumed to extend to the concentration that is 50% of the lower flammable limit.

6.3.7 Consequences of Vessel Collisions
In extreme cases, a release of LNG from the FSRU or LNGC could occur as a result of collision with another vessel. The frequencies of such events are very low, as discussed in Section 7.2.4.

Marine accidents of this type have been subjected to detailed analysis by the Sandia National Laboratories in the USA. The study considered accidental and deliberate (i.e. due to terrorist attack) breaches of LNGC cargo tanks. Finite element modelling was used to calculate breach sizes. Note that intentional breaches fall outside the scope of this risk assessment. This analysis indicated that the effective size of breaches in an LNG vessel due to accidental events would be in the range 0.5 m$^2$ to 1.5 m$^2$.

Sandia performed a re-assessment of this study in 2008, to account for the largest LNG carriers that were then coming into service. The 2008 study did not result in any changes to the breach sizes for accidental cases; and focussed on intentional breaches. However, the sizes of spills were increased to allow for the observed increases in tanker sizes.

For large spills resulting from collisions with either the FSRU or LNGC the following have been assumed:
- Effective release diameter: 1200 mm (i.e. an area of 1.1 m\(^2\); within the range calculated by Sandia)
- Available volume: 41,000 m\(^3\)
- Liquid head: 20 m

It should be noted that these values represent the largest vessels in service and therefore provide an upper bound to the likely consequences. The assumptions are also highly conservative compared to the assumptions stated in the Dutch ‘Purple Book’ for such events, where a ‘large’ spill has a volume of only 126 m\(^3\). In view of the Sandia studies the Purple Book large spill size is not considered to be a good representation of releases from vessel collision events of the type considered in this analysis and a large spill case based on the Sandia reports has been considered in the QRA. For small spills a size of 32 m\(^3\) for a semi-gas (refrigerated) tanker has been used, as given in the Purple Book.

The frequencies of such collision events are discussed in Section 7.2.4.

### 6.3.8 Impact Distances

Review of the area surrounding the proposed terminal location indicates features that may be at risk from a release on LNG or NG, the locations of on-site populations are presented in Table 4 and the locations of off-site populations are presented in Table 5. Detailed population data for the region around the site are not available. Hence the population densities in Table 5, taken from the Dutch ‘Green Book’, have been used to define off-site populations.

<table>
<thead>
<tr>
<th>Units</th>
<th>Estimated Population</th>
</tr>
</thead>
<tbody>
<tr>
<td>FSRU</td>
<td>44</td>
</tr>
<tr>
<td>LNGC</td>
<td>44</td>
</tr>
<tr>
<td>Jetty</td>
<td>10</td>
</tr>
</tbody>
</table>

**Table 4: Location of On-Site Populations**

<table>
<thead>
<tr>
<th>Units</th>
<th>Distance from FSRU (m)</th>
<th>Estimated Population</th>
</tr>
</thead>
<tbody>
<tr>
<td>EAC Power Plant</td>
<td>1750</td>
<td>200 (150 staff + 50 contractors)</td>
</tr>
<tr>
<td>Cement Factory</td>
<td>1900</td>
<td>350 (250 staff + 100 contractors)</td>
</tr>
</tbody>
</table>

**Table 5: Location of Off-Site Populations**

### 6.3.8.1 Impact Criteria

The criteria shown in Table 6 were used for the analysis.

This criteria are based on the guidance notes for new industrial sites near existing installations with regards to major accident impacts related to dangerous substances as specified by the Cyprus Department of Labour Inspection.
### Thermal Impact

<table>
<thead>
<tr>
<th>Zone</th>
<th>Impact Value</th>
<th>Units</th>
<th>Effect</th>
</tr>
</thead>
<tbody>
<tr>
<td>Zone I</td>
<td>15</td>
<td>kW/m²</td>
<td>C-degree burns at a rate of over 50% of the population</td>
</tr>
<tr>
<td>Zone II</td>
<td>6</td>
<td>kW/m²</td>
<td>C-degree burns to 1% of the population</td>
</tr>
<tr>
<td>Zone III</td>
<td>3</td>
<td>kW/m²</td>
<td>A-degree burns in a substantial part of the population</td>
</tr>
</tbody>
</table>

