FSRU FACILITY AT JAIGARH PORT

QRA Study Report

H-Energy Gateway Private Limited

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Applicable contract(s) governing the provision of this Report:

Objective:

The main objective of QRA study is to quantify and assess risk from process hazards from the FSRU and associated facilities and to ensure that they comply with adopted risk criteria and to demonstrate that risk has been reduced to the extent that is reasonable and is compliant with risk management process.

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EXECUTIVE SUMMARY

H-Energy Gateway Private Limited hereafter named H-Energy is in process of building an 8 MMTPA LNG Regasification Terminal Located at Jaigargh Port, Ratnagiri, approximately 330km south of Mumbai on the West coast of Maharashtra. The H-Energy Gateway LNG Terminal will be within the boundary limits of JSW Jaigargh Port which is owned and operated by JSW Jaigargh Port Ltd. (JSWJPL).

As a part of Phase 1 of the H-Energy Gateway LNG Project, an FSRU is envisaged to be moored at the planned LNG berth.

DNVGL has been invited by H-Energy Gateway Private Limited to carry out Quantitative risk assessment for the FSRU facility at Jaigarh port.

The main objective of QRA study is to quantify and assess risk from process hazards from the FSRU and associated facilities and to ensure that they comply with adopted risk criteria and to demonstrate that risk has been reduced to the extent that is reasonable and is compliant with risk management process.

In order to meet the objective of assessment, DNVGL has identified and assessed potential scenarios and specified the likelihood and consequences related to potential accidental releases occurring in the facility. Further, based on the results from the assessment, DNVGL had made appropriate recommendations for further risk mitigating measures.

Below are the findings from the QRA Study:

<u>Location Specific Individual Risk (LSIR)</u>

The Location Specific Individual Risk (LSIR) gives a measure of the risk that will apply to each location (in this case, each area, generally), independent of the population, where:

- The process LSIR results show that Trunk deck and Regas module being the key contributors. This is due to the presence of loading hose, LNG loading mains, LNG spray mains and HP NG unloading arm. And the risk results in the Regas module are high owing to the high pressure natural gas release.
- The peak values are for Trunk deck and Regas Module at 6.78E-04 per year and 6.18E-04 per year respectively. For the majority of the other process modules, the LSIR is typically between 5 E-05 and 1E-05 per year.

<u>Safety Exclusion Zone:</u>

SIGTTO guidelines recommend that port traffic should be excluded from the environs of an LNG marine terminal. A specific exclusion distance is not provided in the guidelines. Hence the same is determined, based on the 'maximum credible spill of LNG during transfer operations and the likely pattern of dispersal for the resulting gas cloud' at the facility under study. This is typically modelled using dispersion from a 50mm hole on the LNG unloading hose from the LNGC due to its high failure frequency. During the conceptual stage of the project, a 150 mm hole was considered to estimate the Exclusion zone. However, considering the safety systems provided in the design and constant monitoring of the loading operations, it is unrealistic for a 150 mm hole or a loading hose rupture. Though it is a worst case scenario, the same is not credible. The credible spill was agreed as a release of LNG through a 50mm hole from the unloading hose for a 30 second duration assuming operation of the emergency shutdown facilities. For this credible spill, the dispersion modelling predictions indicate that an exclusion zone of around 140m from the location of the LNG loading facilities.

Individual Risk Per Annum

It can be seen that the Maximum IRPA applies to the Deck crew category and is estimated at around 4.93 x 10^{-5} per year. This is due to the longer duration of Deck crew on the Trunk deck.

Potential Loss of Life (PLL)

The potential loss of life (PLL) accounts for the number of people in each case and provides an indication of the overall key risk contributors, where:

- The location that makes the largest contribution to the PLL is Trunk Deck at 1.83E-04 per year (due to contribution from LNG import, NG export, Spray Main and BOG main lines) and Regas Module at 1.10 E-04 per year (due to contribution from Regasification trains) followed by Compressor Module at 9.96E-05 per year (boil off gas and High pressure gas from compressors).

Based on the observations and conclusions following are the recommendations of the study:

Consider an exclusion zone around the jetty transfer facilities of around 140m.

Loading Arm: Presently Loading hoses are used to transfer LNG from LNGC to FSRU. These loading hoses have a higher failure frequency compared to loading arms. Consider providing Loading arms in place of loading hoses to reduce the frequency of failure and subsequently risk levels.

Alternately consider replacement of hose at regular intervals. Loading hoses shall be inspected and tested at regular intervals.

Emergency Shut-Down (ESD) systems are considered to shut down and limit the inventory within 30 seconds of the occurrence of a leak in the process area, unloading equipment or pipeline. The same shall be validated during Engineering development. A Safety Integrity Level Assessment shall be performed to determine the integrity levels of Safety Instrumented Systems and the same shall be validated throughout the life cycle of the installation.

An Escape Muster Evacuation Rescue Analysis (EMERA) study shall be carried out to assess the adequacy of escape routes, evacuation systems and muster area for accommodation of POB and the lifesaving equipment.

General Asphyxiation Guidelines: Consideration should be given to providing air packs or escape packs where people may be walking in clouds of 19.5% minimum oxygen content or less.

General Cryogenic Guidelines: Minimize cryogenic impact due to LNG on deck or upper part of installation to avoid brittle fractures or spalling in concrete by use of appropriately rated and validated materials, containment of spills, and application of passive fire protection to vulnerable structures. Consider design improvisations (e.g. minimising flanges or provision of flange guards) to prevent failure of facility not designed for cryogenic service due to cold spots from cryogenic contact.

Spill Containment Guidelines: Leaks in LNG welded piping systems shall be contained in troughs. Sufficient deck curbing, barriers shall be provided around the perimeter of the deck.

Slop deck shall be free draining not to hold cryogenic liquid spill overboard thereby mitigating the pool fires, and potentially reducing the extent of the vapour cloud that may arise on the deck.

Active Fire Protection Guidelines: Special consideration shall be given to design of water sprays as it may increase the rate of evaporation thereby increasing the size of the gas cloud and hence the risk of asphyxiation. Water sprays, if aimed directly at the liquefied gas, may deflect it to other areas; Contact between liquefied gas and water may result in a rapid phase transfer which can be violent and present a risk to people nearby; Also water may freeze, producing a slippery surface and impeding escape. Ensure emergency procedures are appropriate and do not increase the risk. Firefighting foam deluge systems shall be used to mitigate LNG spills by keeping the vapours down.

It is recommended to revisit the QRA when design details are firmed up.

1 INTRODUCTION

1.1 Background

H-Energy Gateway Private Limited hereafter named H-Energy is in process of building an 8 MMTPA LNG Regasification Terminal Located at Jaigargh Port, Ratnagiri, approximately 330km south of Mumbai on the West coast of Maharashtra. The H-Energy Gateway LNG Terminal will be within the boundary limits of JSW Jaigargh Port which is owned and operated by JSW Jaigargh Port Ltd. (JSWJPL).

As a part of phase 1 of the H-Energy Gateway LNG Project, an FSRU is envisaged to be moored at the planned LNG berth.

DNVGL has been invited by H-Energy Gateway Private Limited to carry out Quantitative risk assessment for the FSRU facility at Jaigarh port.

1.2 Objectives

The main objective of this study is to evaluate the potential risk levels for personnel due to accidental release of hazardous materials from loss of containment scenarios from the FSRU facilities and to demonstrate that individual risks are within the broadly acceptable regions.

The Objectives of QRA are as follows:

- Hazard identification and selection of failure case scenarios
- Calculation of physical effects of failure case scenarios which include Estimation of Jet Fire, Pool Fire heat radiation distances, Flammable gas dispersion distances, and Vapour cloud explosion distances
- Failure Frequency evaluation
- Individual risk quantification in terms of LSIR and IRPA
- Societal risk quantification and Potential Loss of Life estimation
- Perform a risk assessment to confirm that risk can be reduced consistent with the ALARP principle according to the UK HSE risk acceptance criteria
- Recommend risk reducing measures to ensure that all risks are in ALARP or in Acceptable region
- Recommend Safety Exclusion Zone distances around the NG vapour unloading arm from FSRU, and the LNG loading Hose from LNGC

1.3 Scope of Work

The scope of work covers the delivery of a QRA report for the FSRU facilities, addressing Process hazards within the FSRU during normal operation. The scope of work for this QRA includes the following:

- LNG loading hose from LNGC to FSRU, Process Equipment with Regas and BOG Modules within the FSRU, LNG Loading/ unloading mains from Cargo tanks, BOG vapour mains from Cargo tanks, LNG spray mains and High Pressure NG unloading arm from FSRU

1.4 Layout of Report

The remainder of this document is set out as follows:

Section 2 provides a description of the FSRU design, areas defined and the manning details

Section 3 provides an overview of the approach adopted in this analysis.

Section 4 provides a summary of the failure case defined for the study.

Section 5provides the failure frequency derived for each failure case.

Section 6summarises the consequence modelling incorporated in the risk model.

Section 7sets out criteria to be used to determine the acceptability of the risks, summarises risk results.

Section 8 sets out conclusions and recommendations.

Section 9 lists down the references used for the QRA Study.

Supporting details for the above sections are given in Appendices.

