1 INTRODUCTION

1.1 Background

JGC Corporation is responsible for the Pre-FEED of the proposed LNG Terminal at Pakistan using Floating Storage Regasification Unit (FSRU) technology (hereinafter referred as "the Project") owned by Mitsubishi Corporation.

1.2 Objectives of Study

The main objectives of the channel modeling and simulation report was:

- Assessment of the risk to plant associated to dangerous liquid or gas release and resulting hazardous scenarios;

1.3 Scope

The scope of work of the QRA and Navigation Simulation includes the following studies:

- This study has been developed based on the most updated information available for the project and in compliance with international best practice for risk assessment;
- The QRA study aims to identify credible scenarios related to piping and equipment failure leasing to possible fluid releases and assesses the effects of the resulting scenarios in terms of likelihood of occurrence and associated physical and chemical consequences with respect to people health and safety;
- Random rupture (loss of containment) and findings of Hazard Identification (HAZID) study have been analyzed in this QRA study, considering the available control and safety devices used for the prevention and/or mitigation of hazardous scenarios;
- The navigation study was to preliminary assess the technical and safety aspects of the proposed berth related to navigation though the Chann Wadoo Channel and the berthing and unberthing of different types and sizes of LNG carriers

2 ATTACHMENTS

Attachment -1 QRA Report
Attachment -2 Appendix A Assumptions Sheet
Attachment -2 Appendix B Event Tree Analysis
Attachment -3 Appendix C Consequence Plots
Attachment -4 Appendix D Navigation Study Report

4634

JGC Corporation
Karachi, Pakistan

QRA for Tabeer LNG Terminal at Port Qasim

Quantitative Risk Assessment

Doc. No. P0009270-1-H2 Rev. 4 – November 2018

Rev.	4
Description	Editorial modification
Prepared by	I. Mazza
Controlled by	M. Pontiggia
Approved by	G. Uguccioni
Date	21/11/2018

1535

QRA for Tabeer LNG Terminal at Port Qasim

Quantitative Risk Assessment

Rev.	Description	Prepared by	Controlled by	Approved by	Date
4	Editorial modification	I. Mazza	M. Pontiggia	G. Uguccioni	21/11/2018
3	Fourth Issue	M. Di Francesco	M. Pontiggia	G. Uguccioni	31/10/2018
2	Third Issue	M. Di Francesco	M. Pontiggia	G. Uguccioni	14/09/2018
1	Second Issue	M. Di Francesco	M. Pontiggia	G. Uguccioni	03/08/2018
0	First Issue	M. Di Francesco	M. Pontiggia	G. Uguccioni	20/07/2018

TABLE OF CONTENTS

537

LIST OF TABLES

LIST OF FIGURES

ABBREVIATIONS AND ACRONYMS

ALARP	As Low As Reasonably Practicable
ETA	Event Tree Analysis
FEED	Front End Engineering Design
FTA	Fault Tree Analysis
HAZID	Hazard Identification (Study)
IRPA	Individual Risk Per Annum
MTTF	Mean Time to Failure
NA	Not Applicable
NR	Not Reached
LFL	Lower Flammability Limit
LNG	Liquefied Natural Gas
LNGC	Liquefied Natural Gas Carrier
LSIR	Local Specific individual Risk
PFD	Process Flow Diagrams
P&ID	Piping and Instrumentation Diagrams
QRA	Quantitative Risk Assessment

EXECUTIVE SUMMARY

This report presented findings of the QRA carried out for the LNG Facility foreseen as a part of LNG Receiving Facilities feasibility study.

The LNG (Liquefied Natural Gas) facilities foreseen for the Project consist of an FSRU, in which the LNG is pumped up to required pressure and vaporized by means of seawater. Then, vaporized gas is send to Onshore Receiving Facility (ORF) through three HP Loading Arms and new pipeline. In addition, power generation, service water, nitrogen and fire water system are installed on Offshore Platform.

The QRA (Quantitative Risk Assessment) study aimed to identify credible scenarios related to piping and equipment failure leading to possible fluid releases and to assess the effects of the resulting scenarios in terms of likelihood of occurrence and associated physical and chemical consequences with respect to people, health and safety.

The analysis has been focused for the risk to operators and public due to the hazards relevant to the new installations and the maritime traffic in the channel.

The following steps have been applied:

- ✓ Identification of risk;
- ✓ Calculation of frequencies and consequences;
- ✓ Risk assessment and evaluation.

Risk identification has been performed by means of existing HAZID study review and random rupture review for applicable isolatable sections in the project.

Frequency of Maritime hazards has been assessed as negligible; this result is mainly due to the foreseen navigation procedures which require the presence of a tug always connected to the LNG carries during channel navigation and the simultaneous presence of at least two working tugs during berthing and un-berthing maneuvers.

Frequencies of release due to random ruptures from loading arms, pipeline and equipment at ORF included in the SoW have been also calculated. Event Tree Analysis has been used to obtain associated frequencies for associated final outcomes (jet fire, flash fire, unignited dispersion).

Explosion scenarios have been neglected: no congested areas are to be observed in the jetty area or along pipeline routing (the assessment has been performed by reviewing aerial photography of the area of interest. More detailed assessment should be performed during later project stages). In absence of congested areas, combustion of premixed flammable cloud would lead to negligible overpressure values. Moreover, the focus of the analysis is the assessment of risk for people (both personnel and public); as a consequence, attributing the whole delayed ignition to the flash fire scenario and extending the probability of fatality down to LFL/2 concentration value will result in conservative assumption, since distances reached by LFL/2 concentration are generally greater than overpressure distances in presence of low confinement.

Consequences have been assessed by means of DNV Phast.

Results have been expressed in terms of LSIR for public and IRPA for operators.

Maximum LSIR along the pipeline has been assessed in the range of 1E-07 ev/y, thus falling in the continuous improvement area. No further barriers or mitigation measures are therefore envisaged to reduce the risk.

Maximum LSIR in the Terminal and ORF area has been assessed in the range of 1E-05 ev/y, with 1E-06 ev/y extending for less of 500 m from the loading arms.

Risk in the Terminal and ORF is evaluated in the lower boundary of ALARP region; as additional mitigation measure, the installation of a Fire and Gas detection system is advised, in order to provide audible and visual warnings in case of loss of containment. Automatic actuations in case of fire of gas detection should be evaluated in future project phases.

The set-up of an exclusion zone of approximatively 500 m from the jetty could be also taken in consideration, if technically and economically feasible.

1 INTRODUCTION

The project proponent, JGC Corporation, is intending to develop a FSRU based LNG import terminal at Port Qasim. The terminal will receive, re-gasify and transport re-gasified LNG (i.e. natural gas) via pipeline to a delivery point onshore.

The project includes constructing and operating a Liquefied Natural Gas (LNG) terminal, inclusive of ship berthing and import facilities, floating storage and regasification equipment. The project intends to provide facilities for receiving supplies of LNG via a conventional LNG carrier, for offloading, transfer and loading into a Floating Storage and Regasification Unit (FSRU). The FSRU will store and re-gasify the LNG and deliver the regasified liquefied natural gas (RLNG) via jetty and associated facilities to the Onshore Receiving Facility, and then to the existing CTS Pipeline.

The LNG import terminal will be located at Port Qasim, in Chann Waddo Channel (in the following Site Channel - Figure 1.1) that currently is not in operation. Presently, the LNG carrier traffic is fully managed through the Main Channel for both entrance and exit manoeuvers due to the fact that two terminals (Mitsubishi and Terminal X) in operation are both located in the Main Channel.

Terminal X and Mitsubishi Terminal coordinates are as follows:

- Terminal X: 24°43' 15"N; 67°13' 43.78"E
- Mitsubishi (Miti) Terminal: N 2 735 081.214; E 319 481.630 (UTM 42N)

Picture below reports the exact location of the above mentioned LNG Terminals.

Figure 1.1: Mitsubishi Terminal and Terminal X Location

Mitsubishi terminal is far away from Terminal X, the distance between the two terminals is around 2 km. So that, the traffic related to LNG Carriers reaching Miti Terminal will not affect Terminal X.

In general, the requirements related to the safety distance can vary from terminal to terminal, depending on the safety philosophy in each location, on the terminal operator, port and national administration.
Safety distances will be influenced by many factors and should be determined from a risk assessment studies. PIANC Report no.116 – 2012 "Safety aspects affecting the berthing operations of tankers to oil and gas

terminals" at Chapter 9 provides some general indications about the safety distance to be maintained between a moored LNG tanker and a passing vessel, indicated with W1 in figure below.

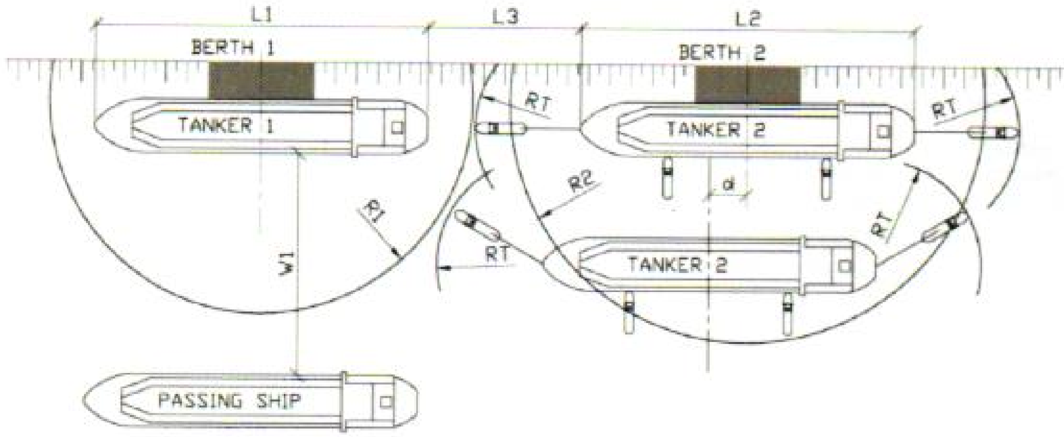


Figure 1.2: PIANC Report no.116-2012 Alongside Distances and Passing Ships

PIANC typical values for W1 in case of LNG tankers is in the range between 100 and 300 m. PIANC provides also some indications about the safety zone R1 around manifold at berth; for LNG terminal typical values of R1 are between 200 and 300 m. So that, the safety distances considered for the present project are in accordance with PIANC guidelines.

Furthermore, SIGTTO guidelines do not provide any indication about the safety distance to be maintained between an LNG carrier moored to a passing vessel; it advices only to perform a dedicated risk assessment, a QRA in particular, that has been already carried out for the present project.

2 SCOPE OF THE DOCUMENT

The scope of this document is to assess the risk to plant associated to dangerous liquid or gas releases and resulting hazardous scenarios.

This study has been developed based on the most updated information available for the Project, and in compliance with international best practices for risk assessment.

The Quantified Risk Assessment (QRA) study aims to identify credible scenarios related to piping and equipment failure leading to possible fluid releases and assesses the effects of the resulting scenarios in terms of likelihood of occurrence and associated physical and chemical consequences with respect to people health and safety.

Random rupture (loss of containment) and findings of Hazard Identification (HAZID) Study have been analysed in this QRA Study, considering the available control and safety devices used for the prevention and/or mitigation of hazardous scenarios.