### Blast Overpressure Limits

<table>
<thead>
<tr>
<th>Zone</th>
<th>Limit</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>Zone I</td>
<td>350 mbar</td>
<td>Severe and irreparable damage to the supporting structure and walls of buildings</td>
</tr>
<tr>
<td>Zone II</td>
<td>140 mbar</td>
<td>Damage to the supporting structure and exterior or interior walls</td>
</tr>
<tr>
<td>Zone III</td>
<td>50 mbar</td>
<td>Damage to doors and windows, light cracks in walls</td>
</tr>
</tbody>
</table>

### Flash Fire

<table>
<thead>
<tr>
<th>Event</th>
<th>Zone I</th>
<th>Zone II</th>
<th>Zone III</th>
</tr>
</thead>
<tbody>
<tr>
<td>Jet Fire or Pool Fire (Kw/m²)</td>
<td>15</td>
<td>6</td>
<td>3</td>
</tr>
<tr>
<td>Flash Fire</td>
<td>0.5LFL</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>Explosion (mbar)</td>
<td>350</td>
<td>140</td>
<td>50</td>
</tr>
</tbody>
</table>

**Table 6: Impact Criteria**

### 6.4 Modelling Cases

Using the Major Accident Hazard scenario list in Table 2, models for consequence assessment were developed. A summary of the cases selected is presented in Table 7 which includes details of temperature, pressures, pipe diameters and leak hole sizes.
<table>
<thead>
<tr>
<th>System</th>
<th>Node Reference</th>
<th>Description</th>
<th>Max Line Diameter (mm)</th>
<th>Temperature (°C)</th>
<th>Pressure (barg)</th>
<th>Representative Leak Size (mm)</th>
</tr>
</thead>
<tbody>
<tr>
<td>FSRU</td>
<td>L01</td>
<td>LNG release from pipework between the FSRU storage Tank 4 and Recondenser</td>
<td>350</td>
<td>-161.4</td>
<td>10</td>
<td>5, 25, 350</td>
</tr>
<tr>
<td></td>
<td>L02</td>
<td>LNG release from Recondenser to the HP Booster Pumps</td>
<td>400</td>
<td>-161.4</td>
<td>10</td>
<td>5, 25, 400</td>
</tr>
<tr>
<td></td>
<td>L03</td>
<td>LNG release from HP Booster Pumps discharge pipework up to LNG-Seawater Heat exchanger</td>
<td>200</td>
<td>-161.4</td>
<td>100</td>
<td>5, 25, 200</td>
</tr>
<tr>
<td></td>
<td>L04</td>
<td>LNG release from cargo distribution header line (From Tank 4)</td>
<td>400</td>
<td>-161.4</td>
<td>100</td>
<td>5, 25, 400</td>
</tr>
<tr>
<td></td>
<td>G01</td>
<td>NG release from the pipework between the LNG-Seawater Heat exchanger and gas export manifold ESDV</td>
<td>400</td>
<td>10</td>
<td>100</td>
<td>5, 25, 400</td>
</tr>
<tr>
<td></td>
<td>G02</td>
<td>NG release from the gas export manifold</td>
<td>400</td>
<td>10</td>
<td>100</td>
<td>127, 400</td>
</tr>
<tr>
<td></td>
<td>G03</td>
<td>NG release from pipework between gas unloading arm and jetty ESDV</td>
<td>600</td>
<td>10</td>
<td>100</td>
<td>5, 25, 600</td>
</tr>
<tr>
<td></td>
<td>G04</td>
<td>NG release from cargo vapour return line on deck</td>
<td>600</td>
<td>-149</td>
<td>0.2</td>
<td>5, 25, 600</td>
</tr>
<tr>
<td></td>
<td>S01</td>
<td>Release of LNG from the FSRU during a ship collision event by approaching LNGC</td>
<td>-</td>
<td>-161.4</td>
<td>1</td>
<td>1200</td>
</tr>
<tr>
<td>FSRU/LNGC</td>
<td>L05</td>
<td>LNG release from liquid unloading hoses (STS Operations)</td>
<td>250</td>
<td>-161.4</td>
<td></td>
<td>5, 25, 250</td>
</tr>
<tr>
<td></td>
<td>G05</td>
<td>NG release from vapour return hoses (STS Operations)</td>
<td>250</td>
<td>-149</td>
<td>0.2</td>
<td>5, 25, 250</td>
</tr>
<tr>
<td>LNGC</td>
<td>L06</td>
<td>LNG release from cargo distribution header between the LNGC tanks (Tank 4) to the cargo manifold (STS Operations)</td>
<td>300</td>
<td>-161.4</td>
<td>5</td>
<td>5, 25, 300</td>
</tr>
<tr>
<td></td>
<td>G06</td>
<td>LNG release from cargo vapour return header to LNGC storage tanks (Tank 4) (STS Operations)</td>
<td>250</td>
<td>-149</td>
<td>1</td>
<td>5, 25, 250</td>
</tr>
</tbody>
</table>