1.5 Abbreviations

ALARP	As Low As Reasonably Practicable
DNVGL	Det Norske Veritas Germanischer Lloyd
ESD	Emergency Shut Down
ESDV	Emergency Shut Down Valve
FSRU	Floating Storage and Regasification Unit
GIIGNL	International Group of Liquefied Natural Gas Importers
IRPA	Individual Risk Per Annum
LNG	Liquefied Natural Gas
LNGC	Liquefied Natural Gas Carrier
LQ	Living Quarters
LSIR	Location Specific Individual Risk
OGP	Oil & Gas Producers
P&ID	Piping and Instrumentation Diagram
PFD	Process Flow Diagram
PHAST	Process Hazard Analysis Software Tool
PLL	Potential Loss of Life
POB	Personnel on Board
QRA	Quantitative Risk Assessment
SIGTTO	Society Of International Gas Tanker & Terminal Operators Ltd
SDV	Shut Down Valve
UKOOA	UK Offshore Operators Association

2 FACILITY DESCRIPTION

2.1 Overall Facility

The H-Energy Gateway LNG Terminal at Jaigarh port is under development. As a part of phase 1 of the H-Energy Gateway LNG Project, an FSRU is envisaged to be moored at the planned LNG berth. The FSRU and minimum facilities shall be suitable to transfer the high pressure natural gas onshore and then dispatch the same to the jetty pipeline for distribution.

The feedstock is received from LNG Carrier using unloading hose and shall be regasified on the FSRU and exported as high pressure natural gas to onshore facilities via HP gas unloading arm on LNG Berth.

The proposed location of the FSRU is shown in the Figure 1

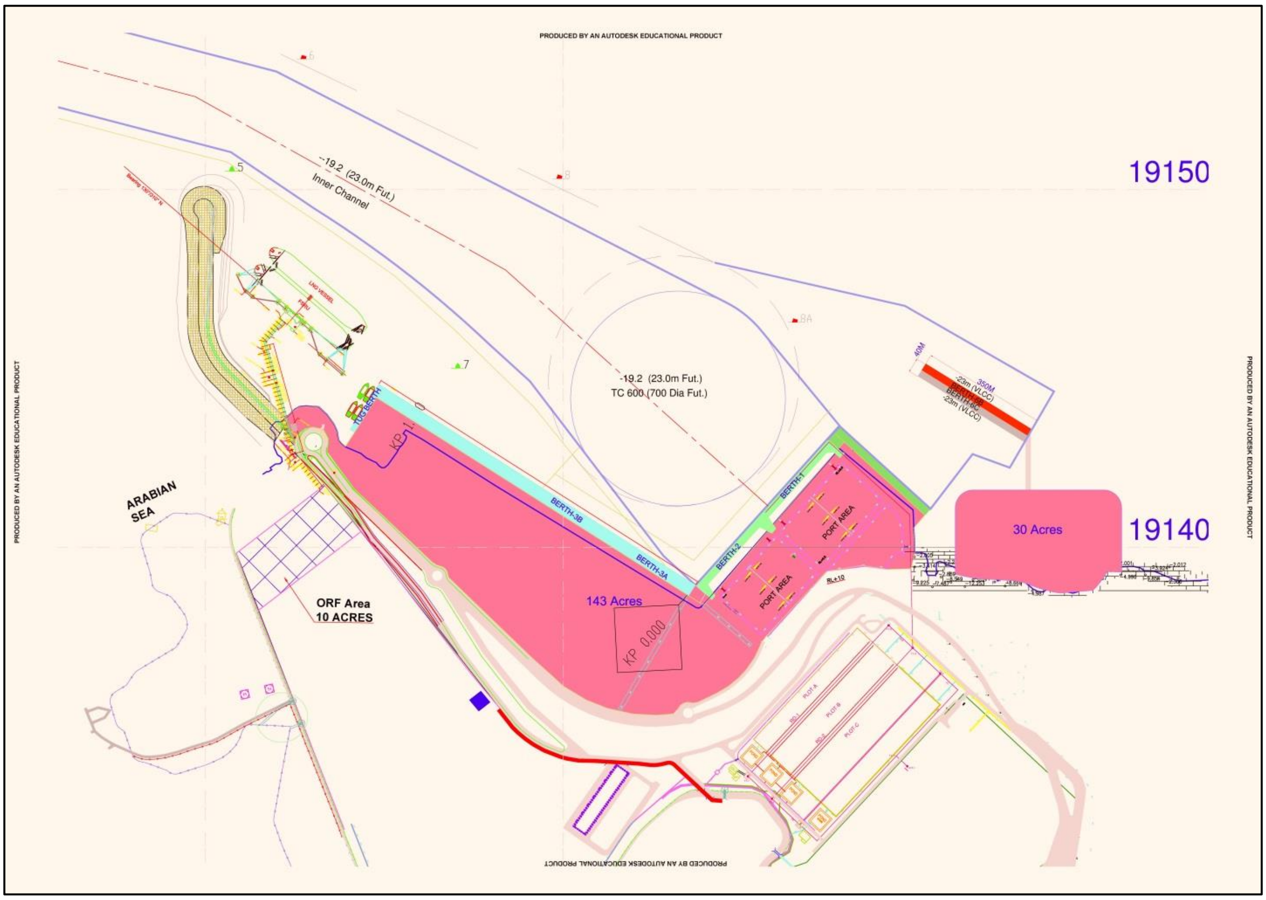

Figure 1: Jaigargh Port showing location of FSRU and LNGC

2.2 Process Description

The FSRU receives LNG feedstock from LNG Carriers (LNGCs), which unload the LNG feed stock via hose transfer. The unloading takes place with the LNG Carrier moored to the FSRU in a side by side configuration.

The LNG imported is stored in the four on-board storage tanks within the FSRU. The feedstock is regasified on the FSRU and exported as high pressure gas to onshore facilities via HP gas unloading arm on LNG Berth.

A brief overview of the regasification process is shown in figure below

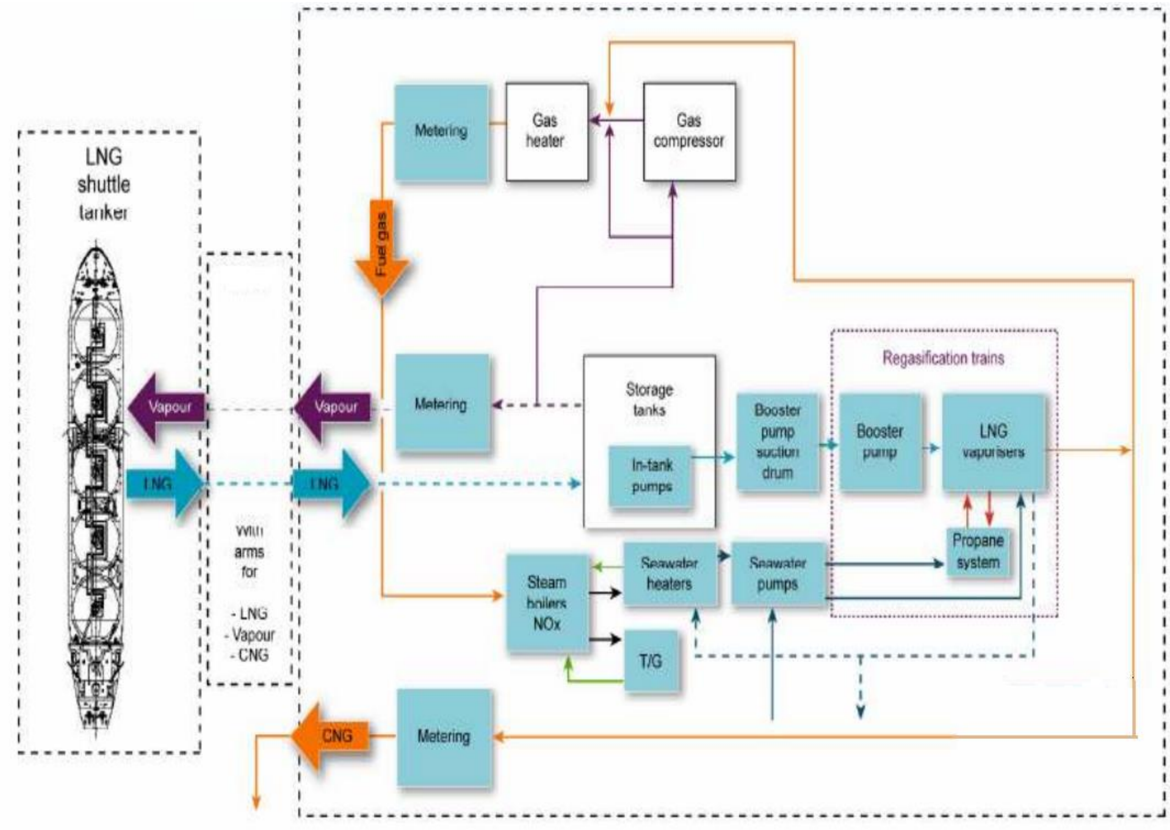

Figure 2: LNG FSRU – Typical Block Flow diagram

2.3 Study Basis and Layouts

The general arrangement drawing provided is used for the risk assessment. An indication of the layout is given by Figure 2-3, which shows the areas used in the QRA.

The FSRU design consists of 4 storage tanks located in the Hull of the FSRU. Two decks, i.e. Main deck and Trunk deck, are located over the LNG Storage tanks. The LNG loading hoses are located on the starboard side and NG unloading arms are located on the port of the vessel.

On the Trunk deck, the Regas module and the Cargo compressor room are located as shown in the Figure 2-3. The Loading/Unloading headers (manifolds connected to each LNG storage tank) are located on the Trunk deck.