3 QRA METHODOLOGY

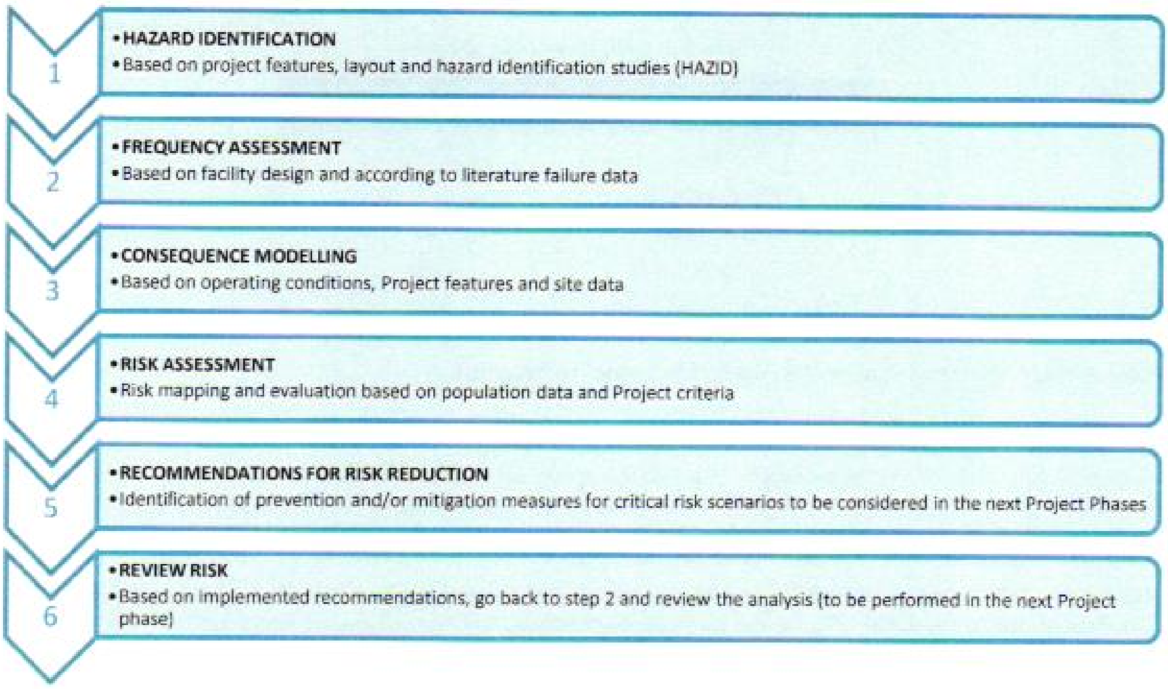
This QRA assesses the overall risk of LNG Facilities due to fire, explosion and flammable gas dispersion occurring as a consequence of identified Loss of Containment Events.

The steps through which the QRA is developed are listed in the following, and each methodological step is discussed in the relevant paragraph(s):

- ✓ Hazards identification;
- ✓ Frequency assessment;
- ✓ Consequence Analysis;
- ✓ Risk assessment;
- ✓ Recommendations for risk reduction.

The above mentioned tasks are detailed in the following paragraphs; particularly, the QRA has been developed in accordance to the "Guideline for Quantitative Risk Assessment" [20] and the risk has been evaluated in accordance to criteria provided by NFPA 59A [21] and HSE UK [15].

Typical QRA process flow chart followed in the study is shown here below.



3.1 HAZARD IDENTIFICATION

Main credible accidental events that can lead to fire, explosion and flammable gas dispersion scenarios have been identified starting from results of HAZID held on 24th and 25th of April 2018 via teleconference between Meeting Venue in Karachi, Pakistan and JGC Corporation Head Office in Yokohama, Japan [27].

Causes of loss of containment can be split between:

- ✓ Accidental releases from process equipment;
- ✓ Marine accident involving FSRU and/or LNGC.

In order to perform the consequence analysis, the process conditions and composition of the released fluids has been investigated for both accidental releases from process equipment and marine accidents. Composition of the fluids and other relevant process parameters used to characterize each accidental event considered in the analysis are given in the following.

Table 3.1: LNG Composition

LNG Composition	Lean Case (mol%)	Rich Case (mol%)
C1	97.7	81.6
C2	1.8	13.4
C3	0.2	3.7
C4+	0.2	0.7
N_2	0.1	0.7
Molecular Weight	16.4	19.3
Liquid Density [kg/m^3]	427	485

Table 3.2: LNG Stream Properties

Stream Properties	
Phase	Vapor
Temperature [°C]	11
Pressure [barg]	98
Flowrate [MMSCFD]	750
Peak Flowrate [MMSCFD]	1000

QRA simulations has been performed using "Lean case" composition.

3.1.1 Accidental Releases from Process Equipment

Scope of this step of the assessment is to identify potential sources of loss of containment from process equipment included in the Scope of Work. Loss of LNG from process equipment such as pipework, valves and flanges is possible due to different causes, as e.g. corrosion or mechanical defects or failure; events related to process deviations are not considered since relevant HAZOP study is not available.

During this Project Phase an HAZID analysis was carried out, and the results of the HAZID were used as input to the Project and to the QRA [27], for the purpose of identifying the type of events and scenarios which can be considered.

The loss of containment events analysed at current stage are those referred to as "random ruptures", i.e. those caused by unexpected failures due to material defects, fabrication errors, excessive wearing or corrosion, maintenance errors, etc. It is common practice to consider these cases by assuming a set of representative leak diameters for components (vessels, pipework, pumps, compressors, valves, etc.) in each section of the plant.

Isolatable sections have been identified on the PFDs (Process Flow Diagrams) (Ref. [8]) and the P&IDs (Piping and Instrumentation Diagrams) (Ref. [1] to [7]), considering the process sections that can be isolated during emergency shutdown. An "isolatable section" is defined as a part of a system that, in case of emergency, can be completely separated from the rest of the system. This isolation can be activated automatically or manually, for example through shut down valves or pumps trip.

The process plant, therefore, has been divided into different isolatable sections with reference to the positioning reported in the project P&IDs of shut-down valves, pumps and particular manual valves (if in safe location). Where information was not available or conflicting between sources, reasonable assumptions in line with Standards and industrial best practices have been made to define position of isolating devices and extent of isolatable sections, as discussed in the assumption list (Ref. [19]).

Representative streams for release modelling have been selected on the basis of available data (Ref.[19]) for each isolatable section considering accidental events due to loss of containment from the following hole sizes reported in Table 3.3.

Table 3.3: Hole sizes

DESCRIPTION	HOLE SIZE [mm]
Very small leak	7
Small leak	36
Leak	110
Large leak	150

Representative Hole Sizes have been derived from taxonomy used by OGP Data directory (Ref. [11][12][13]) to statistically elaborate frequency of release from process equipment. Five different ranges are provided by OGP, namely:

- 1 mm – 3 mm;
- 3 mm – 10 mm;
- 10 mm – 50 mm;
- 50 mm – 150 mm;
- >150 mm.

First range (1 mm – 3 mm) has been neglected. Consequences associated to very small release size for flammable (non-toxic) gases are limited to the close proximity from the release point and are generally not included in the focus of the QRA.
Since the release rate is linearly dependent upon release area (which in turn varies linearly with the square of hole diameter), average of squared values has been used to calculate the representative hole size within each range. (For example: very small leak are considered representative of 3 mm – 10 mm OGP range; squared limits are 9 mm^2 and 100 mm^2. Averaged squared limits is 54 mm^2, which correspond to a square root of 7.4 mm, approximated to 7 mm).

3.1.2 Marine accident Releases from Process Equipment

In addition to sources of loss of containment identified for process equipment as described in previous paragraph, also LNG releases caused by external interference and third parties interactions have to be taken into account. Particularly, considering the design of the analyzed Plant (Jetty provided with permanently moored FSRU and LNGC approaching FSRU for LNG unloading), the following cases of external interference can be identified:

- Passing vessel drifting against FSRU;
- LNGC impact on passing vessel or grounding;
- LNGC loss of control during berthing.

3.2 FREQUENCY ASSESSMENT

3.2.1 Loss of containment event frequency evaluation

The leak frequency assessment has been performed on the basis of loss of containment data given in literature, by counting equipment and characterizing the piping containing hydrocarbon from process drawings (P&IDs). To evaluate the frequency of each loss of containment event, a "parts count" has been performed on each identified isolatable section and the statistical data on frequency of failure for all passive components identified (piping, filter, atmospheric tank, etc.) have been added up to calculate the final failure frequency of that specific section.

Historical failures data from the following database have been applied to assess the frequency of occurrence of the identified events:

- OGP REPORT No. 434-1 for process equipment (Ref. [11]);
- OGP REPORT No. 434-3 for storage vessels (Ref. [12]);
- OGP REPORT No. 434-4 for pipeline/sealine (Ref.[13]);
- NFPA 59A ."Standard for the Production, Storage, and Handling of Liquefied Natural Gas (LNG), 2013

Relevant data have been reported in Table 3.4 to Table 3.7.

Table 3.4: Leak frequency for process piping (OGP Report No. 434-1)

HOLE DIAMETER RANGE (mm)	PIPING DIAMETER CLASSES		
	2" (50 mm)	6" (150 mm)	12" (300 mm)
	LEAK FREQUENCIES (ev./(m*y))		
1 to 3	5.50E-05	2.60E-05	2.30E-05
3 to 10	1.80E-05	8.50E-06	7.60E-06
10 to 50	7.00E-06	2.70E-06	2.40E-06
50 to 150	0.00E+00	6.00E-07	3.70E-07
>150	0.00E+00	0.00E+00	1.70E-07

Note: Frequency for piping of 2" has been conservatively considered also for piping of 4", whereas frequency for piping of 6" has been considered also for piping of 8"

Table 3.5: Leak frequency for flanges (OGP Report No. 434-1)

HOLE DIAMETER RANGE (mm)	FLANGE DIAMETER CLASSES		
	2" (50 mm)	6" (150 mm)	12" (300 mm)
	LEAK FREQUENCIES (ev./y)		
1 to 3	4.40E-05	6.50E-05	9.60E-05
3 to 10	1.80E-05	2.60E-05	3.90E-05
10 to 50	1.50E-05	1.10E-05	1.60E-05
50 to 150	0.00E+00	8.50E-06	3.20E-06
>150	0.00E+00	0.00E+00	7.00E-06

Note: In this QRA study all flanges are assumed as ring joints; therefore no modification factor has been used.

Table 3.6: Leak frequency for actuated valves (OGP Report No. 434-1)

HOLE DIAMETER RANGE (mm)	VALVE DIAMETER CLASSES		
	2" (50 mm)	6" (150 mm)	12" (300 mm)
	LEAK FREQUENCIES (ev./y)		
1 to 3	2.40E-04	2.20E-04	2.10E-04
3 to 10	7.30E-05	6.60E-05	6.30E-05
10 to 50	3.00E-05	1.90E-05	1.80E-05
50 to 150	0.00E+00	8.60E-06	2.40E-06
>150	0.00E+00	0.00E+00	6.00E-06

Table 3.7: Leak frequency for manual valves (OGP Report No. 434-1)

HOLE DIAMETER RANGE (mm)	VALVE DIAMETER CLASSES		
	2" (50 mm)	6" (150 mm)	12" (300 mm)
	LEAK FREQUENCIES (ev./y)		
1 to 3	2.00E-05	3.10E-05	4.30E-05
3 to 10	7.70E-06	1.20E-05	1.70E-05
10 to 50	4.90E-06	4.70E-06	6.50E-06
50 to 150	0.00E+00	2.40E-06	1.20E-06
>150	0.00E+00	0.00E+00	1.70E-06

Table 3.8: Leak frequency for Storage Vessels (OGP Report No. 434-3)

HOLE DIA RANGE (mm)	NOMINAL HOLE SIZE (mm)	STORAGE VESSEL LEAK FREQUENCY (ev./y)
1 to 3	2	2.30E-05
3 to 10	5	1.20E-05
10 to 50	25	7.10E-06
50 to 150	100	4.30E-06
>150	Catastrophic	4.70E-07

Table 3.9: Leak frequency for PIPELINE (OGP Report No. 434-4)

PIPELINE	CATEGORY	FAILURE FREQUENCY (km/year)
GAS Pipeline Onshore	wall thickness ≤ 5mm	4.00E-04
	5mm < wall thickness ≤10mm	1.70E-04
	10mm < wall thickness ≤15mm	8.10E-05
	wall thickness> 15mm	4.10E-05

Table 3.10: Leak frequency for Loading Arm (NFPA 59A Ref.[21])

DESCRIPTION	HOLE SIZE	FAILURE FREQUENCY (ev/year)
Transfer equipment — rupture of loading/unloading arm	Leak	3E-08

3.2.2 Ship Impact Frequency

In addition to sources of loss of containment identified for process equipment as described in previous paragraph, also LNG releases caused by external interference and third parties interactions have to be taken into account. Particularly, considering the design of the analyzed Plant (Jetty provided with permanently moored FSRU and LNGC approaching FSRU for LNG unloading), the following cases of external interference can be identified:

- ✓ Passing vessel drifting against FSRU;
- ✓ LNGC impact on passing vessel or grounding;
- ✓ LNGC loss of control during berthing.