**Table 7: MAH scenarios modelling cases**
7. FREQUENCY ASSESSMENT

7.1 Frequency Data Sources

7.1.1 Ignition Probabilities

Ignition probability assumptions are based on Appendix IX, Table IX.6.2 of Reference 4. These data are reproduced Table 8 below.

<table>
<thead>
<tr>
<th>Release Rate Category</th>
<th>Release Rate (kg/s)</th>
<th>Ignition Probability (Immediate)</th>
<th>Ignition Probability (Delayed)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Small</td>
<td>&lt;5</td>
<td>0.005</td>
<td>0.02</td>
</tr>
<tr>
<td>Medium</td>
<td>5-25</td>
<td>0.04</td>
<td>0.2</td>
</tr>
<tr>
<td>Large</td>
<td>&gt;25</td>
<td>0.3</td>
<td>0.9</td>
</tr>
</tbody>
</table>

*Table 8: Generic Ignition Probabilities*

7.2 Failure Rates

7.2.1 Failures of Process Equipment

Data were obtained from Reference 2 and from Lloyd’s Register’s own survey Data Base.

Due to the preliminary state of design a full parts count has not been performed and some assumptions for the lengths of pipework have been taken in the assessment. These data have been used to inform the selection of a release frequency category during the frequency assessment process, taking into account typical equipment present.

7.2.2 Failures of Articulated arms

Articulated arms are used for the transfer of natural gas from the FSRUs to the Jetty.

The UK Health and Safety Executive have developed a set of failure frequency data for failure of LNG unloading arms on the basis of fault tree analysis. This data was obtained from FRED and has been used in the assessment.

Natural Gas Offloading Arm

Transfer of natural gas from the FSRU to the Jetty is assumed to be continuous and as the available failure rate data from FRED is based on the number of transfer operations (rather than time) this is an area of uncertainty. The following assumptions have been made when calculating the arm failure rates for NG.

The HSE FRED data for articulated arm failures is comprised of two components: one for coupling failures (which is related to the number of times per year that connections are made and broken) and one for ranging failures (which is related to the length of time the arm is in use and the frequency of passing ships).

The FRED data is based on a 12 hour offloading time and for the FSRU it has been assumed that this equates to 730 transfers per year (i.e. two per day). A further assumption in the FRED data is that 10 ships pass the vessel that is unloading within the 12 hour off-loading period. However, the available data indicate that the actual frequency of shipping traffic past the FSRU at the PGPL terminal is less than this (closer to 1 vessel during a 12 hour period).