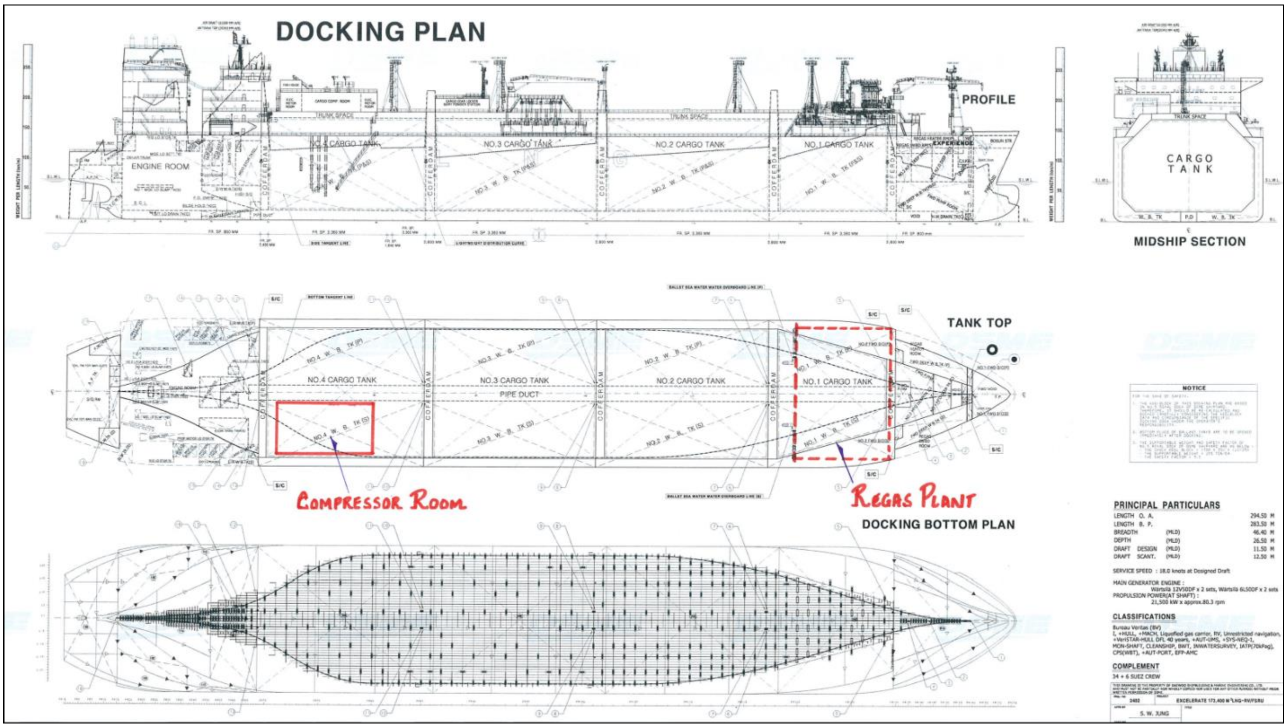

Figure 3: FSRU Layout and Docking Plan

No Temporary Refuge (TR) is identified on the vessel. The primary muster area is located aft of the Accommodation block or Living Quarter at the Stern of the vessel.

2.4 Area Definition

Different "Areas" are defined in the risk model according to the different populations that may apply, as well as to differentiate between the different impacts / risks that will apply in different locations (due to both differing hazards and differing levels of protection).The Areas defined in the risk model are detailed in table below

Table 1: Areas Defined on the FSRU

Module	Facility covered
Living Quarter	Living quarter on the Aft Side of the FSRU
Forward deck	Tank top deck level on the Bow of the vessel
Trunk deck	All equipment on the upper deck. Loading/unloading area equipment, pipeline/pipe rack
Regas module	All equipment in the Regas module
Compressor module	All equipment in the Compressor module
Aft deck inc. workshop	Tank top deck level on the Stern of the vessel

On the Upper deck, the areas "Regas module", "Compressor module" and "Main deck" are considered. Although there is no physical segregation by means of fire or blast walls, the areas are differentiated from one another for ease of risk estimation and to ensure the Location Specific Individual Risk for these areas is calculated more accurately, i.e. the risk arising from different areas is not distributed across all areas where there may or may not be an impact, instead it gives a clear picture on the risk accumulation for these congested process areas.

On the tank top deck, the areas "Forward deck" and "Aft deck including Workshops" are considered. This is mainly because the release elevation of the events on the Upper deck is different from the releases in these areas.

The Main deck or Trunk deck area consists of the whole Upper deck minus the Regas module and the Compressor module. This also includes the Pipe rack consisting of all the Main pipelines, i.e. Loading/Unloading Main, Vapour Main.

2.5 Manning Details

Population exposure is very critical for the estimate of the risk resulting from an incident.

For individual risk calculation, people expected to be affected by the hazard are grouped based on their work (e.g. operators, maintenance personnel etc.), which reflects a particular pattern of exposure to major accident hazards.

For societal risk calculation, specific population areas are determined and the average number of inhabitants at each population area throughout the year is set as below:

The overall Population on Board (POB) will have a key influence on the FN curve estimates, while the distribution of personnel will have particular relevance to both the FN curve and IRPA estimates.

The total crew at peak operation time is taken as 27, which is made up of the following worker categories (with the number in each group shown in brackets):

- Master (1)
- Officers, trainees and chief engineer (6)
- Engineers (5)
- Deck crew (6)
- Engine room crew (5)
- Catering (4)

Masters, Officers, Trainees and Engineers fall under Type 1 crew who work 8 weeks ON and 8 weeks OFF rotation and Deck Crew, Engine Crew and Catering Crew fall under type 2 crew who work 6 months ON and 2 months Off rotation.

3 QRA METHODOLOGY

3.1 Introduction to Risk Assessment

Risk (either health, Safety or economic), is inherent in all activities. In order to control, prevent or minimize loss of life or injury, damage to property or impact on environment, risk must be analysed and managed.

Risk Assessment is a step-by-step process to identify the probability of extent of adverse consequences resulting from a specific activity, quantify risk and compare the same with known risk criteria so as to prepare and implement appropriate risk reduction measures.

3.2 Risk Assessment Methodology

The study methodology follows the standard risk assessment steps outlined below. Figure below presents a flow chart of the risk assessment steps followed.

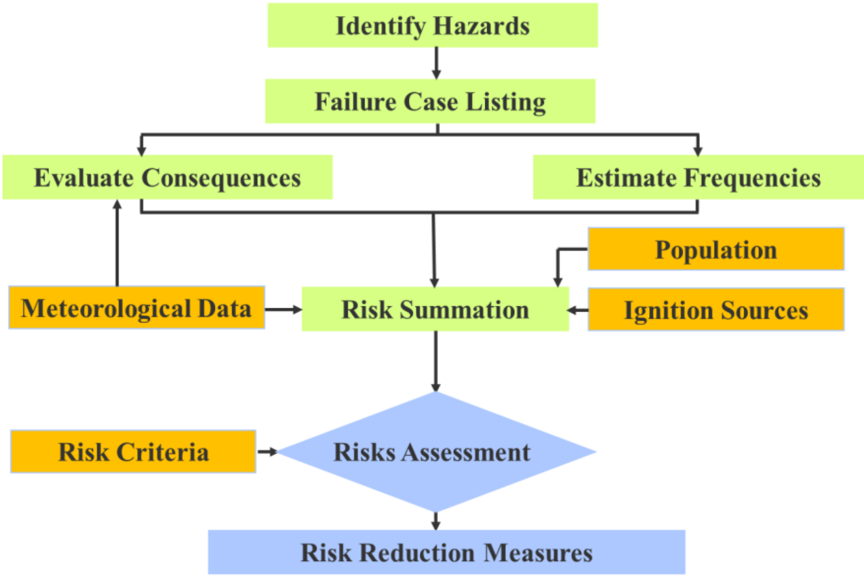

Figure 4: Risk Assessment Methodology

<u>Data Collection</u>

The initial activity of the QRA is to compile all relevant data so that the analysis can be built on the most accurate information possible. Relevant data compiled include drawings and documentation relating to design and operations of the facilities.Relevant data will be obtained with respect to the site, its surroundings, Operating Parameters of Process facilities, PFD's, P&ID's, Equipment Datasheets, Equipment layouts as well as Overall Plot plan of the Facility.

<u>Hazard Identification</u>

A hazard is an undesired situation or event which may cause harm to people or to the environment, or damage to property. The main hazard from process facilities is that of an uncontrolled release of hydrocarbons which may subsequently be ignited. The causes and consequences of the major hazards with respect to the plant would be studied under this task based on historical accidents at similar installations, discussion with the Engineer and expert judgment.

Consequence Analysis

The type of consequence assessment performed and the level of detail depends on the actual hazard considered. In general, the consequence calculations for hydrocarbon fire and explosion events comprise the following main steps:

- Estimation of release rate and duration
- Gas dispersion calculations
- Fire calculations including radiation estimates, dimensions and duration

Frequency Analysis

The frequencies for the identified release scenarios are estimated from historical data. Historic data (OGP) will be used for release scenarios.

Risk Estimation

The risk associated with each hazard category is calculated by combining the frequency and consequences of all potential outcomes of the initial event. Event tree analysis techniques are used when an event may have more than one outcome. Risk is measured as individual risk and societal risk.

The following risk indicators have been used in this risk assessment:

Individual risk measures: IR is a measure of the risk at a location, without regard to whether a person might present or not.