Passing Vessel Drifting against FSRU

This event accounts for the possibility that a vessel sailing through Site Channel, due to a loss of control for any reason (e.g., steer failure, motor failure, Tug failure, etc.) in proximity of the LNG Terminal, change its planned route and impacts against the jetty or FSRU, resulting in damages of the structures and with consequent potential loss of containment.

Site Channel is currently not navigated; the traffic data of Main Channel are conservatively assumed as representative of future traffic in Site channel.

The series of conditions that are required in order to have this event are:

- Loss of control of the passing vessel (e.g., failure of the motor);
- Failure of one of the support Tugs;
- Impact of the drifting vessel against the LNG Terminal.

The frequency of impact of passing vessel against LNG Terminal has been evaluated in accordance to the following equation:

$$F_{passing} = N_{vessels} \cdot P_{LNGC,motor,1} \cdot P_{TUG,1} \cdot P_{impact,1}$$

Where:

- $F_{passing}$: frequency of impact of passing vessel against LNG Terminal;
- $N_{vessels}$: number of passing vessel along Main Channel (from and to Port Qasim) in 2015 (data provided by Port Qasim Authority), representative of future traffic in Site channel;
- $P_{LNGC,motor,1}$: probability of failure of passing vessel motor, derived by the MTTF of vessel motor provided in [17];
- $P_{TUG,1}$: probability of failure of Tug motor, derived by the MTTF of vessel motor provided in [17]; since the number of Tugs used to escort the vessels during the passage in the Site Channel depends on the size and typology of vessel itself, it has been conservatively assumed that the failure of one Tug will lead, in case of loss of LNGC motor, to the complete loss of control of the Carrier (this is conservative because in most of the cases the Tugs are more than one and the failure of one of them will not lead to the loss of control of the vessels, since others can work and control it);
- $P_{impact,1}$: probability that, in case of drifting vessel, the trajectory is the one that drives the vessel to impact against the Terminal (often called "geometric collision probability"). Merchant vessels will usually sail in dedicated lanes during passage from one destination to another. The location of the ships within these lanes is assumed to be distributed with a Gaussian Law (according to DNV-RP-F107). P_{impact} is therefore given by:

$$P_{impact} = \int_{d}^{d+D} \frac{1}{\sqrt{2\pi\sigma^2}} e^{-\frac{1}{2}\left(\frac{x}{\sigma}\right)^2} dx$$

Where:

- D is the Collision diameter equal to $W_a + B_{vessel}$, where W_a is apparent platform width and B_{vessel} is ship beam,
- σ is the standard deviation calculated to ensure that 99% of ship passages lays within 99% of channel width ($W_{channel}$). This workaround is made necessary by the fact that normal distribution is defined between ±∞; it is therefore mathematically impossible to impose 100% of vessel passages within 100% of channel width,
- d is the distance from centre of lane to the installation equal to $W_{channel}/2 - D$.

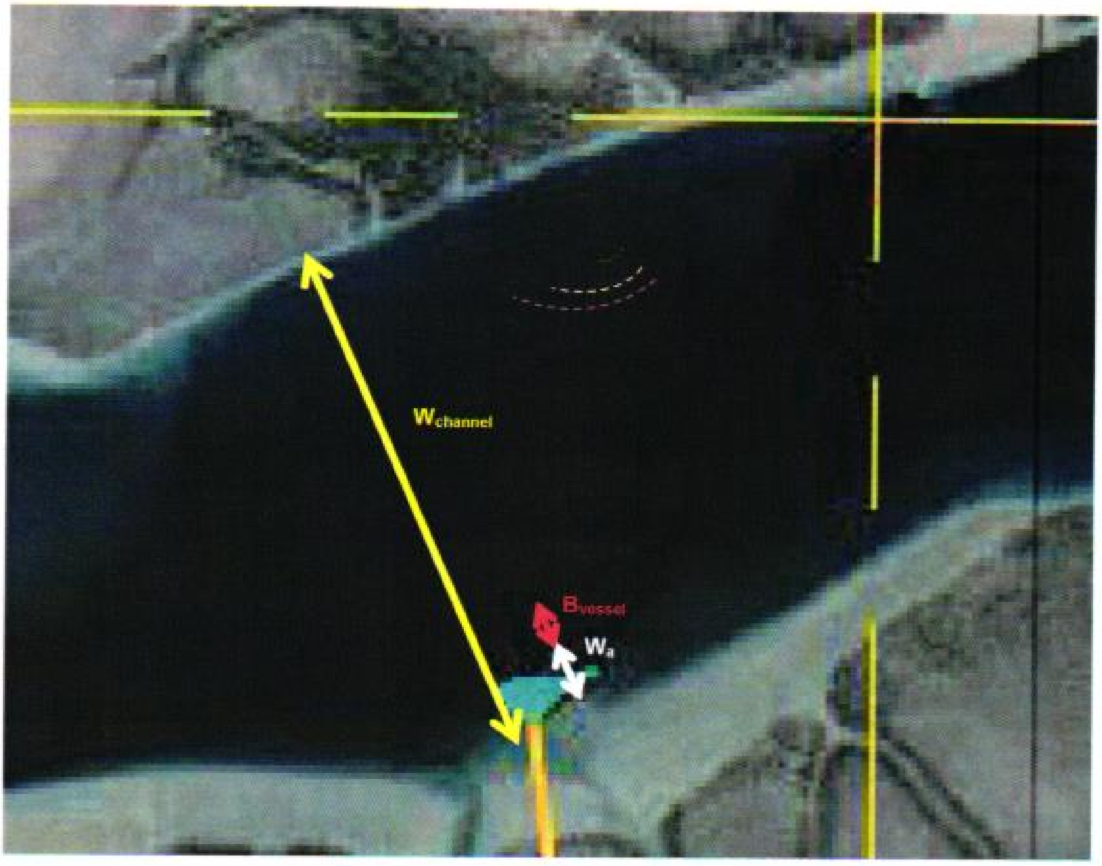


Figure 3.1: Length used for P_{impact} Calculation

LNGC Impact on Passing Vessel or Grounding

This event takes into account the loss of control of a LNGC sailing through the Site Channel (e.g., steer failure, motor failure, Tug failure, etc.) resulting in grounding or collision of the Carrier against other Terminals or installations.

Site Channel is currently not navigated; the traffic data of Main Channel are conservatively assumed as representative of future traffic in Site channel.

The series of conditions that are required in order to have this event are:

- Loss of control of the passing vessel (e.g., failure of the motor);
- Failure of two of the support Tugs;
- Damage of the Carrier in case of aground/collision.

The frequency of loss of control of LNGC resulting in grounding/collision is evaluated in accordance to the following equation:

$$F_{aground/collision} = N_{LNGC} \cdot P_{LNGC,motor,2} \cdot P_{TUG,2} \cdot P_{damage}$$

Where:

- $F_{aground/collision}$: frequency of grounding/collision;
- N_{LNGC}: number of LNGC along Main Channel (from and to Port Qasim) in 2015 (data provided by Port Qasim Authority), representative of future traffic in Site channel;
- $P_{LNGC,motor,2}$: probability of failure of LNGC motor, derived by the MTTF of vessel motor provided in [17];

- $P_{TUG,2}$: probability of failure of Tug motor, derived by the MTTF of vessel motor provided in [14], for this specific case (for more details see paragraph 6.2.2.1);
- P_{damage}: probability that, in case of grounding/collision, the Carrier is such damaged to have loss of LNG. According to "LNG Risk Based Safety – Modeling and Consequence Analysis" [15], from 1959 it has never been registered a serious accident to a LNGC either in port or in open sea resulting in spillage or loss of LNG. Considering this, the P_{damage} factor has been conservatively set equal to 0.1, meaning that the 10% of grounding/collision events will results in LNG spillage (while this is never happened in more than 50 years).

LNGC Loss of Control during Berthing

This event accounts for the loss of control of the LNGC during the berthing, resulting in collision with the Terminal and with associated potential spillage of LNG.

The series of conditions that are required in order to have this event are:

- Failure of both support Tugs;
- Impact against Terminal in case of Loss of Control.

The frequency of this event will be evaluated in accordance to the following equation:

$$F_{impact} = N_{LPGC} \cdot \left(P_{Tug,3}\right)^2 \cdot n_{combination} \cdot P_{impact,3}$$

Where:

- F_{impact}: frequency of impact of LNGC against Terminal;
- N_{LPGC}: number of LNGC along Main Channel (from and to Port Qasim) in 2015 (data provided by Port Qasim Authority), representative of future traffic in Site channel;
- $P_{Tug,3}$: probability of failure of Tug motor, derived by the MTTF of vessel motor (MTTF based on experience on similar study in the port Qasim area); this probability will be squared since in case of loss of one Tug the manoeuvre of the LPGC can be safely completed, it is assumed that two Tugs have to be unavailable in order to not be able to control the LNGC;
- $n_{combination}$: since it is assumed that the failure of 2 of the 4 Tugs can lead to the loss of control of the Carrier, the number of combination of failure of 2 of the 4 Tugs (equal to 6) has to be considered;
- $P_{impact,3}$: probability that, in case of loss of two escort Tugs during berthing manoeuvre, the LNGC will impact against the jetty; there are several operations that can be done in order to put the LPGC in a safe condition in order to avoid the impact against the FSRU. Therefore this factor has been put equal to 0.1.

Vessel Traffic Data

Based on experience on similar study in the port Qasim area and on information provided by Port Qasim Authority, the number of vessels considered for ship impact analysis is 2600 vessels/y. This number is referred to 2015 traffic data of the Main channel, and is conservatively considered representative of the future traffic in Site channel.

A total of 100 vessels/y is assumed for LNGC passages (that is, 2 vessels every week).

Failure of Vessel Motor

In order to evaluate the frequencies of the marine accidents identified the probability of failure of the motor of the vessels is needed (both passing vessels, LNGC or Tugs). A failure rate of about 1.45E-05 events per hour has been assumed for vessel motor [14].

In order to convert this failure rate to a probability of failure, the assumptions described here below have been applied.

The component of interest, the motor of the vessel, has been considered as "non-repairable" component, since it cannot be repaired during the time from its failure to the mooring of the ship. If the failure rate (λ) of the component is considered constant (common hypothesis), then the probability of failure ($F(t)$) of the component is calculated as:

$$F(t) = (1 - e^{-\lambda t})$$

where λ is the failure rate and t the operation time. Considering the product λt small enough, then the probability of failure will be evaluated as:

$$F(t) \approx \lambda t$$

Depending on the scenarios of marine incidents identified, a different time (t) has been considered, since the time interval during the maneuver when the failure of the motor is critical and can lead to the accident is specific of each scenario.

- **Passing vessel drifting against LNG Terminal**: the critical part of the route of the vessels in the Channel is the one close to the Terminal. The time required to complete this part of route is calculated considering the length of the route and the vessel speed. The length has been assumed about 1.25 NMi based on channel configuration. If the loss of control of the vessel occur in this length, then the impact against the Terminal is possible, while if the loss of control occurs in other part of the route, then the impact against the Terminal is not possible due to the conformation of the Channels and the positions of the Terminal. The speed of the vessel has been set equal to 6 knots, since the speed of the vessels in the Channels is between 10 knots and 6 knots, and the lower speed results in higher time and then higher failure probability;
- **LNGC loss of control resulting in collision**: For this case, the total length of the Site Channel from open sea to Terminal has been considered for a total of about 4 NMi (about 7.4 km). The speed of LNGC has been set equal to 6 knots, as above;
- **LNGC loss of control during berthing**: In this case it is not possible to evaluate the time considering a characteristic length and the speed, therefore based on general practice and engineering judgement, duration of berthing has been set equal to 2 h (maximum credible time).