It is also noted that uncoupling/coupling of the arm takes place monthly to perform maintenance.
Taking into account the factors described above and using the FRED data gives the failure frequencies shown Table 9

<table>
<thead>
<tr>
<th>Release Size</th>
<th>Frequency (per year)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Full bore (400 mm)</td>
<td>$5.1 \times 10^{-4}$</td>
</tr>
<tr>
<td>Hole (10% CSA, 127 mm)</td>
<td>$5.6 \times 10^{-5}$</td>
</tr>
</tbody>
</table>

Table 9: Unloading Arm Failure Frequencies

7.2.3 Failures of LNG STS Transfer Cryogenic Hoses

It is noted that the ship-to-ship transfer method considered here, using cryogenic hoses, is relatively new technology and therefore specific historical frequency data for such systems are not available. This represents an area of uncertainty within the assessment.

Data were obtained from Reference 2, which contains generic frequency data for frequencies of leaks during transfer of cargoes of dangerous substances. The base failure rate for transfer operations involving Flammable liquefied gases is $7.6 \times 10^{-3}$ per transfer. This is the total combined failure rate for all release sizes.

Assuming that the facility operates all year round, it is estimated that there will be 52 transfers per year.

This gives a total failure rate of $52 \times 7.6 \times 10^{-3} = 3.95 \times 10^{-3}$ per transfer operation per year.

The frequency distribution is estimated on the assumption that the small leaks are more frequent than large/full bore failure by a factor of 10, and that there is an approximate step increase in the distribution by a factor of 3 between of respective loss of containment scenarios, giving the failure rates detailed in Table 10.

<table>
<thead>
<tr>
<th>Release Size</th>
<th>Distribution</th>
<th>Failure/year</th>
</tr>
</thead>
<tbody>
<tr>
<td>Small</td>
<td>70%</td>
<td>$2.96 \times 10^{-4}$</td>
</tr>
<tr>
<td>Medium</td>
<td>23%</td>
<td>$8.89 \times 10^{-3}$</td>
</tr>
<tr>
<td>Large/Full bore</td>
<td>7%</td>
<td>$2.77 \times 10^{-3}$</td>
</tr>
</tbody>
</table>

Table 10: STS Cryogenic Hose Failure Frequencies

7.2.4 Frequency of Vessel Collision

The frequency of an LNGC colliding with an FSRU on approach giving rise to the spill of LNG, has been calculated using the method presented in the Dutch ‘Purple Book’.

For the type of vessel of interest (FSRU) the release frequencies are calculated as follows:

Frequency of small spill:

$$F_{\text{small}} = 0.00012 \times f_o$$

Frequency of large spill:

$$F_{\text{large}} = 0.025 \times f_o$$

Where $f_o$ is the base failure rate and is given by:

$$f_o = 6.7 \times 10^{-11} \times T \times t \times N$$

Where:
The following assumptions have been made:

- There are 52 deliveries by LNGC per year, each lasting 18 hours;
- That the FSRU is present all year;
- There is an average of 0.032 large ships per hour passing the terminal

This gives the failure frequencies shown in Table 11 below.

<table>
<thead>
<tr>
<th>Spill Size</th>
<th>Frequency for FSRU (per year)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Small</td>
<td>$4.05 \times 10^{-7}$</td>
</tr>
<tr>
<td>Large</td>
<td>$8.45 \times 10^{-5}$</td>
</tr>
</tbody>
</table>

*Table 11: Frequency of Releases from FSRU / LNGC due to Collision*
8. RESULTS

8.1 Individual Risk

The individual risk contours illustrate the levels of individual risk to a person who is assumed to be present all of the time at the given location (24 hours a day, 365 days a year). In this way it is possible to represent with accuracy the risk levels generated by hazards at a defined location (FSRU terminal) throughout a period of one year and compare their acceptability with International criteria.

Risk contours also represent visually three important zones:

1. The location zone where risks may be higher than the acceptable level (unacceptable) for the public or third operating parties. Based on international standards this applies when the risk exposure is greater than 1 in 10,000 \((10^{-4})\) per year

2. The location zone where risks are at tolerable level (acceptable due to small only exposure to risk) for the public or third operating parties in the area. Based on international standards this applies in the area between risks 1 in 10,000 \((10^{-4})\) to 1 in 1,000,000 \((10^{-6})\) per year.