Societal risk measures: Societal Risk is typically presented as an FN curve plotted on a log-log scale. SR is a measure of the relationship between the cumulative frequency (F) and number of fatalities (N). It is defined as the risk experienced by a group of people (including workers and the public) exposed to the hazard.

Risk Assessment

Risk assessment is the process of comparing the level of risk against a set of criteria as well as identifying major risk contributors. In the risk assessment stage, the quantified risk results are compared to pre-established risk criteria (from governmental regulatory requirements, recommended guidelines, or corporate guidelines) to indicate whether the risks are tolerable or to make some other judgment about their significance. In this study HSE UK risk acceptance criteria for Individual and Societal Risk has been used.

Risk assessment identifies the level of risk associated with loss of containment and evaluates against risk acceptance criteria. It also can be used to identify recommendations that may further reduce the risk to tolerable levels, if risks are found to be intolerable, or to reduce the overall level of risk to a level As Low As Reasonably Practicable (ALARP).

4 FAILURE CASE DEFINITION

Hydrocarbon releases from FSRU and associated facilities are broadly categorised as follows:

- Releases from Process Equipment within the FSRU:
  a) Process Equipment within the Regas Module
  b) Process Equipment within the Compressor Module
  c) Loading/ Unloading Mains, Spray Mains and BOG Vapour Mains on the Trunk Deck
- Release from LNG Loading Hose from LNGC to FSRU
- Release from NG Unloading Arm from FSRU

4.1 Isolatable Sections

Consequence modelling is based on isolatable sections, and there is a range of potential consequences within each isolatable section. The list of isolatable sections for the FSRU along with process parameter of the isolatable sections such as operating pressure and temperature are given in below tables.

Table 2: Process Conditions for LNGC & FSRU Cargo

Isolatable Segment	Description	Pressure (barg)	Temperature (^{0}C)
LNGC/Iso1/LNG from LNGC Cargo/L	LNG Release from LNGC Cargo	0.09	-162
FSRU/Iso2/LNG from FSRU Cargo/L	LNG Release from FSRU Cargo	0.09	-162

Table 3: Process Conditions for Loading Arm

Isolatable Segment	Description	Pressure (barg)	Temperature (^{0}C)
LNG Transfer/Iso3/LNG Loading Hose/L	LNG Transfer from LNGC to FSRU via Loading Hose	4.5	-162
NG Offloading/Iso14/NG Unloading Arm/G	NG Offloading to Jetty	100	5

Table 4: Process Conditions for Isolatable Segments within FSRU

Isolatable Segment	Description	Pressure (barg)	Temperature (^{0}C)
Regas Module			
Regas module/Iso4/LNG Suction drum/L	Suction drum catering to all LNG gasification trains	4.49	-162
Regas module/Iso 5/LNG HP Pump_D/L	LNG HP Pump send-out upto LNG vaporization train inlet	98.99	-157
	BOG Recondenser	98.99	-145
Regas module/Iso6/LNG Vaporizer_D/G	Discharge from LNG vaporizers in the vaporization train	98.99	5
Regas module/Iso7/Propane System/L	Propane Tank	3.49	-5
	Discharge from Propane Pump	4.99	-5
BOG Module			
Compressor module/Iso8/ Compressor_S/G	Suction to BOG Compressor	0.09	-140
Compressor module/Iso9/Compressor_D/G	Discharge from BOG Compressor	6.89	28
Trunk Deck			
Trunk deck/Iso10/LNG Loading main/L	LNG Loading main location-1 (typical)	3.49	-162
Trunk deck/Iso11/BOG Vapour main/G	BOG vapour main location-1 (typical)	0.49	-140
Trunk deck/Iso12/LNG Offloading main/L	LNG offloading main location-1 (typical)	5.99	-162
Trunk deck/Iso13/Spray Main/L	Spray main location-1 (typical)	3.99	-162

The isolatable sections are identified according to the location of emergency shutdown ESD valves that can isolate relevant hydrocarbon volume in one section from hydrocarbon volumes in other sections. In the event of a release, only the material in a single isolatable section is considered to be released.

Mark-up of the isolatable sections identified for the FSRU and associated facilities are provided in appendix II.

4.2 Leak Size Categories

A release of flammable material could occur through holes of size from small to large. Large leaks tend to produce very severe but short-lived fires and explosions whereas small leaks tend to produce localized but long-lasting fires or delayed explosions.

Considering the severity and failure frequency, the following representative hole sizes have been adopted for each identified isolatable sections.

Leak Size for Process Installations:

- Small leak –with the leak size diameter of 12 mm.
- Medium leak - with the leak size diameter of 25 mm.
- Large leak –with the leak size diameter of 50 mm.

Release from loading hoses

- Small leak –with the leak size diameter of 12 mm.
- Medium leak- with the leak size diameter of 25 mm.
- Large leak –with the leak size diameter of 50 mm.
- Full-bore leak (Rupture)

Release from HP Natural Gas loading arm

- Small leak –with the leak size diameter of 12 mm.
- Medium leak - with the leak size diameter of 25 mm.
- Large leak –with the leak size diameter of 50 mm.

5 FREQUENCY ANALYSIS

Historical failure frequency data sets including SIGTTO, OGP, RIVM Guidelines for quantitative risk assessment 'Purple Book', and DNV Technical Notes on Marine Transport Accident Frequencies were used in this QRA study to estimate failure frequency for the FSRU and associated facilities.

Failure Frequency for Process Equipment

Failure frequency estimation for process equipment within the FSRU involves parts count calculation and followed by estimation of leak frequencies of the same.

For each failure case or isolatable section identified within the FSRU, a 'parts count' is required which is a count of every equipment item from as large as pumps to and filters to as small as flanges and instrument connections. Parts count was done using P&IDs. The parts count is then combined with the generic failure rates to obtain the required failure frequencies per failure case.

Each of the failure frequencies thus calculated from Leak will be for a section, location/ area and release size.

Table 5: Failure Frequency for Process Equipment

Isolatable Section Description	Small	Medium	Large	Total
Regas module/Iso4/LNG Suction drum/L	4.50E-03	5.02E-04	6.88E-04	5.69E-03
Regas module/Iso 5/LNG HP Pump_D/L	2.27E-02	1.67E-03	9.95E-04	2.54E-02
Regas module/Iso 5/BOG Recondenser/L	4.30E-03	4.72E-04	2.00E-04	4.97E-03
Regas module/Iso6/LNG Vaporizer_D/G	1.10E-02	1.01E-03	3.48E-04	1.24E-02
Regas module/Iso7/Propane System/L	1.12E-02	1.15E-03	9.55E-04	1.33E-02
Propane Tank	1.61E-03	2.90E-04	4.45E-04	2.35E-03
Propane Pump	9.54E-03	8.57E-04	5.10E-04	1.09E-02
Compressor module/Iso8/ Compressor_S/G	2.11E-03	3.26E-04	2.08E-04	2.64E-03
Compressor module/Iso9/Compressor_D/G	9.04E-03	8.07E-04	2.70E-04	1.01E-02
Trunk deck/Iso10/LNG Loading main/L	1.00E-02	7.35E-04	2.04E-04	1.10E-02
Trunk deck/Iso11/BOG Vapour main/G	2.78E-03	2.04E-04	5.67E-05	3.04E-03
Trunk deck/Iso12/LNG Offloading main/L	2.80E-02	2.05E-03	1.10E-03	3.11E-02
Trunk deck/Iso13/Spray Main/L	2.81E-02	2.06E-03	1.06E-03	3.12E-02

Failure Frequency for Loading Arm

Frequency for Failure of Arm is taken as 5.73E-05 per visit. 60 approx. LNG Carriers visits have been assumed per year for the study.

The breakdown of leak events into rupture, large and small sizes is a judgment based on DNV's estimates of the leak sizes typical for all loading arm failures, together with comparison against hole size distributions for typical process leaks and road tanker loading arm failures. Failure frequency is distributed as 70% for Small leaks, 25% for Medium leaks and as 5% for Large leaks.

Failure Frequency for Loading Hose

Frequency for Failure of Loading Hose is taken as 4E-06 $Hour^{-1}$ for Full-bore rupture and 4E-05 $Hour^{-1}$ for Leak scenarios. Failure frequency for Leak is distributed as 70% for Small leaks, 25% for Medium leaks and as 5% for Large leaks.

Failure Frequency for LNG Cargo Tanks:

The cargo containment system consists of insulated cargo tanks encased within the inner hull and situated in-line from forward to aft. The spaces between the inner hull and outer hull are used for ballast and will also protect the cargo tanks in the event of an emergency situation, such as collision or grounding. The cargo tanks are separated from other compartments, and from each other, by transverse cofferdams which are dry compartments.