3.2.3 Event Tree Analysis

Starting from the release frequency of occurrence evaluated as described in the previous paragraph, the frequency of each specific scenario (pool/jet fire, explosion and flash fire) has been calculated by Event Tree Analysis.

An Event Tree (ET) is a visual representation of all the events which can occur in a system during an escalating incident sequence. The starting point ("initiating event") is the undesired accidental event (in this case, the loss of containment of hazardous material). The "trees" display the sequences of events: each possible scenario is quantified on probabilistic basis.

Each branch of the event tree represents a separate accident sequence (that is a defined set of functional relationships between the initiating event and the subsequent events).

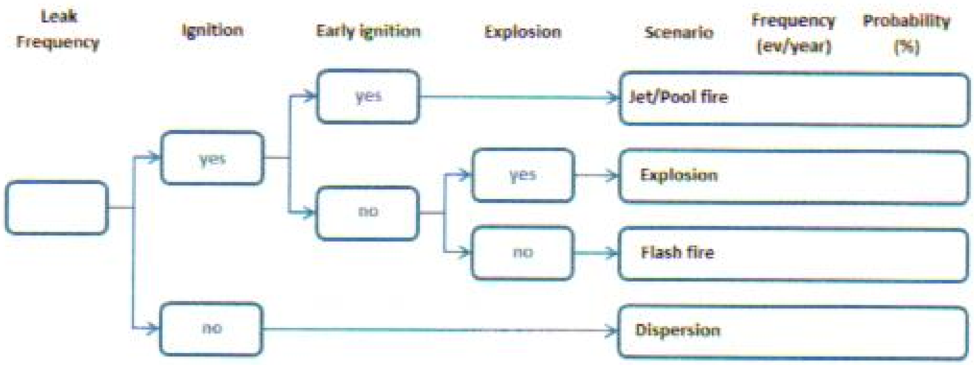


Figure 3.2: Event Tree: Example for LNG Release

Ignition probability has been calculated accordingly to the IP-UKOOA report (Ref.[16]) based on the following formula:

$$P_{ignition} = 10^{a \cdot M + b}$$

Where:

- $P_{ignition}$ is the total ignition probability;
- $\dot{M}$ is the mass release rate (kg/s);
- a and b are fitting coefficient of the experimental correlation.

For each event, the total ignition probability has been assessed according to the leak rate calculated in the consequence modelling.

In the following table the UKOOA Look-up correlations adopted for assessing the total ignition probability for the events studied in this QRA are shown.

Table 3.11: Look-up Correlation Adopted

Correlation No.	DESCRIPTION
5	Small Plant Gas LPG
9	Large Plant Liquid

In this QRA the 30:70 distribution between early and delayed ignitions has been adopted. Delayed ignition (i.e. one minute after the release) would result in a flash fire or explosion. For this analysis, explosion probability has been neglected (i.e. explosion conditional probability has been set equal to zero); no congested areas are to be observed in the jetty area or along pipeline routing (the assessment has been performed by reviewing aerial photography of the area of interest. More detailed assessment should be performed during later project stages). In absence of congested areas, combustion of premixed flammable cloud would lead to negligible overpressure values. Moreover, the focus of the analysis is the assessment of risk for people (both personnel and public); as a consequence, attributing the whole delayed ignition to the flash fire scenario and extending the probability of fatality down to LFL/2 concentration value will result in conservative assumption, since distances reached by LFL/2 concentration are generally greater than overpressure distances in presence of low confinement.

3.3 CONSEQUENCE MODELLING

The DNV PHAST 7.22 software has been used to analyse the consequences of accidental releases, from release rate calculations to final outcome damage distances; simulations have been based on the process data derived from the available Project documentation or on reasonable assumptions as detailed in the Assumption List issued prior to QRA.

The following accidental scenarios have been analysed:

- Jet Fire;
- Flash Fire;

In case of gaseous releases, the direction of the jet has been considered as horizontal.

Releases from buried pipeline sections have been modelled assuming an impinged release angle 45° from horizontal; the impingement causes a reduction in release speed to mimic the effect of the interaction between high velocity jet and the soil/water; the direction has been set to reflect the vertical behaviour of the released gas (in order to escape from the buried pipeline the gas shall assume a vertical velocity component).

Jet fire, pool fire and flash fire modelling has been performed directly linked to outflow modelling for the identified sources of releases, as enabled by PHAST software.

Since no congested areas have been identified along the pipeline routing, no explosion scenarios have been included in the analysis.

3.4 RISK ASSESSMENT

Based on the results of consequence and frequency analysis, the vulnerability of the personnel potentially exposed to the accidental scenarios has been calculated considering the physical accidental effects and the duration of the exposure.

Risk to personnel can be defined as the overall risk of death in a fixed time period to which a worker may be exposed taking into account all credible hazards and sources of releases.

The calculation of the risk to individuals has been performed on the basis of the following indexes:

- ✓ LSIR Location Specific Individual Risk;
- ✓ IRPA Individual Risk Per Annum.

3.4.1 Vulnerability and Domino Effect

This section describes the correlation of the physical effects to vulnerability (probability of fatality for people).

The IRPA - Individual Risk Per Annum - is the frequency of fatality for a certain individual or group; therefore, only fatalities are considered in the vulnerability assessment. Nevertheless, distance to each threshold level (3 kW/m^2 for slight health effect, 5 kW/m^2 for minor health effect, 7 kW/m^2 for major health effect, 12.5 kW/m^2 for single fatality and 37.5 kW/m^2 for multiple fatalities, considering a 30 s exposure time) are reported in the analysis, for completeness.

3.4.2 Thermal Radiation

In order to correlate exposure to thermal radiation to vulnerability, a Probit function is used. The Probit is a statistic method (namely the inverse cumulative distribution function associated with the standard normal distribution) widely used for regression modelling of binary response variables. In risk assessment, it is applied to transform the percentage of people affected by a selected binary outcome (in this analysis fatality/no fatality) into "probability unit" linearly dependent upon the logarithm of the absorbed dose.

Coefficients reported by TNO Green Book (Ref. [23]) are used, assuming an exposure time of 30 s (time required for people to escape from damage area in case of accident):

$$Pr = -36.38 + 2.56 \ln\left(q^{4/3}t\right)$$

where:

- Pr Probit;
- q Heat radiation [W/m^2]
- t Exposure time [s]

A graphical representation of the vulnerability to thermal radiation, defined by applying the above Probit Equation, is provided in Figure 3.3.

The beginning of the vulnerability for people is set at about 7 kW/m^2, according also to the single fatality damage threshold generally used in risk assessment; the multiple fatality threshold (12.5 kW/m^2), on the other hand, roughly corresponds to the 50% vulnerability value.

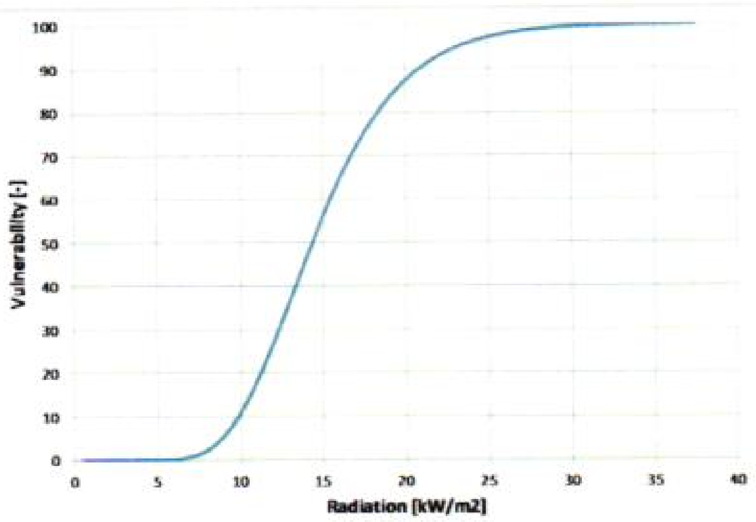


Figure 3.3: Vulnerability vs Heat Radiation

3.4.3 Overpressure

For exposure to overpressures resulting from explosions, vulnerability for people has been set at 100% for overpressure greater than 0.3 bar, and 0% for overpressure smaller than 0.07 bar (Figure 3.4).

The 0.07 bar value is usually associated to the major/permanent injuries threshold; in this QRA it has been conservatively associated to vulnerability higher than 0 in order to account for the effect of projectiles caused by the blast wave propagation, that could pose a threat for human safety. Analogously, 0.14 bar has been associated to the 50% vulnerability and 0.30 bar to the 100% vulnerability level.

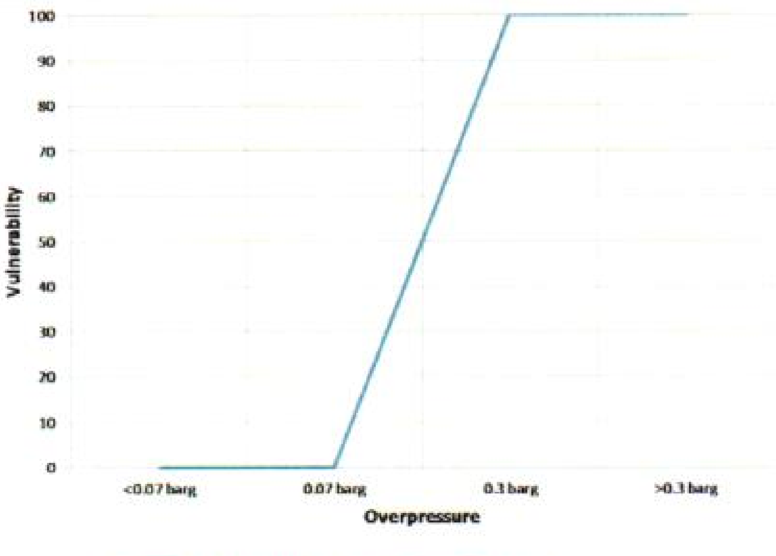


Figure 3.4: Vulnerability vs Overpressure

3.4.4 Flammable Gas Dispersion

In case of late ignition of flammable gas masses in open air, the vulnerability of anyone within the area of the flash fire has been assumed as 100% within LFL concentration limits and 0% outside LFL/2 concentration limits, varying linearly between these values for intermediate concentration values (Figure 3.5).

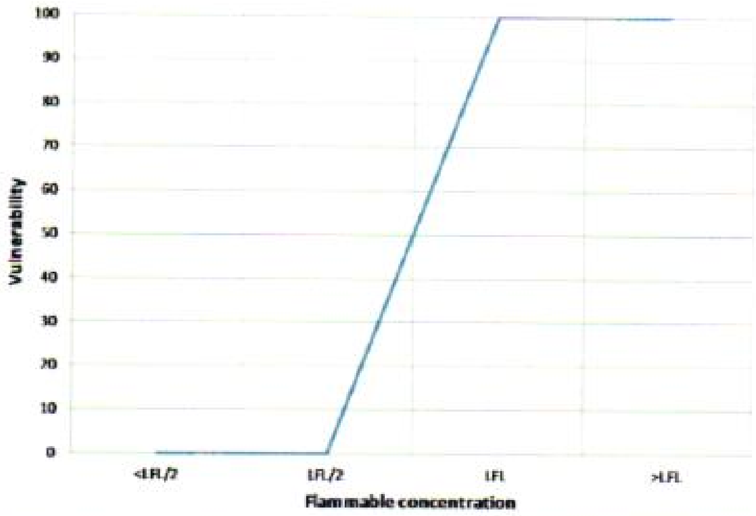


Figure 3.5: Vulnerability vs Flammable Concentration

3.4.5 Individual Risk Calculation

Individual risk is the frequency at which an individual may be expected to sustain a pre-fixed level of harm from the deployment of specified hazards.

The level of harm for people is conventionally assumed the risk of death, and usually expressed as the frequency associated to fatality events per year.

The frequencies and the impacts of all the accidental scenarios have been taken into account in the calculation of the overall, aggregated, risk.

Location-specific individual risk (LSIR) identifies the risk calculated in a particular location, assuming the permanent presence (24 hours per day, 365 days per year) of a hypothetical individual.