3. The location zone where risks are at an acceptable level (due to insignificant exposure to risk) for the public or third operating parties. Based on international standards this applies when the risk exposure is lower than 1 in a 1,000,000 per year \((10^{-6})\).

For this preliminary study, contours have been produced for people who are indoors all of the time. ‘Indoors’ in this context refers to people being inside a typical house or building. Individual risk contours for people indoors are therefore useful in judging the levels of individual risk to which off-site residential public are exposed.

8.1.1 Individual Risk at the Terminal

The risk contours for people indoors in the vicinity of the Terminal are shown in Figure 5.
8.2 Societal Risk

As mentioned in Section 5.6.2, societal risk reflects the potential for major accidents to affect significant numbers of people in one event. In this study, societal risk results are presented as ‘FN curves’, where F is the frequency with which N or more people are affected. This illustrates the frequency with which different numbers of people could be affected by a MAH generated at the terminal.

FN curves for the on-site worker population and off-site public populations have been produced and are presented in Figure 6 below.

![Figure 6: Vassilikos FSRU Terminal FN Curve for workers](image)

Red: Mandatory measures above this line; Yellow: continuous improvement below this line; Blue: Terminal FN Curve for workers when no LNGC is present; Green: Terminal FN Curve for workers when LNGC is present during STS Operations
9. Findings and Conclusions

In order to evaluate the potential risk exposure to personnel and third parties generated by the FSRU operations at Vassilikos terminal, individual risk contours have been calculated as shown in Figure 5. These contours also provide a visual representation of the potential risk zones within which terminal or third party operations will take place.

As a point reference for the contours generation is considered to be the LNG manifolds and hoses area during STS operations as this represents the most conservative approach requiring the highest number of operating personnel (FSRU + LNGC) attending on outside deck areas at one time.

With reference to the Figure 5 the following apply:

- It is noted that the QRA has indicated no presence of $10^{-4}$ per year contour thus all generated risks have been identified to be within tolerable and acceptable levels.
- The violet colour contour represents risks close to tolerable zone level $10^{-5}$ per year which means what all risks for operating personnel on-board the FSRU and LNGC are considered to be well within the typical levels expected in an oil & gas terminal installation.
- The green colour contour represents risks at $10^{-6}$ per year which means that the risk exposure of personnel or third parties beyond that contour are in the broadly acceptable zone level of risks without any specific mitigation required to be additionally provided (except the FSRU terminal’s own operating procedures). This indicates also that passing shipping traffic and tanker operations at the buoy would not be affected by FSRU operations.
- The same applies also for all areas beyond the orange colour contour representing zone risk level $10^{-7}$ per year; this also indicates that there is no possible zone risk generated affecting the further away EAC Power Plant, Cement Factory or any third parties operations in the area including public activities.

The FN curve for the Terminal (Figure 6) lies within the ‘tolerable if ALARP’ region. Given the extent of the individual risk contours and the location of on-site populations, both curves representing FSRU (blue) and LNGC (green) similarly lie very close to the acceptable yellow region rising slightly at a level representing STS operations and never exceeding the maximum criteria indicated by the red line (as per International Standards). It is noted that a conservative assumption was applied that personnel presence has taken to be continuous for 24 hrs/ 7 days a week at location. Again this FN curve is similar with typical FSRU terminals with STS operations internationally and near Cyprus region (e.g. Hadera FSRU terminal in Israel).
10. REFERENCES

10.1 Documents

1. DEFA Vassilikos- PCI Cynergy LNG Project EIA Submission Report Rev 3 70036368-CYP-REP-002
12. Quantitative Risk Assessment of Escobar LNG Terminal Report No. 50102232-R0

10.2 Plans and P&IDs

1. Draft- Alternative Layouts FSRU/FSU June 2017
2. Draft- Layout of Jetty/FSRU and Emergency Shelter July 2017
4. Site Plan View 70036368-CYP-DRG-101 Rev A
5. Preliminary Pipe Route 70036368-CYP-DRG-102 Rev B