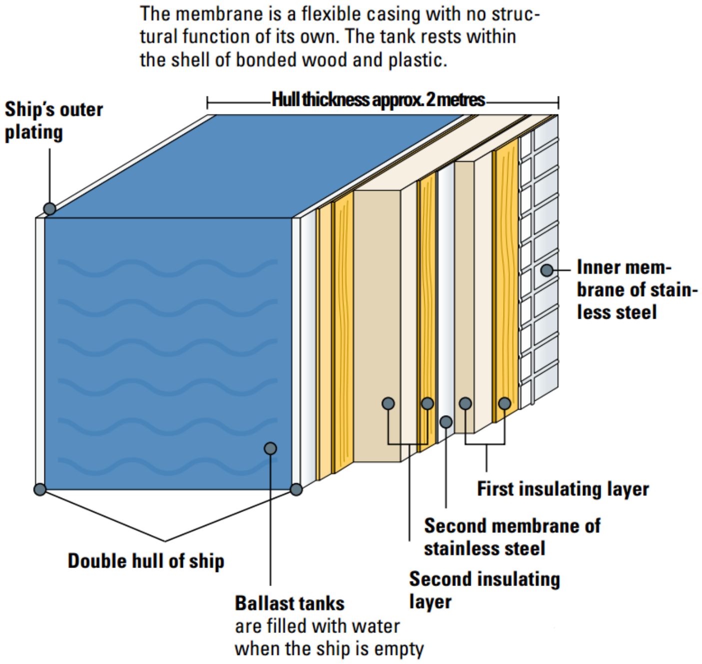

Figure 5: Structure of a Membrane Tanker

The inner hull, that is, the outer shell of each of the cargo tanks, is lined internally with the tank containment and insulation system. This consists of the following:

The tank lining thus consists of two identical layers of membrane and insulation, so that in the event of a leak in the primary barrier, the cargo will be contained by the secondary barrier. This system ensures that all the hydrostatic loads of the cargo are transmitted through the membranes and insulation to the inner hull plating of the ship.

The function of the membranes is to prevent leakage, while the insulation supports and transmits the loads and, in addition, minimises heat exchange between the cargo and the inner hull. The secondary membrane, sandwiched between the two layers of insulation, not only provides a safety barrier between the two layers of insulation, but also reduces convection currents within the insulation.

The primary and secondary insulation spaces are maintained under a pressure-controlled nitrogen atmosphere in order to prevent the membrane from collapsing inwards. The insulation design should ensure that the heat flow into the tank is limited to such an extent that the evaporation or boil-off rate is minimum based on sea surface temperature and ambient air temperature.

The inner hull steel does not attain a temperature below its minimum design value, even in the case of failure of the primary barrier. Any deflections resulting from applied strains and stresses are acceptable by the primary barrier.

In addition to the above, the insulation acts as a barrier to prevent any contact between ballast water and the primary barrier, in the event of leakage through the inner hull.

Thus based on the above, failures Frequencies of these Tanks are very low of the order of 1E-08 per year. And hence a release from the same is considered non-credible and not assessed in detail.

6 CONSEQUENCE ANALYSIS

6.1 Release Scenario Development

The key parameters determining the behaviour of each release, and the subsequent consequences, are the representative release rate, release duration, isolation times and the release inventory. The general approach adopted in deriving each of these parameters is explained in detail in the following sections.

6.2 Release Mechanism and Orientation

When Liquefied Natural Gas releases from a pipeline or equipment, it results in a pool formation and the initial pressure of the escaping fluid would scour the area, allowing the contents to flow directly into the environment. The rapid spreading of the pool results in evaporation forming a flammable vapor plume; liquid leaks injected into water under pressure or from a moderately high elevation give rise to a rapid phase transition (RPT) explosion.

The vapor evaporating from the pool disperses downwind and when it encounters an ignition source, flashes back to the pool resulting in pool fire. Any amount of unignited vapor cloud that gets drifted along the downwind direction results in vapor cloud explosion when it gets encountered by an ignition source.

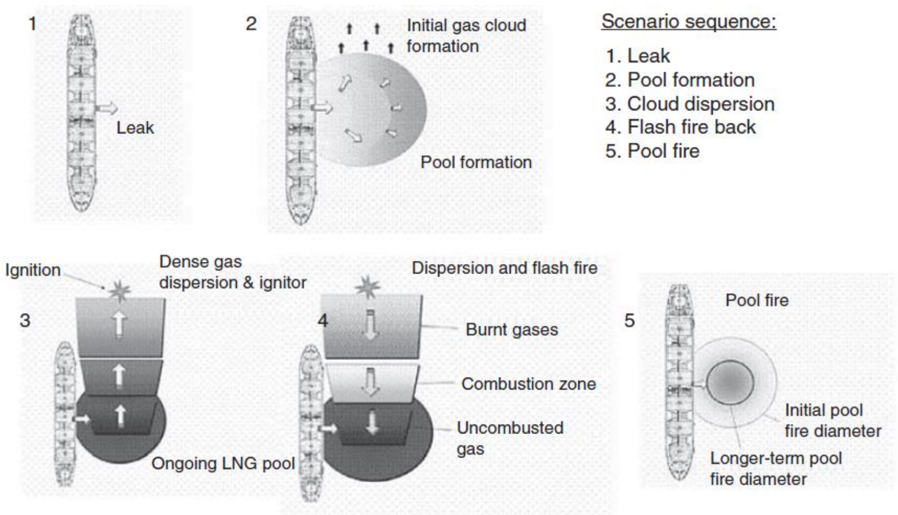

Figure 6: Release Mechanism of LNG

Leaks from the FSRU and associated facilities are modelled as horizontal releases which gives conservative worst case results

6.3 Release Rate

The rate of release of LNG through a leak depends mainly on the pressure inside the pipeline or equipment and the size of the hole. The release rate decreases with time as the pressure in the system decreases. The inventory releases depends mainly on the time taken to isolate the leak within the isolatable section.

6.4 Release Detection and Isolation

The release rate affects the size of the resulting gas cloud and hence the probability of ignition. Reduction in release rate (in effect, the duration of the release) is important because it limits the damage that the fire may cause.

Detection Time is the time required by the Leak Detection System or manual inspection to detect a leak.

Response Time is the time taken by the operator to validate the leak and respond.

Shutdown Time is the time for the valves to close down (an industry standard assumption of 1 inch per second is used).

Leaks within process installations can be quickly detected by leak detection systems and by operator vigilance.

Credit of ESD system to enable quick and safe means of stopping the LNGC to FSRU transfer of LNG in a controlled manner is considered in this QRA study. Credit is also given to the availability of Powered Emergency Release Coupling (PERC)

Release Duration for Loading Arms/ Loading Hose:

Release duration of 30 seconds is considered for releases from Loading Arms/ hoses on successful ESD activation.

Release Duration for Process Equipment:

Release duration of 30 seconds is considered for releases from Process Equipment with a comprehensive gas detection system with executive action.

6.5 Consequence Modeling

This part of the analysis involves physical modeling of the releases using the failure case data developed. Consequence calculations for each identified failure is performed starting with the release of a material from the source, and then calculates the dispersion and behaviour of the released material in the environment.

The modeling then proceeds to determine the effect zones for the various possible outcomes of Methane release. A release may ignite immediately as the result of the event which causes it, or it may ignite close to the source before the flammable cloud has travelled away from the release source.

LNG is a liquid at atmospheric pressure when it is at or below its boiling point (-163°C). The critical point of methane is -82.75°C, Natural Gas cannot be liquefied by pressure alone at ambient temperature. Rather, it must be cooled to liquefy. At atmospheric pressure, it must be cooled below the boiling point.

The expansion factor in going from liquid at the boiling point to vapor at standard ambient temperature is around 600 (594 – 625). Since the expansion ratio of liquid to vapor is 600:1, even a small flash can generate a large volume of gas.

LNG liquid and evaporated vapor immediately above the pool are at a constant temperature at the normal boiling point (typically -160°C). Upon mixing with air, the temperature increases, and above approximately -113°C, LNG vapor is lighter than air. This is considered a cut-off point for vapor affecting impairment. If wind turbulence is high, it will quickly dissipate to a non-flammable concentration.

The possible event outcomes of LNG release:

- Pool Fire
- Flash fire
- Jet fire
- Vapour Cloud Explosion

Jet Fire: A jet fire is very destructive to anything within it. This is because, as well as producing thermal radiation, the jet fire causes considerable convective heating to objects within the flame, and erosion of the surface by the jet.

Table 6: Jet Fire Hazard Zones

Isolatable Segment	Equivalent Hole Size (mm)	Jet Fire Hazard Distance (m)					
		2F Weather			5D Weather		
		5 kW/m²	12.5 kW/m²	37.5 kW/m²	5 kW/m²	12.5 kW/m²	37.5 kW/m²
LNG Transfer/Iso3/LNG Loading Hose/L	12	35	30	25	30	25	21
	25	67	57	47	58	48	40
	50	123	104	88	108	89	73
	250	284	238	199	264	217	179
Regas module/Iso4/LNG Suction drum/L	12	36	31	26	31	26	22
	25	69	59	49	60	50	41
	50	127	108	91	112	92	76
Regas module/Iso 5/LNG HP Pump_D/L	12	56	48	42	50	41	35
	25	109	93	80	96	80	67
	50	202	172	148	179	148	124
Regas module/Iso 5/BOG Recondenser/L	12	55	47	41	48	41	34
	25	107	91	79	94	78	66
	50	198	169	146	175	145	122
Regas module/Iso6/LNG Vaporizer_D/G	12	24	20	16	24	21	17
	25	50	41	32	51	43	35
	50	96	77	59	97	80	63
Regas module/Iso7/Propane System/ Propane Tank /L	12	32	27	22	28	23	19
	25	61	51	43	56	45	37
	50	115	95	80	104	84	68
Regas module/Iso7/Propane System/ Propane Pump /L	12	34	28	24	30	25	20
	25	65	55	46	59	48	39
	50	122	101	85	111	89	72
Compressor module/Iso8/ Compressor_S/G	12	5	4	0	5	4	0
	25	11	9	9	10	8	7
	50	21	18	16	18	16	13
Compressor module/Iso9/Compressor_D/G	12	5	0	0	5	0	0
	25	13	10	0	13	11	0
	50	27	22	18	27	23	19
Trunk deck/Iso10/LNG Loading main/L	12	35	30	25	30	25	21
	25	67	57	47	58	48	40

Isolatable Segment	Equivalent Hole Size (mm)	Jet Fire Hazard Distance (m)					
		2F Weather			5D Weather		
		5 kW/m²	12.5 kW/m²	37.5 kW/m²	5 kW/m²	12.5 kW/m²	37.5 kW/m²
	50	123	104	87	108	89	73
Trunk deck/Iso11/BOG Vapour main/G	12	6	5	0	5	4	0
	25	12	10	9	10	9	7
	50	23	20	17	20	17	14
Trunk deck/Iso12/LNG Offloading main/L	12	38	32	27	33	27	23
	25	72	61	52	63	52	43
	50	133	113	95	117	97	80
Trunk deck/Iso13/Spray Main/L	12	35	30	25	31	26	21
	25	68	58	48	59	49	41
	50	125	106	89	110	91	75
Trunk deck/Iso 14/NG Unloading Arm/G	12	24	20	16	24	21	17
	25	50	41	32	51	43	35
	50	96	77	59	97	80	63

Vapor Cloud Dispersion:

When LNG is released it expands 600 times it volume to form vapor clouds that are dispersed by the initial momentum of the release, turbulence around the obstructions, natural ventilation, and the wind. The sizes of these gas clouds above their lower flammable limit (LFL) are important in determining whether the release will ignite.