The LSIR will be represented by risk contour plots displayed on layout.

LSIR takes into account:

- Frequency of the release events;
- Likelihood of specific conditions determining the outcomes (including e.g. ignition probability, weather conditions, wind direction probabilities, etc.);
- Vulnerability (i.e. the fatality probability related to physical effects such as heat radiation, overpressure);
- The LSIR at a given location X is then calculated as follows:

$$LSIR(X) = \sum_{l} \lambda_l * \sum_{s} P_{scen_{s,l}} * \sum_{w} (P_{wind} * V(X))_{l,s,w}$$

Where:

λ_l	Release Frequency (sum over release events, index l)
$P_{scen_{s,l}}$	Scenario Probability, given the release (sum over outcome scenarios, index s)
P_{wind}	Wind Direction Probability (sum over wind directions, index w)
V	Vulnerability

Individual Risk per Annum (IRPA) is generally defined as the risk of fatality to a named individual, belonging to a working category present in the installation, or a generic member of the public off-site. Practically, IRPA values will be calculated from the corresponding LSIR values (outdoor or indoor) by including the 'presence probability' factor.

As detailed in the Assumption List (Ref. [19]), probability of presence in continuously manned areas of the plant, i.e. loading gantries, control building and jetty will be based on an average work shift of 8 hours per 200 working days per year, whereas a generic probability of presence of 5% has been assumed for not continuously manned plant areas.

Table 3.12: IR Acceptability Criteria (workers)

Level of IR	Risk Criteria
Broadly acceptable region	Risk < 1.00E-06 ev/y
ALARP Region	1.00E-06 ≤ Risk < 1.00E-03 ev/y
Unacceptable region	Risk ≥ 1.00E-03 ev/y

Table 3.13: IR Acceptability Criteria (public)

Level of IR	Risk Criteria
Broadly acceptable region	Risk < 1.00E-06 ev/y
ALARP Region	1.00E-06 ≤ Risk < 1.00E-04 ev/y
Unacceptable region	Risk ≥ 1.00E-04 ev/y

For the purposes of the present QRA, reference is made to the Individual risk criteria given in Table 3.13.

4 INPUT DATA AND ASSUMPTIONS

Input data and assumptions considered for this QRA are according to issued Assumption List (Ref. [19]) which has been attached in Appendix 1. For convenience, main site meteorological data considered for the study are also reported in the following section 4.1.

4.1 SITE DATA

Site conditions considered for modeling have been extracted from Ref. [24] and are here after summarized; site wind rose is shown in Figure 4.1.

- ✓ Location: Karachi, Pakistan;
- ✓ average monthly mean temperature over 2001-2009 period = 28.5°C;
- ✓ average humidity = 64 %;
- ✓ average mean seawater temperature = 26°C.

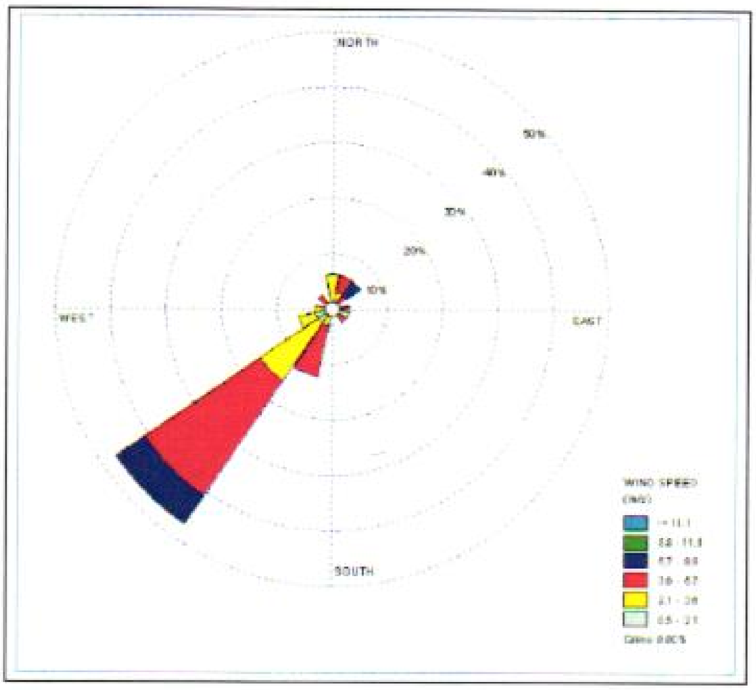


Figure 4.1: Karachi Airport Wind Rose

According to Ref. [24], the following weather classes, representative of wind speed and Pasquill Class combinations, have been considered for consequence modeling: ***2F*** and ***5D***; the respective occurrence probabilities are 25% and 75%.

5 RESULTS

5.1 IDENTIFICATION OF CREDIBLE HAZARDS

The Project has been subdivided into fourteen Isolatable Sections according to PFDs, P&IDs, operative conditions and plant layout, taking into account ESDVs/SDVs, equipment and manual valves capable to isolate the section in case of shutdown, as detailed in the methodology section of this report and in the Assumption List.

The complete list of isolatable sections identified, along with related operating conditions considered for modelling, is reported in the following Table 5.1.

Table 5.1: Identified Isolatable Sections

ID	Section Name	Operating Conditions		
		Phase	P (barg)	T (°C)
1	Unloading Arms	Gas	98	11
2	Line to platform BL	Gas	98	11
3	Sealine/Pipeline	Gas	98	11
4	Metering Station and Analyzer House package	Gas	82.7	11

5.2 FREQUENCY ASSESSMENT

Frequency of loss of containment scenarios has been calculated based on the statistical data reported in the OGP Risk Assessment Data Directory (Ref). A set of 4 representative release diameters has been considered:

- Very small leak (3 to 10 mm);
- Small leak (10 to 50 mm);
- Leak (50 to 150 mm);
- Large leak (>150 mm).

The leak frequency of each identified Isolatable Section has been assessed considering pipe lengths within each section and applying the "parts count" approach for flanges, valves and equipment.

The number and typology of equipment have been assessed from P&IDs (Refs. [1] to [8]), while the piping length evaluating the distance between the connected equipment on plot plan.

Calculated loss of containment frequencies are summarized in the following Table 5.2. For each section, release frequencies for each selected hole class have been reported.

Table 5.2: Calculated Release Frequencies

ID	Section Name	Release Frequencies (ev./y)			
		10 mm	50 mm	150 mm	>150 mm
1	Unloading Arms	0.00E+00	0.00E+00	0.00E+00	6.00E-08
2	Line to platform BL	9.61E-03	3.2E-04	3.32E-05	3.32E-05
3	Sealine/Pipeline	2.09E-04	2.09E-04	1.42E-04	2.45E-04
4	Metering Station and Analyzer House package	6.63E-04	2.11E-04	3.00E-05	2.94E-05

Ship impact analysis results are summarized in the following tables: Table 5.3 reports expected vessel motor failure during considered potential impact scenarios and Table 5.4 reports calculated impact scenario frequencies based on methodology outlined in section 3.2.2.

The number of passing vessels in the Chann Waddo, due to the presence of TEPL and Terminal X terminals has been evaluated according to four different cases, considering the possible paths for LNGC and other shipments in the channel and the annual increase of 6% of other ships in the channel:

	LNGC(for FSRU in Chhan Waddo)		LNGC(for FSRU in Main Channel)		Other Shipments	
	Entry	Exit	Entry	Exit	Entry	Exit
Case 1	Chhan Waddo	Chhan Waddo	Phitti Creek	Phitti Creek	Phitti Creek	Phitti Creek
Case 2	Chhan Waddo	Chhan Waddo	Phitti Creek	Chhan Waddo	Phitti Creek	Phitti Creek
Case 3	Chhan Waddo	Chhan Waddo	Phitti Creek	Phitti Creek	Phitti Creek	Chhan Waddo
Case 4	Chhan Waddo	Chhan Waddo	Phitti Creek	Chhan Waddo	Phitti Creek	Chhan Waddo

Results for the considered cases are reported in the table below.

	2020-21	2021-22	2022-23	2023-24	2024-25
Case 1	0	162	162	162	162
Case 2	0	369	369	369	369
Case 3	0	2,384	2,570	2,763	2,964
Case 4	0	2,591	2,777	2,970	3,171

In the worst case scenario the total number of ships passing through the channel is 3171 ships per year.

In the calculation however has been conservatively considered a number of passing vessel of 5200 vessels per year, equal to the full number of vessel passing into the Chann Waddo channel in 2015, and completely deviated into the Site Channel.

Results are reported in Table 5.3 and 5.4.

Table 5.3: Times and Failure Probability Values of Motor

Failure Scenario	Operation Time (min)	Probability of Failure
Failure of motor of passing vessel	12.5	3.02E-06
Failure of motor of LNGC and Tug during navigation	40	9.67E-06
Failure of motor of LNGC or Tug during berthing	120	2.90E-05

Table 5.4: Calculated Impact Scenario Frequencies

Impact Scenario	Frequency of Occurrence (ev/y)
Failure of motor of passing vessel	1.72E-09
Failure of motor of LPGC or Tug in proximity of Terminal	9.34E-10
Failure of motor of LPGC or Tug during berthing	5.05E-08

The frequencies calculated for Marine Accidents and releases from unloading arms are several orders of magnitude lower with respect to Process Release frequencies. In light of this, these events will not be taken into consideration as credible events during the consequences modeling.

Results of Event Tree Analysis (ETA) in terms of outcomes frequencies are reported in the following Table 5.5; the complete set of event trees is attached in Appendix 2.

Table 5.5: Calculated Outcome Frequencies

ID	Section Name	Hole Size (mm)	Scenario Frequencies (ev./y)			
			Jet Fire	Explosion	Flash Fire	Dispersion
2	Line to platform BL	10	6.21E-07	0.00E+00	1.45E-06	9.59E-04
		50	4.90E-06	0.00E+00	1.14E-05	3.04E-04
		150	2.62E-06	0.00E+00	6.11E-06	2.45E-05
		>150	4.13E-06	0.00E+00	9.64E-06	1.94E-05
3	Sealine/Pipeline	10	1.35E-07	0.00E+00	3.14E-07	2.08E-04
		50	3.19E-06	0.00E+00	7.44E-06	1.98E-04
		150	1.12E-05	0.00E+00	2.61E-05	1.05E-04
		>150	3.05E-05	0.00E+00	7.12E-05	1.43E-04
4	Metering Station and Analyzer House package	10	4.01E-07	0.00E+00	9.35E-07	6.62E-04
		50	2.81E-06	0.00E+00	6.57E-06	2.02E-04
		150	2.06E-06	0.00E+00	4.81E-06	2.31E-05
		>150	3.19E-06	0.00E+00	7.44E-06	1.88E-05

5.3 HAZARDOUS SCENARIOS CONSEQUENCES

The Complete set of modeled hazardous scenarios consequences is reported in the following sub-sections; the related consequence plots obtained by means of DNV PHAST 7.22 software are attached in Appendix 3.

5.3.1 Release Flow Rates

Release flow rates calculated by means of DNV PHAST 7.22 software are reported in the following Table 5.6.

According to the approach defined in the methodology and in the assumption list, sections downstream pumps and fed by pumps have limited outflow rates accounting from maximum pump output.

Table 5.6: Calculated Release Rates

ID	Section Name	Release rate (kg/s)			
		10 mm	50 mm	150 mm	>150 mm
2	Line to platform BL	0.7	17.4	162	302
3	Sealine/Pipeline	0.7	17.4	162	302
4	Metering Station and Analyzer House package	0.5	14.4	134	250

5.3.2 Fire Scenarios

5.3.2.1 Jet Fire Consequences

Modeled jet fire scenarios distances to threshold levels are reported in the following table for each isolatable section.

The listed distances mark the effect radius of the jet fire radiation threshold values from the release point: e.g. considering the 12.5 kW/m^2 threshold, which marks the onset of lethality for exposed personnel and of severe damage to atmospheric equipment, the distance reported represent the effect area from the release point over which such consequences are expected to occur.