A flash (or cloud) fire occurs when a cloud of gas burns without generating any significant overpressure. The cloud is typically ignited on its edge, remote from the leak source. The combustion zone moves through the cloud away from the ignition point. The duration of the flash fire is relatively short, but it may stabilize as a continuing jet fire from the leak source.

Table 7: Hazard Zones of Vapor Cloud Dispersion

Isolatable Segment	Equivalent Hole Size (mm)	LFL Hazard Distance (m)			
		2F Weather		5D Weather	
		100%	50%	100%	50%
LNG Transfer/Iso3/LNG Loading Hose/L	12	33	48	20	39
	25	65	87	62	96
	50	113	148	132	187
	250	526	1285	314	499
Regas module/Iso4/LNG Suction drum/L	12	38	51	22	43
	25	69	92	66	101
	50	121	156	138	197
Regas module/Iso 5/LNG HP	12	47	114	44	97

Isolatable Segment	Equivalent Hole Size (mm)	LFL Hazard Distance (m)			
		2F Weather		5D Weather	
		100%	50%	100%	50%
Pump_D/L	25	118	224	119	227
	50	257	394	281	435
Regas module/Iso 5/BOG Recondenser/L	12	45	109	41	95
	25	112	223	111	224
	50	249	395	268	438
Regas module/Iso6/LNG Vaporizer_D/G	12	12	31	11	27
	25	33	84	30	83
	50	79	195	77	208
Regas module/Iso7/Propane System/ Propane Tank /L	12	19	48	14	31
	25	53	98	44	86
	50	127	178	119	192
Regas module/Iso7/Propane System/ Propane Pump /L	12	20	52	15	35
	25	58	104	48	95
	50	136	190	131	207
Compressor module/Iso8/ Compressor_S/G	12	2	4	2	3
	25	5	8	4	6
	50	9	23	8	17
Compressor module/Iso9/Compressor_D/G	12	3	6	3	5
	25	7	14	6	10
	50	14	35	12	31
Trunk deck/Iso10/LNG Loading main/L	12	33	48	20	40
	25	65	87	62	96
	50	113	147	131	187
Trunk deck/Iso11/BOG Vapour main/G	12	3	5	2	4
	25	5	9	4	7
	50	10	26	8	19
Trunk deck/Iso12/LNG Offloading main/L	12	41	55	25	47
	25	75	98	70	109
	50	131	167	148	211
Trunk deck/Iso13/Spray Main/L	12	36	49	21	41
	25	67	89	64	99
	50	117	152	135	192
Trunk deck/Iso 14/NG Unloading Arm/G	12	12	31	11	27
	25	33	84	30	83

Isolatable Segment	Equivalent Hole Size (mm)	LFL Hazard Distance (m)			
		2F Weather		5D Weather	
		100%	50%	100%	50%
	50	79	195	77	208

LFL distances represent the maximum distance within which an ignition source could ignite a release leading to a flash fire. Additionally, for the benefit for H-Energy, half LFL distances are also reported in this consequence analysis section.

Vapor Cloud Explosion:

LNG is not stored under pressure rather stored as a sub-cooled liquid at near atmospheric pressure. Although a large amount of energy is stored in LNG, it cannot be released rapidly enough if released into the open environment to cause the overpressures associated with an explosion. LNG vapors (methane) mixed with air are not explosive in an unconfined environment. A major incident resulting in a large release of LNG could result in a fire, but only if there is the right concentration of LNG vapor in the air (5% – 15%) and a source of ignition.

The quantity of release for the duration considered is low and does not have adequate energy to create an explosion in unconfined open space and hence VCE are not assessed.

Pool Fire:

The liquid fraction is the liquid portion from release orifice. When LNG is at about -162 deg C, it does not flash on release. It falls on water or deck plates depending upon the point of leak and starts spreading forming a pool. The pool vaporises taking heat both from deck/water surface and wind. The liberated NG vapours drift in the direction in which the wind blows forming a vapour cloud.

The vapor evaporating from the pool disperses downwind and when it encounters an ignition source, flashes back to the pool resulting in pool fire. Below table gives the pool fire radiation distances for the release of LNG from rupture of unloading hose.

Table 8: Pool Fire Hazard Zones

Isolatable Segment	Equivalent Hole Size (mm)	Pool Fire Hazard Distance (m)					
		2F Weather			5D Weather		
		5 kW/m^2	12.5 kW/m^2	37.5 kW/m^2	5 kW/m^2	12.5 kW/m^2	37.5 kW/m^2
LNG Transfer/Iso3/LNG Loading Hose/L	250	196	202	138	147	84	101

In the case of release of LNG from small, medium and large leaks, significant pool formation is not observed. Any small amount of LNG that is released forms a very small pool that is located close to the origin of release and evaporates quickly as it picks up heat from the ambient and quickly evaporates.

A full-bore rupture scenario of the LNG loading hose is unrealistic and the same is not credible. However, damage impacts from the same are reported to analyse the worst case consequences.

6.6 Safety Exclusion Zone

A Worst Case Event can be defined as the most severe incident, considering only incident outcomes and their consequences, of all identified incidents and their outcomes. The Worst Case Approach appears attractive as a decision support tool as "whatever happens, it can't be worse than this" and those responsible for public protection can be assured that the nominated consequence levels will not be exceeded. A disadvantage of the worst case approach is that ignoring safeguarding features that have been considered in the design to either reduce the occurrence or reduce the impact results into impractical design and avoidable expenditures.

A Maximum Credible Event on the other hand is defined as the most severe incident that is considered plausible or reasonably believable. By bringing in the aspect of plausibility, the ability of safeguarding system provided in the design to reduce the probability of an event and to reduce the scale of possible events from the maximum possible to some lesser scale is permitted. Safeguarding can reduce the likelihood of the event (prevention) or reduce its potential outcome (mitigation).

SIGTTO guidelines recommend that port traffic should be excluded from the environs of an LNG marine terminal. A specific exclusion distance is not provided in the guidelines. Hence the same is determined, based on the 'maximum credible spill of LNG during transfer operations and the likely pattern of dispersal for the resulting gas cloud' at the facility under study. This is typically modelled using dispersion from a 50mm hole on the LNG unloading hose from the LNGC due to its high failure frequency. During the conceptual stage of the project, a 150 mm hole was considered to estimate the Exclusion zone. However, considering the safety systems provided in the design and constant monitoring of the loading operations, it is unrealistic for a 150 mm hole or a loading hose rupture. Though it is a worst case scenario, the same is not credible. Hence a hole size of 50 mm is considered credible and used for estimating the safe exclusion zone.

The credible spill is defined as a release of LNG through a 50mm hole for a typical duration of 30 seconds assuming operation of the emergency shutdown facilities, then dispersion modelling would indicate distances to the lower flammable limit of 113m in stable weather conditions (2 m/sec wind velocity and F stability) and 132m for neutral weather conditions (5 m/s wind and D stability). An exclusion zone would therefore be 140 meter (rounded off to next multiple of 10) from the location of the LNG transfer facilities as a conservative approach.

In the event of vapour dispersion due to release of NG from a 50 mm hole size in the HP NG unloading arms, LFL concentration of the cloud can reach upto a distance of 79m. This distance is much lower compared to a distance of 140m. Hence a distance of 140m is taken as safe exclusion zone from the LNG transfer facilities.

6.7 Consequences and Impacts

The particular outcome(s) modeled depends on the behaviour of the release and the dilution regimes, which exist. The relative likelihoods of the different outcomes are dealt with in the risk calculations. The consequence module undertakes these calculations for selected representative meteorological conditions derived from the annual meteorological conditions in the study area.

The relevant meteorological conditions are wind speed, wind direction and atmospheric stability. Atmospheric stability is itself determined partly by wind speed. A hot day with little wind will create highly unstable atmospheric conditions, and enhance mixing and dispersion of the cloud. On a clear still night, highly stable conditions will weaken mixing and dispersion. On a windier or cloudier day, conditions will be closer to neutral and hence dispersion will be in between these extremes.

6.8 Ignition Probability

The ignition probability is taken from the UKOOA ignition model for Releases of flammable gases, vapour or liquids significantly above their normal (NAP) boiling point from within offshore process modules or decks on Floating Production Storage Offloading Units.