Table 5.7: Calculated Distances at Threshold Level – Jet Fire

ID	Section Name	Hole Size (mm)	Weather Class	Distances to Fire Radiation (meters)				
				3 kW/m²	5 kW/m²	7 kW/m²	12.5 kW/m²	37.5 kW/m²
2	Line to platform BL	10	2F	14	13	12	11	7
			5D	14	13	12	11	9
		50	2F	80	70	65	57	43
			5D	79	70	66	59	48
		150	2F	232	197	178	151	112
			5D	227	195	178	154	118
		>150	2F	310	262	236	198	147
			5D	304	260	236	203	154
3	Sealine/ Pipeline	10	2F	15	12	10	N/A	N/A
			5D	15	12	10	8	N/A
		50	2F	70	57	50	34	N/A
			5D	69	56	48	39	N/A
		150	2F	200	162	143	107	N/A
			5D	194	157	135	109	N/A
		>150	2F	268	216	191	145	N/A
			5D	259	209	180	145	50
4	Metering Station and Analyzer House package	10	2F	13	12	11	10	N/A
			5D	12	12	11	10	N/A
		50	2F	73	64	59	52	40
			5D	72	64	60	54	44
		150	2F	212	181	163	139	103
			5D	207	179	164	142	110
		>150	2F	284	240	216	182	136
			5D	278	239	217	186	142

5.3.3 Flammable Gas Dispersion

Results of flammable gas dispersion modeling performed by means of DNV PHAST 7.22 are reported in the following Table 5.8 in terms of distances to LFL and LFL/2 concentrations, representative of potentially ignitable clouds which can result in flash fires or explosion in case a congested area is reached.

Results conservatively report maximum damage distances reached up to 10 m above ground, in order to account for personnel and ignition sources presence at height (i.e. on elevated structures, buildings, vessels or due to topography).

Table 5.8: Flammable Gas Dispersion Results

ID	Section Name	Hole Size (mm)	Weather Class	Distance to Dangerous Concentration (m)	
				LFL	LFL/2
2	Line to platform BL	10	2F	N/A	12
			5D	N/A	9
		50	2F	42	100
			5D	40	104

ID	Section Name	Hole Size (mm)	Weather Class	Distance to Dangerous Concentration (m)	
				LFL	LFL/2
		150	2F	156	359
			5D	161	392
		>150	2F	219	499
			5D	227	545
3	Sealine/ Pipeline	10	2F	N/A	2
			5D	N/A	12
		50	2F	42	100
			5D	40	104
		150	2F	156	359
			5D	161	392
		>150	2F	219	499
			5D	227	545
4	Metering Station and Analyzer House package	10	2F	N/A	10
			5D	N/A	N/A
		50	2F	37	88
			5D	35	90
		150	2F	138	304
			5D	142	328
		>150	2F	195	412
			5D	201	442

5.4 RISK ASSESSMENT

5.4.1 LSIR

The LSIR contours for LNG Terminal is shown in the following Figure 5.1.

In the figure the contours are as follows:

- ✓ blue contour represents a LSIR value equal to 1.00E-07 ev/y;
- ✓ green contour represents a LSIR value equal to 1.00E-06 ev/y;
- ✓ yellow contour represents a LSIR value equal to 1.00E-05 ev/y.

Figure 5.1: LSIR Contours for LNG Terminal

LSIR in the Jetty and ORF area is higher 1.00E-05ev/y, but it never reaches 1.00E-04ev/y. Areas surrounding the Jetty may be interested by a LSIR lower than 1.00E-05 ev/y; even considering a probability of presence equal to 1 for third parties and public, this risk level falls in the ALARP or broadly tolerable region.

Along the pipeline, calculated risk is always lower than 1.00E-06 ev/y, thus meaning that a broadly tolerable risk level is achieved.

The position of the LNG Terminal has been also evaluated considering both the HSE UK and the NFPA 59A criteria. Regarding the NFPA 59A, the most restrictive LSIR value proposed (i.e. 1.00E-05 ev/y) has been considered, resulting in a minimum safety distance of 250 m. Regarding the HSE UK standard the threshold of 1.00E-04 ev/y is never reached. The distance from Terminal X location is about 2 km from Mitsubishi terminal, far away from Jetty, resulting in risk area lower than 1.00E-07 ev/y, thus being in broadly acceptable risk area.

5.4.2 Individual Risk

Based on the results of consequences and frequency analysis, the vulnerability of the personnel exposed to the potential accidents is calculated considering the physical accidental effects and the duration of the exposure.

The risk results, in terms of IRPA level assuming a probability of presence equal to 1, are provided in the following Table.

Table 5.9: IRPA Results

Operators	IRPA [ev/y]
Workers on FSRU, LNGC, Jetty	1.00E-05
Workers in ORF	1.00E-05

The IRPA values obtained are in the lower bound of the ALARP region (1.00E-06 ev/y < IRPA < 1.00E-03 ev/y) of the adopted criterion (Table 3.12).

6 SENSITIVITY ANALYSIS

In this chapter has been evaluated the impact of the simultaneous presence of the terminal and the Terminal X. Terminal X process and design data are not available for this analysis. The terminal however is an LNG Terminal that can be reasonably assumed to be similar to the Terminal object of this study; the risk contours of the Terminal X have therefore been assumed to be the same calculated for Mitsubishi Terminal, shifted on the location of the Terminal X and pipelines.

The LSIR contours for LNG Terminal and Terminal X are shown in the following Figure

In the figure the contours are as follows:

- blue contour represents a LSIR value equal to 1.00E-07 ev/y;
- green contour represents a LSIR value equal to 1.00E-06 ev/y;
- yellow contour represents a LSIR value equal to 1.00E-05 ev/y.

In red is reported the position of Terminal X.

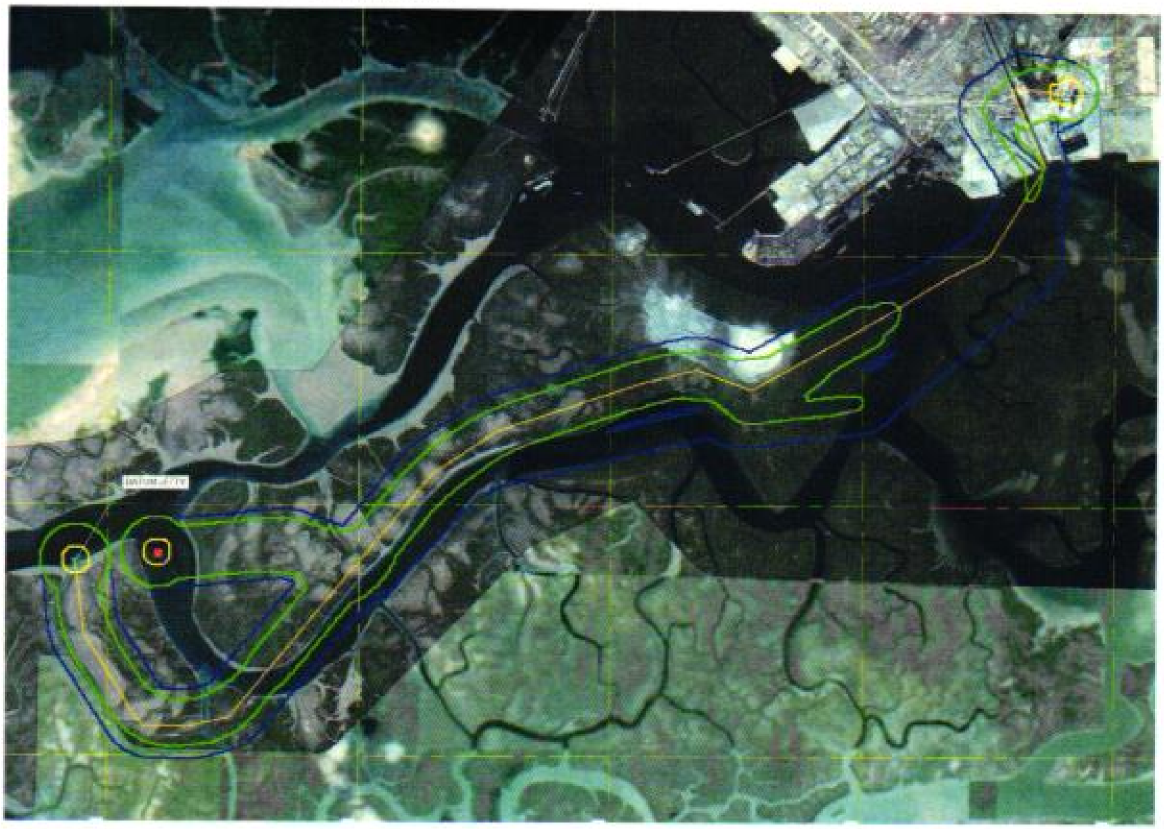


Figure 6.1: LSIR Contours for LNG Terminal and Terminal X Terminal and Pipelines

The values of risk resulting in Figure 6.1 is the sum of the risk related to the Pipeline of LNG terminal and Terminal X Terminal.

Also considering the simultaneous presence of the two terminals and pipelines, the maximum value reached is 1.00E-05 ev/y. Risk is in the broadly acceptable risk area, and no further recommendations or improvements are required.

7 CONCLUSIONS

The report summarizes the main assumptions, methodological steps and results of the Quantitative Risk Assessment conducted for the LNG terminal and the pipeline connection to ORF in the framework of the Project proposed by JGC Corporation.

The analysis has been focused for the risk to operators and public due to the hazards relevant to the new installations and the maritime traffic in the channel.

The following steps have been applied:

- ✓ Identification of risk;
- ✓ Calculation of frequencies and consequences;
- ✓ Risk assessment and evaluation.

In the QRA the Risk assessment has been performed by means of the following risk indexes:

- ✓ LSIR;
- ✓ IRPA.

Maximum LSIR along the pipeline has been assessed in the range of 1E-07 ev/y, thus falling in the continuous improvement area. No further barriers or mitigation measures are therefore envisaged to reduce the risk.
Maximum LSIR in the Terminal and ORF area has been assessed in the range of 1E-05 ev/y, with 1E-06 ev/y extending for less than 500 m from the loading arms.

The position of the LNG Terminal has been evaluated considering both the HSE UK and the NFPA 59A criteria. Regarding the NFPA 59A, the most restrictive LSIR value proposed (i.e. 1.00E-05 ev/y) has been considered, resulting in a minimum safety distance of 250 m. Regarding the HSE UK standard, the threshold of 1.00E-04 ev/y is never reached.

The distance from Terminal X location is 1250 m from jetty being in risk area lower than 1.00E-07 ev/y, thus being in broadly acceptable risk area.

In terms of IRPA level assuming a probability of presence equal to 1, values obtained are in the order of 1.00E-05, in the lower bound of the ALARP region (1.00E-06 ev/y < IRPA < 1.00E-03 ev/y) of the adopted criterion.
As additional mitigation measure, the installation of a Fire and Gas detection system is advised, in order to provide audible and visual warnings in case of loss of containment. Automatic actuations in case of fire of gas detection should be evaluated in future project phases. The set-up of an exclusion zone of approximatively 500 m from the jetty could be taken in consideration, if technically and economically feasible.

No further recommendations or improvements are required.

Also considering the simultaneous presence of LNG terminal and Terminal X, the risk is in broadly acceptable risk area, and no further recommendations or improvements are required.