- The ignition model takes into account a number of factors, including:
  - Release rate, pressure and inventory;
  - Release molecular weight and phase (gas or liquid);
  - Flammability of material released;
  - Wind Speed;
  - Details of the process area around leak including:
    - Dimensions of the area;
    - Amount of hot works;
    - Electrical Shutdown Time;
    - Plant area type (Offshore basic process module through to rural offsite); and
    - Volume blockage ratio and vent area.
  - Details of the adjacent process areas (If applicable); and
  - Details of the overall site area (if applicable).

These factors are used in the model to estimate the immediate and delayed ignition probability of the release. For the explosion analysis, only the delayed ignition is taken into account, as an immediate ignition is expected to only result in a fire event.

7 RISK ASSESSMENT

The risk associated with a hazardous event is assessed based on both the damage caused and probability of its occurrence.

Risk is function of ***Consequence*** and ***Frequency***.

The risks are defined in terms of risks to an individual and risk to a group of population as a whole. The frequency and consequence assessments for selected failure scenarios were combined to calculate individual and societal risk. The risk results have been presented as contours on a plot plan and FN curves. The risk results are then assessed against the risk criteria to determine risk acceptability and to provide necessary mitigating measures if applicable.

Individual Risk

The individual risk results show the geographical distribution of risk. It is the frequency at which an individual may be expected to sustain a given level of harm from the realization of specified hazards and is normally taken as risk of death (fatality). It is expressed as risk per year.

This is the risk to a hypothetical individual being present at that location continuously there for 24 hours a day and 365 days a year.

Societal Risk

Societal Risk is the risk experience in a given time period by the whole group of personnel exposed, reflecting the severity of the hazard and the number of people in proximity to it. It is defined as the relationship between the frequency and the number of people suffering a given level of harm (normally taken to refer to risk of death) from the realization of the specified hazards. It is expressed in the form of F-N curve.

7.1 Risk Criteria

Individual Risk Criteria:

Risk criteria for **Individual Risk for Worker** are as follows:

- Individual risk levels above 1 x 10^{-3} per year will be considered unacceptable and will be reduced, irrespective of cost.
- Individual risk levels below 1 x 10^{-6} per year will be deemed acceptable.
- Risk levels between 1 x 10^{-3} and 1 x 10^{-6} per year will be reduced to levels as low as reasonably practicable (ALARP). That is the risk within this region is tolerable only if further risk reduction is considered impracticable because the cost required to reduce the risk is grossly disproportionate to the benefit gained

Risk criteria for **Individual Risk for Public** are as follows:

- Individual risk levels above 1 x 10^{-4} per year will be considered unacceptable and will be reduced, irrespective of cost
- Individual risk levels below 1 x 10^{-6} per year will be deemed acceptable
- Individual risk between 1 x 10^{-4} per year to 1 x 10^{-6} per year will be considered to be in the ALARP region

Societal Risk Criteria:

A formal risk criterion is used at all for societal risk; the criterion most commonly used is the FN curve. Like other forms of risk criterion, the FN curve may be cast in the form of a single criterion curve or of two criterion curves dividing the space in to three regions – where the risk is unacceptable, where it is negligible and where it requires further assessment. The latter approach corresponds to application to societal risk of the ALARP principle. Risk criteria for UK HSE have been considered for the present study and it is shown in Table below.

Table 9: Societal Risk Criteria

Group	Maximum Tolerable Intercept With N=1	Negligible Intercept With N=1	Maximum Tolerable Intercept With N=100	Negligible Intercept With N=100
Workers	10^{-2}	10^{-4}	10^{-4}	10^{-6}
Public	10^{-3}	10^{-5}	10^{-5}	10^{-7}

Note that the above are the primary risk measures used to determine the formal risk acceptability. However, the above results should be supported by consideration of other risk measures, including:

- Location Specific Individual Risk (LSIR) estimates, which apply to each defined location and are independent of the population.
- For both IRPA and LSIR it is important to ensure a clear presentation of the contributors to each in terms of broad hazard types, specific failure cases, location, incident phase (immediate, escape), etc.
- Societal risk results will also be presented to support the understanding of the risks in the form of Potential Loss of Life (PLL) values and an overall F-N curve (showing the cumulative frequency, F, of exceeding N fatalities), although where explicit criteria are not defined.

7.2 Location Specific Individual Risk (LSIR)

Table11 lists the individual risk values predicted for each location, in terms of the Location Specific Individual Risk (LSIR), where the distribution is then illustrated by Figure 6. This gives the average risk across each Area (as defined in the risk model) to a person continuously present and, hence, is the basis for the IRPA and PLL calculations, which use these values when accounting for the population or proportion of time spent in each location.

Table 10: Location Specific Individual Risk (LSIR) by Area

Hazard	LSIR
Aft Machine Space	2.78E-06
Compressor Module	5.58E-05
Forward Deck	4.92E-05
Forward Space	1.08E-05
Living Quarter	1.18E-06
Regas Module	6.18E-04
Trunk Deck	6.78E-04

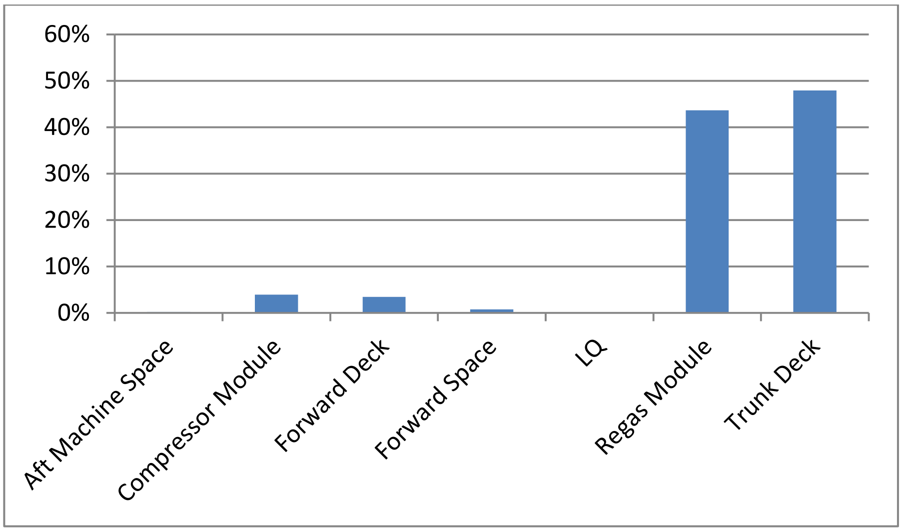

Figure 7: Distribution of Process LSIR by Location

It can be seen from the LSIR results that the Trunk deck and Regas module being the key contributors. This is due to the presence of loading hose, LNG loading mains, LNG spray mains and HP NG unloading arm. And the risk results in the Regas module are high owing to the high pressure natural gas release.

The peak values are for Trunk deck and Regas Module at 6.78E-04 per year and 6.18E-04 per year respectively. For the majority of the other process modules, the LSIR is typically between 5 E-05 and 1E-05 per year.

These results are not directly comparable, since the LSIR results per module include the risks arising from all locations, rather than just the source module. Hence, there are LSIR values for modules with no hazards specified (such as the Forward deck and Aft deck including workshop) due to the risks associated with escalation from other areas.

7.3 Individual Risk Per Annum (IRPA)

Below table 12 shows the IRPA values for each of the worker categories as an absolute figure, in Table 13 the IRPA values are converted to a percentage of the IRPA value per worker category which makes the distribution of the IRPA clearly visible.

Table 11: IRPA Results for Worker Group

Worker Category	IRPA
Master	7.48E-06
Officers, Trainees and Chief engineer	1.01E-05
Engineers	1.50E-05
Deck Crew	4.93E-05
Engine Room Crew	4.18E-06
Catering	2.26E-06

Table 12: IRPA Results Breakdown for Worker Group

Worker Category	IRPA
Master	8%
Officers, Trainees and Chief engineer	11%
Engineers	17%
Deck Crew	56%
Engine Room Crew	5%
Catering	3%

It can be seen that the Maximum IRPA applies to the Deck crew category and is estimated at around 4.93×10^{-5} per year followed by Engineers and Officers.

7.4 Potential Loss of Life (PLL)

The Potential Loss of Life (PLL) risk measure corresponds to the average number of fatalities per year.

The PLL is summarised in Table 14, which gives the key contributors to the PLL in terms of the locations, or areas, contributing to the PLL.

Table 13: Potential Loss of Life (PLL) by Location

Hazard	PLL by Location
Living Quarter	3.59E-05
Forward Space	4.57E-06
Forward Deck	2.04E-05
Trunk Deck	1.83E-04
Regas Module	1.10E-04
Compressor Module	9.96E-05
Aft Machine Space	1.55E-05

The distribution of the PLL around the FSRU is illustrated by Figure 7.

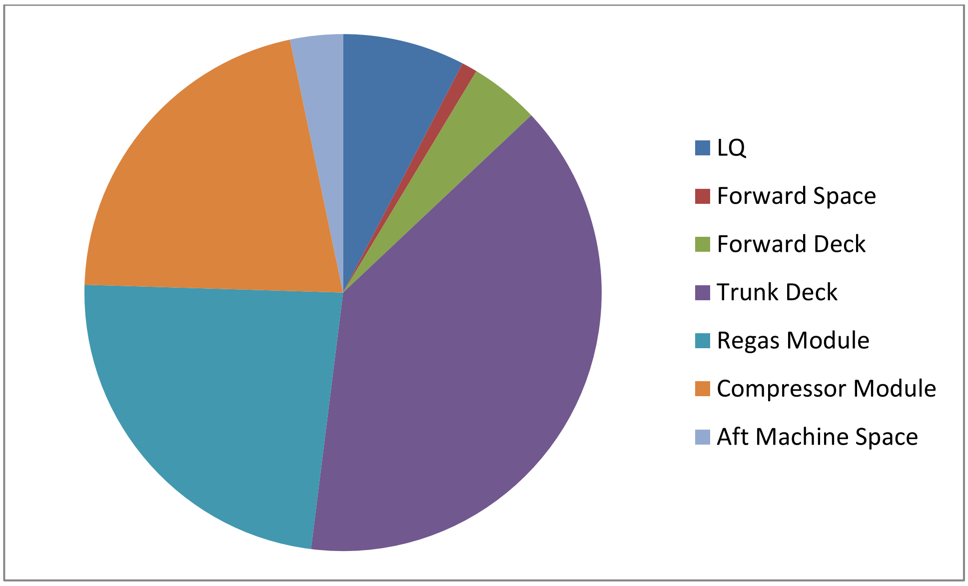

Figure 8: Distribution of PLL by Location

The location that makes the largest contribution to the PLL is Trunk Deck (due to contribution from LNG import, NG export, Spray Main and BOG main lines) and Regas Module (due to contribution from Regasification trains) followed by Compressor Module (boil off gas and High pressure gas from compressors).

7.5 FN Curve

Following FN curve shows the frequency (F) of there being 'N' of more fatalities due to different failure cases from the FSRU and associated facilities.

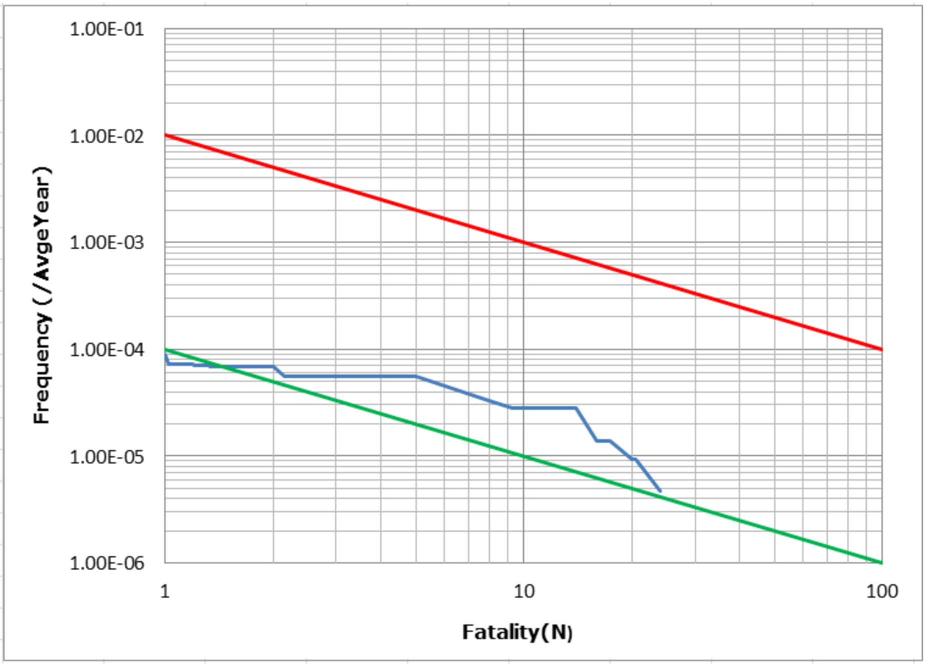

Figure 9: FN Curve

From the FN Curve it is observed that FN curve falls partly in ALARP and Broadly Acceptable regions. The maximum fatality count is 27 at the frequency of 4.6E-06 per year.

8 CONCLUSIONS AND RECOMMENDATIONS

8.1 Risks to People

The main objective of this QRA study is to quantify and assess risk from process hazards from the FSRU and associated facilities and to ensure that they comply with adopted risk criteria and to demonstrate that risk has been reduced to the extent that is reasonable and is compliant with risk management process.

In order to meet the objective of assessment, DNVGL has identified and assessed potential scenarios and specified the likelihood and consequences related to potential accidental releases occurring in the facility. Further, based on the results from the assessment, DNVGL had made appropriate recommendations for further risk mitigating measures.

Below are the findings from the QRA Study:

Location Specific Individual Risk (LSIR)

The Location Specific Individual Risk (LSIR) gives a measure of the risk that will apply to each location (in this case, each area, generally), independent of the population, where:

- The process LSIR results show that Trunk deck and Regas module being the key contributors. This is due to the presence of loading hose, LNG loading mains, LNG spray mains and HP NG unloading arm. And the risk results in the Regas module are high owing to the high pressure natural gas release.
- The peak values are for Trunk deck and Regas Module at 6.78E-04 per year and 6.18E-04 per year respectively. For the majority of the other process modules, the LSIR is typically between 5 E-05 and 1E-05 per year.

Safety Exclusion Zone:

SIGTTO guidelines recommend the establishment of an exclusion zone around the FSRU Facility to reduce the likelihood of ignition in the event of a release of LNG. The extent of the exclusion zone is a matter for local determination, in the context of the prevailing conditions, and this can be informed by predicted dispersion distances for credible spills of LNG. The credible spill was agreed as a release of LNG through a 50mm hole from the unloading hose for a 30 second duration assuming operation of the emergency shutdown facilities. For this credible spill, the dispersion modelling predictions indicate that an exclusion zone of around 140m from the location of the LNG loading facilities.

Individual Risk Per Annum

It can be seen that the Maximum IRPA applies to the Deck crew category and is estimated at around 4.93×10^{-5} per year. This is due to the longer duration of Deck crew on the Trunk deck.

Potential Loss of Life (PLL)

The potential loss of life (PLL) accounts for the number of people in each case and provides an indication of the overall key risk contributors, where:

- The location that makes the largest contribution to the PLL is Trunk Deck at 1.83E-04 per year (due to contribution from LNG import, NG export, Spray Main and BOG main lines) and Regas Module at 1.10 E-04 per year (due to contribution from Regasification trains) followed by Compressor Module at 9.96E-05 per year (boil off gas and High pressure gas from compressors).

8.2 Recommendations

Based on the observations and conclusions following are the recommendations of the study:

Consider an exclusion zone around the jetty transfer facilities of around 140m.

Loading Arm: Presently Loading hoses are used to transfer LNG from LNGC to FSRU. These loading hoses have a higher failure frequency compared to loading arms. Consider providing Loading arms in place of loading hoses to reduce the frequency of failure and subsequently risk levels.

Alternately consider replacement of hose at regular intervals. Loading hoses shall be inspected and tested at regular intervals.

Emergency Shut-Down (ESD) systems are considered to shut down and limit the inventory within 30 seconds of the occurrence of a leak in the process area, unloading equipment or pipeline. The same shall be validated during Engineering development. A Safety Integrity Level Assessment shall be performed to determine the integrity levels of Safety Instrumented Systems and the same shall be validated throughout the life cycle of the installation.

An Escape Muster Evacuation Rescue Analysis (EMERA) study shall be carried out to assess the adequacy of escape routes, evacuation systems and muster area for accommodation of POB and the lifesaving equipment.

General Asphyxiation Guidelines: Consideration should be given to providing air packs or escape packs where people may be walking in clouds of 19.5% minimum oxygen content or less.

General Cryogenic Guidelines: Minimize cryogenic impact due to LNG on deck or upper part of installation to avoid brittle fractures or spalling in concrete by use of appropriately rated and validated materials, containment of spills, and application of passive fire protection to vulnerable structures. Consider design improvisations (e.g. minimising flanges or provision of flange guards) to prevent failure of facility not designed for cryogenic service due to cold spots from cryogenic contact.

Spill Containment Guidelines: Leaks in LNG welded piping systems shall be contained in troughs. Sufficient deck curbing, barriers shall be provided around the perimeter of the deck.

Slop deck shall be free draining not to hold cryogenic liquid spill overboard thereby mitigating the pool fires, and potentially reducing the extent of the vapour cloud that may arise on the deck.

Active Fire Protection Guidelines: Special consideration shall be given to design of water sprays as it may increase the rate of evaporation thereby increasing the size of the gas cloud and hence the risk of asphyxiation. Water sprays, if aimed directly at the liquefied gas, may deflect it to other areas; Contact between liquefied gas and water may result in a rapid phase transfer which can be violent and present a risk to people nearby; Also water may freeze, producing a slippery surface and impeding escape. Ensure emergency procedures are appropriate and do not increase the risk.

Fi Fi 1 (Firefighter 1) foam deluge systems shall be installed at the FSRU and LNGC to mitigate LNG spills by keeping the vapours down.

LNG escort tug boats shall also be equipped with Fi Fi 1 safety equipment based upon an appraisal of future vessels, size of object to be protected and available fire-fighting equipment. The vessel must have a deluge system which will protect the vessel and crew from radiant heat and to project a protective curtain around the surface area of the tug. This water curtain helps to protect the vessel and crew from the effects of radiant heat. This would allow the vessel to escape the scene of a fire in order to reach an area of refuge or it might enable the vessel to enter an area of high heat to safely enable a rescue.

It is recommended to revisit the QRA when design details are firmed up.

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