MICDR/MAP/GMU:sl

F968

REFERENCES

[1] PIANC Report no.116 – 2012 "Safety aspects affecting the berthing operations of tankers to oil and gas terminals

[2] SIGTTO LNG Operations in Port Areas

[3] D-100-1225-001 PIPING AND INSTRUMENTATION DIAGRAM (P&ID) FOR NG UNLOADING ARM

[4] D-100-1225-002 PIPING AND INSTRUMENTATION DIAGRAM (P&ID) FOR OFFSHORE TO PIPELINE

[5] D-200-1225-001 PIPING AND INSTRUMENTATION DIAGRAM (P&ID) FOR PIPELINE TO ONSHORE

[6] D-200-1225-002 PIPING AND INSTRUMENTATION DIAGRAM (P&ID) FOR METERING STATION

[7] D-200-1225-003 PIPING AND INSTRUMENTATION DIAGRAM (P&ID) FOR GAS SENDOUT LINE

[8] PRELIMINARY PROCESS FLOW DIAGRAM (PFD) – OFFSHORE PLATFORM / ORF

[9] PROPOSED PIPE LAYOUT

[10] JETTY MODEL

[11] OGP REPORT No. 434-1 PROCESS RELEASE FREQUENCIES. March 2010

[12] OGP REPORT No. 434-3 STORAGE INCIDENT FREQUENCIES. March 2010

[13] OGP REPORT No. 434-4 RISER & PIPELINE RELEASE FREQUENCIES. March 2010

[14] OGP REPORT No. 434-7 CONSEQUENCE MODELLING. March 2010

[15] HSE UK – FAILURE RATE AND EVENT DATA FOR USE WITHIN RISK ASSESSMENT (28/06/2012)

[16] PIPELINE AND RISER LOSS OF CONTAINMENT 2001 (PARLOC)

[17] Det Norke Veritas, DNV-RP-F107, 2001, "Risk Assessment of Pipeline Protection".

[18] IP-UKOOA IP RESEARCH REPORT - IGNITION PROBABILITY REVIEW. MODEL DEVELOPMENT AND LOOK-UP CORRELATIONS. January 2006

[19] Doc. No. P0009270-1-H1– QRA ASSUMPTION LIST Rev.0 July 2018

[20] TNO - Guidelines for Quantitative Risk Assessment (Green Book). 1992

[21] NFPA 59A, 2013, Standard for the Production, Storage and Handling of Liquefied Natural Gas (LNG).

[22] GAME: Development of Guidance for the Application of the Multi-energy method. Final Report of TNO/PML to Snamprogetti. 1995

[23] Methods for the determination of possible damage to people and objects resulting from release of hazardous materials. TNO CPR 16E "Green Book". 1989

[24] EIA - Final Report PIBT

[25] API 2510: Design and Construction of LPG Installations. American Petroleum Institute. 2001

[26] API 2510A: Fire-Protection Considerations for the Design and Operation of Liquefied Petroleum Gas (LPG) Storage Facilities. American Petroleum Institute. 1996

[27] S-000-1250 REPORT FOR HAZARD IDENTIFICATION WORKSHOP Rev. 0, May 2018

APPENDIX A

570

Appendix A

Assumption List

Doc. No. P0009270-1-H2 Rev. 4 – November 2018

RINA

674

JGC Corporation
Karachi, Pakistan

QRA and Navigation Simulations for LNG terminal at Port Qasim

Assumptions Sheet

Doc. No. P0009270-1-H1 Rev. 1 – July 2018

Rev.	1
Description	Issued after JGC comments and videoconference held on 09/07/2018
Prepared by	A. Rossi / I. Mazza / M. Pontiggia
Controlled by	S. Cappellozza
Approved by	C. Mordini
Date	13/07/2018

5972

QRA and Navigation Simulations for LNG terminal at Port Qasim

Assumptions Sheet

Rev.	Description	Prepared by	Controlled by	Approved by	Date
0	First Issue	Andrea Rossi, Ilaria Mazza, Marco Pontiggia	Stefano Cappellozza	Claudio Mordini	06/07/2018
1	Issued after JGC comments and videoconference held on 09/07/2018	Andrea Rossi, Ilaria Mazza, Marco Pontiggia	Stefano Cappellozza	Claudio Mordini	13/07/2018

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

ABBREVIATIONS AND ACRONYMS

AIS	Automatic Identification System
ARPA	Automatic Radar Plotting Aid
ASD	Azimuth Stern Drive Tug
CLIENT	JGC Corporation
ECDIS	Electronic Chart Display and Information System
FSRU	Floating Storage Regasification Unit
HAZID	Hazard Identification Study
HAZOP	Hazard and Operability Study
HIPPS	High Integrity Pressure Protection System
HSE	Health Safety Environment
IRPA	
LNG	Liquefied Natural Gas
LNGC	LNG Carrier
LPG	Liquefied Petroleum Gas
LSIR	Location Specific Individual Risk
MAH	Major Accident Hazards
N	North
NE	North East
NG	Natural Gas
ORF	Onshore Receiving Facilities
PFD	Process Flow Diagram
PQA	Port Qasim Authority
QRA	Quantitative Risk Analysis
RADAR	Radio Detection and Ranging
R&D	Research and Development
SW	South West
S	South
TBD	To be discussed
UK	United Kingdom

1 PROJECT DESCRIPTION

According to the available information, Diamond Gas International intends to develop a FSRU based LNG import terminal at Port Qasim. The terminal will receive, re-gasify and transport re-gasified LNG (i.e. natural gas) via pipeline to a delivery point onshore.

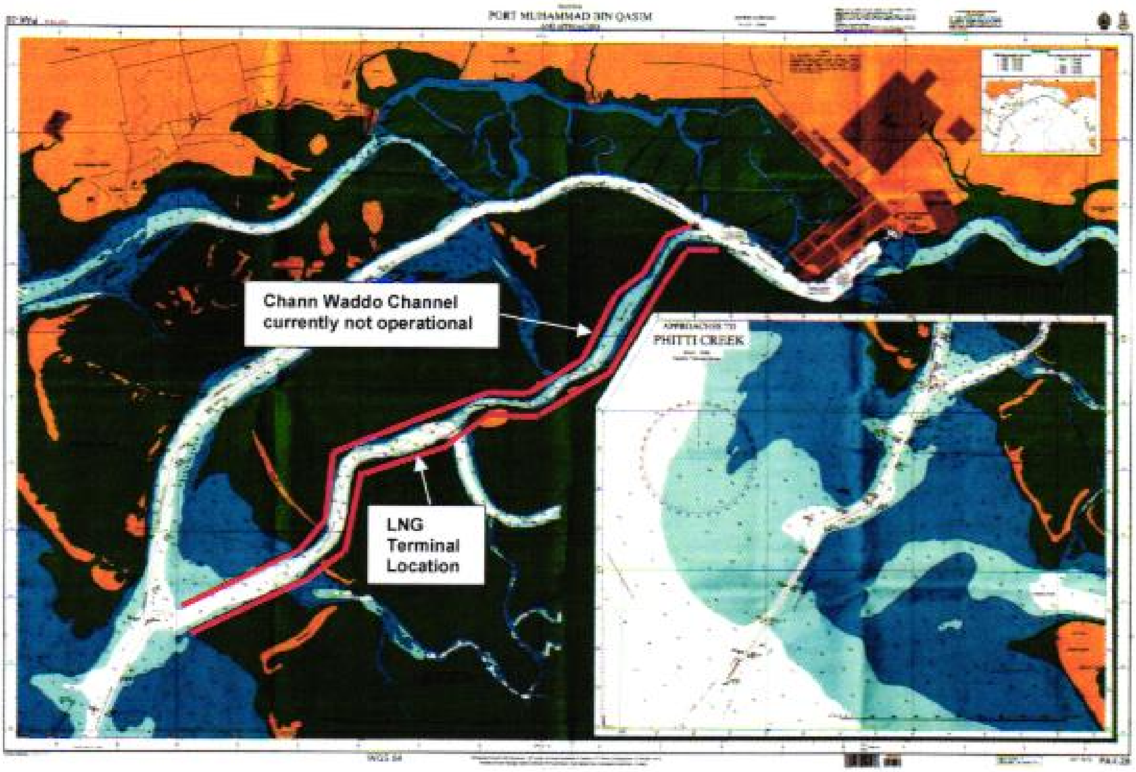


Figure 1.1: Port Qasim LNG Terminal Site

The LNG import terminal will be located at Port Qasim, in Chann Waddo Channel that currently is not in operation. Presently, the LNG carrier traffic is fully managed through the Main Channel for both entrance and exit manoeuvers due to the fact that it is the only one in operation.

2 SCOPE OF THE DOCUMENT

The scope of the present document is to represent the all the necessary inputs, assumptions and data that will be used for the development of the present project.

In the subsequent sections of this document the followings are described:

- ✓ Quantative Risk Analysis (QRA):
  - Main Assumptions and Methodologies;
- ✓ Navigation Study
  - Review of applicable industry standards and practice;
  - Methodology
  - Simulation tool;
  - Metocean data;
  - Analysis assumptions;
  - Preliminary runs table

This document has been updated in accordance with the main assumptions shared and agreed with the Client during the videoconference held on 9th July 2018 (Ref.[13]).

3 QUANTITATIVE RISK ANALYSIS

3.1 MAIN ASSUMPTIONS AND METODOLOGY

The QRA will be developed through the following steps:

- ✓ Hazards Identification;
- ✓ Frequency Assessment;
- ✓ Consequences Assessment;
- ✓ Risk Assessment.

In the following, for each step of QRA a brief description, together with the list of assumptions applied for the step are detailed.

3.1.1 Hazard Identification

Potential hazards sources and related Major Accident Hazards (MAH) will be identified by means of results of HAZID analysis performed for the LNG Terminal. Particularly, potential hazards sources will be identified between the following categories:

- ✓ NG release from process equipment (battery limits are considered the loading arms and HIPPS at ORF, both included);
- ✓ LNG/NG release from LNG Carriers (due to ship collision, wrong manoeuvers);
- ✓ LNG/NG release from Jetty due to ship collision;
- ✓ Others.

3.1.2 Frequency Assessment

Evaluation of frequency of occurrence of LNG release events identified during step 1 will be performed by means of Ref.[1] for the calculation of release frequencies from process equipment. Typical release diameters will be adopted (e.g., 5, 25, 100 and 250 mm);

Ship traffic data along the channels and DNV-RP-F107 (Ref.[2]), together with the results of Manoeuvring Study, will be combined and used in order to evaluate frequency of occurrence of potential accident as ship-ship, ship-jetty collisions, ship-sea bottom collisions.

Since marine traffic data from PQA are currently not available, RINA will consider traffic data of the Main Channel even if it is a very conservative since actually Chann Waddo Channel is not operational.

Once release frequencies are calculated, final scenarios frequencies (e.g., Jet/Pool Fire, Flash Fire and Explosion) will be calculated by means of Event Tree Analysis. The ignition probabilities will be evaluated according to IP-UKOOA Report (Ref.[3]) as detailed in the following:

Ignition probability will be calculated considering the correlation provided by IP-UKOOA. Particularly, for LNG Systems the dedicated correlations "Small Plant Gas LPG", "Large Plant Gas LPG" and "Large Plant Confined Gas LNG" are provided. In addition to these correlations (applicable for gas releases), for liquid releases the correlation "Large Plant Liquid" will be applied, if required.

The share ratio between Early and Delayed Ignition of 30:70 will be applied, as suggested by IP-UKOOA.

Explosion will be considered possible only in case of flammable cloud with an associated flammable mass higher than 100 kg reaching a congested area. If explosion is possible, a share of 50:50 will be adopted between Flash Fire and Explosion.

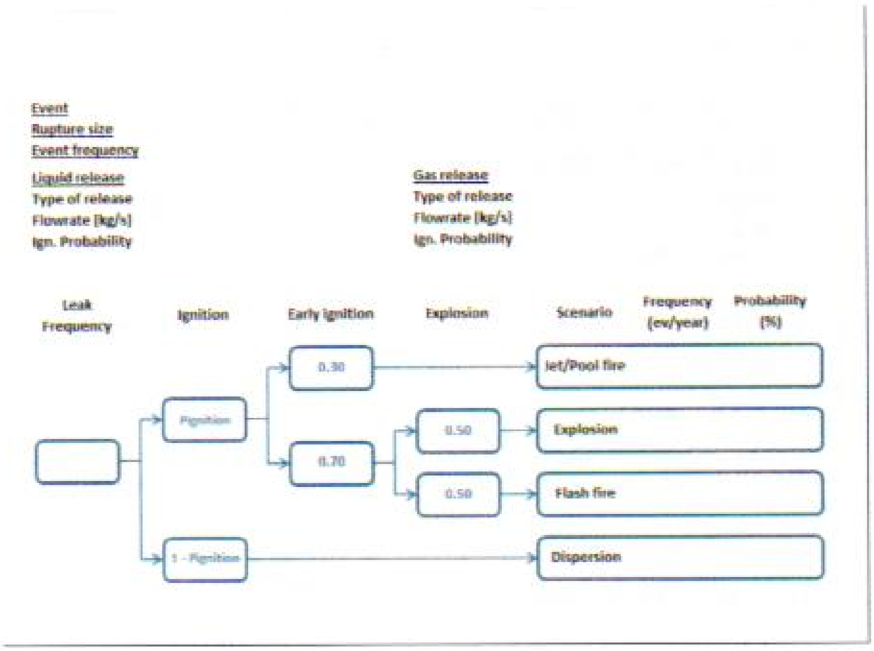


Figure 3.1: Typical Event Tree

3.1.3 Consequences Assessment

Consequences simulation will be performed by means of DNV Phast 7 (Ref.[4]) considering LNG as a stream of 100% methane. Process conditions (e.g., temperature and pressure of each stream) will be taken from PFD.

Release directions will be selected case by case, in order to conservatively maximize the effects of the considered scenario.

In addition, distances results will be calculated considering the initial (peak) flow rate since damage for personnel is usually determined by what happens in the initial 10-20 seconds of the event. Initial peak low rate will be limited to the 150% of the operating flowrate for flow-controlled process streams (e.g. pump discharge line, flow control valve line etc.).

The main results of consequences analysis will be expressed in terms of length of flame (with respect to jet fire), pool diameter (with respect to pool fire) and distances at which the threshold values of radiations, flammable concentrations and overpressure are reached. For the explosions simulations, if any, the TNO Multi-energy Method embedded in Phast 7 will be considered.

The following thresholds, based on international standards, (Italian regulation, Decree 9/5/2001, Minimum requirements for land use planning in areas potentially affected by Major Risks Plants) will be considered representative for each hazardous scenario:

Table 3.1: Scenarios thresholds

Damage thresholds for people and equipment		Damage level			
		Multiple Fatalities	One fatality	Major/ permanent injury	Slight injuries
Accidental Scenario	Pool Fire/Jet Fire	12.5 kW/m2	7 kW/m2	5 kW/m2	3 kW/m2
	Flash-fire	LFL	1/2 LFL	-	-
	Explosion	0.3 bar	0.14 bar	0.07 bar	0.03 bar

Two weather conditions will be considered (namely, 2F and 5D representing nightly and daily conditions) and the environmental conditions will be set as follows:

- ✓ Ambient Temperature: 27°C;
- ✓ Relative Humidity: 50%;
- ✓ Solar radiation: 0.8 kW/m2.

Maps of consequences distances will be provided on plant layout showing the extension of potential fire scenarios in the area around plant location.

3.1.4 Risk Assessment

Risk assessment of each MAH will be performed by means of Individual Risk (IRPA) calculation, considering the following operator distribution along the Plant.

Table 3.2: Operator distribution

Operator distribution		
Location	Number of people	Duration of presence
FSRU	32	24/7, 365 d/y
LNG Carrier	30	6 times/month
Control Room	2	Semi-unmanned. Operator will be not present 24/7, 365 d/y. He will be present for short period of time for monitoring and control only.

Data proposed in Table 3.2 have been agreed with Client as per information provided by email dated 10th July 2018.

LSIR (Location Specific Individual Risk) map will be also include in order to provide an estimation of risk associated to third parties and public.
Individual risk acceptability criteria will be based on HSE UK tolerability criteria, as shown in the following figure.

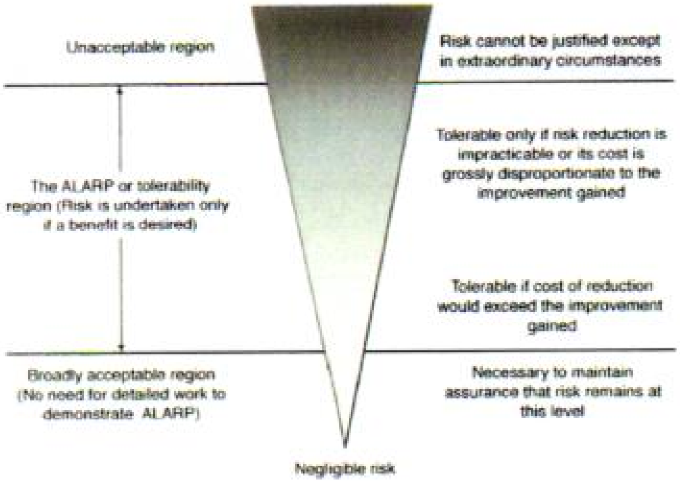


Figure 3.2: Individual risk triangle

Table 3.3: IRPA acceptability criteria (workers) [HSE UK]

Level of IR	Risk Criteria
Broadly acceptable region	Risk < 1.00E-06 ev/yr
ALARP Region	1.00E-06 ≤ Risk < 1.00E-03 ev/yr
Unacceptable region	Risk ≥ 1.00E-03 ev/yr

Table 3.4: IRPA acceptability criteria (public) [HSE UK]

Level of IR	Risk Criteria
Broadly acceptable region	Risk < 1.00E-06 ev/yr
ALARP Region	1.00E-06 ≤ Risk < 1.00E-04 ev/yr
Unacceptable region	Risk ≥ 1.00E-04 ev/yr

4 NAVIGATION STUDY

In this section, the main assumptions and hypothesis related to the navigation study are listed.

4.1 REVIEW OF APPLICABLE INDUSTRY STANDARDS AND PRACTICE

As preliminary general understanding, it has to be highlighted that up to now the LNG ships have been handled at Port Qasim since the establishment of the first LNG terminal in 2015 along the Main Navigation Channel.

During the last three years, another LNG terminal came to operation in Chara Creek and the overall number of LNG operations operated at port Qasim is now exceeding 150 ships. Among the several LNG Carriers, the maximum size currently experienced is Q-Flex size. All the carriers have been operated in the Main Navigation Channel in accordance with the Standard Operating Procedures for LNG (Ref.[10]).

In the light of above, considering that the Chann Waddo Channel is currently not operating, a tentative channel profile, in terms of minimum required depth and width, will be defined and agreed with Client in order to consider a realistic bathymetric scenario for the subsequent simulation runs.

Since the future plans for the development of the mentioned channel is currently not known, RINA suggests to consider a 1-way channel maintaining the same operating philosophy of the Main Channel. The channel dimensions used in the simulations will be based on this assumption.

The mentioned verifications and assumptions will be made according to Ref. [5], [6], [7], [8] and duly discussed with the expert Ship Master that will be involved in the navigation simulation session.

4.2 METHODOLOGY

The navigation study proposed is mainly addressed to perform a risk assessment regarding manoeuvring key aspects for the proposed locations of the new LNG Terminal. The simulation runs will be performed by means of a real time simulator tool described in Section 4.3.1.

All simulations will be carried out in order to optimize the manoeuvring strategy in order to safely operate the terminal and handle the different kind ships in several metocean conditions. In particular the overall runs matrix will be defined in accordance with:

- ✓ Type of ships (Moss type 170,000 m3, Membrane type 130,000 m3, Q-Max);
- ✓ Type of manoeuvre (access or exit)
- ✓ Ship loading condition (full load, ballast);
- ✓ Metocean conditions (tbd);
- ✓ Different kind of failures (main propulsion system, rudder, tug, etc.)

The simulation will be carried out by an experienced LNG Ship Master with the cooperation of engineers and technicians.

4.3 RINA SIMULATION FACILITY

The simulation runs will be performed by means of RINA Consulting real time ship handling simulator in Genova that is a TRANSAS Full Bridge Simulator qualified as Class C fit for purpose especially for engineering activities.

The System is composed by:

- ✓ 1 (one) Instructor Workplace including:
  - Main Instructor Control and Monitoring Module
  - Tug and Mooring Functionality Module
- ✓ 1 (one) Bridge – Software
  - Conning Software (1 module)
  - Navi Sailor 4000 ECDIS Software (1 module)
  - Navi Planner 4000 (planning tools)
  - RADAR/ARPA Software (1 module)

- 1 (one) Bridge - Hardware
  - Maneuvering Console with
  - Mini Azipod right
  - Mini Azipod left
  - Steering Shaft
  - Steering Wheel
  - IBID display, touchscreen (used for AIS, Autopilot, rotate visuals, ...)
  - Mini Telegraph (split, for 1 or 2 propellers)
- 1 (one) General Console Including ECDIS, RADAR, Conning (3 pcs) with dedicated keyboards and 24" monitors
- 3D Scenario on Monitor LCD 50 inches (7 pcs) installed into metal mock-up for 210 degrees visual

Figure 4.1: RINA Consulting Simulator in Genova, Italy (May 2018)

4.3.1 Simulation Tool

RINA Consulting real time ship handling simulator is named NaviTrainerPro 5000, the tool has been developed by TRANSAS and enables simulator training and certification of Officers, Captains and Pilots on all types of vessels as well as port assessment studies.

NTPRO 5000 simulates integration of ship/channel hydrodynamic effects and operational procedures so that simulators can be used not only for traditional maritime training but for number of R&D applications as an effective port /channel /terminal design tool.

In the following, the general algorithms used in the Simulation Mathematical modelling algorithms:

- 6-DoF ship motion equation;
- Hull hydrodynamic model;
- Stability and flotation model;
- Air cushion model;

584

- Heel tank model;
- Ballast tank model;
- Hull aerodynamic model;
- Main engine model;

Propulsive algorithm agents model:
- Active steering devices model;
- Rudder model;
- Engine model;
- Model of environmental effects (wind, waves, current);
- Model of shallow water effect;
- Model of 6-DoF pitch, additional wave resistance and drifting effect;
- Wave roll/pitch model;
- Wind-generated and swell wave model;
- Model of the distributed current effect;
- Model of hydrodynamic interaction with other ships (tugboats, barges) and geographical peculiarities of the area;
- Model of mechanical interaction with other ships (tugboats, barges) and mooring walls;
- Anchor model;
- Model of multi-functional autopilot;
- SMM incorporates the following model types: displacement ships, semi-glider ship, catamaran ships, tugs, barges, helicopters and aircrafts;
- Models are based on the actual prototypes and are adjusted from the data of sea and tank tests (if available).

Furthermore, the following real modelled effects are considered in the mathematical model:
- Shallow water effect on the hydrodynamic properties of the hull, propulsive agents/propeller and helms;
- Shallow water effect on changing the propulsive quality;
- Squat effect;
- Hydrodynamic interaction with other ships (tugboats, barges) and geographical peculiarities of the area (uneven seabed, shoal, mooring wall);
- Hydrodynamic interaction between the ship and waterway boundaries (walls, inclined bottom, channels, underwater banks);
- Ship collision with a ship (tugboat, barge);
- Ship bump with mooring walls and aids to navigation;
- Grounding;
- Soft grounding effect;
- Navigation in muddy strata areas;
- Lock effect;
- Enhanced Planning Effect;
- Air cushion effect;
- Propeller going of water.

In addition to the Simulator itself, each particular scenario can be detailed modeled or modified by means of Model Wizard software (provided by TRANSAS).
Model Wizard allows creation of a 3D model of a geographical area (scene) for Navi-Trainer simulator, therefore the file with scene construction results has a format compatible with one of the scenes to be installed in the simulator.
Bathymetry, berth layouts, navigation aids, and all the other components of the scenario can be properly updated in order to match the actual characteristics of the area.

4.4 METOCEAN DATA

Metocean data are certainly among the most significant parameters affecting the ships navigation and the manoeuver of the ships approaching the berthing area located along Chann Waddo Creek.

Since no current map are available, in order to provide input data for manoeuver analyses, maximum values of metocean parameters will be estimated at the access channel, along the navigation route, and at the turning

basin area, based on site specific waves and currents measured data provided by the Client and on critical interpretation of the available data in accordance with the previous similar jobs performed.
As concern the wind speed, Standard Operating Procedures of Port Qasim Authority (Ref.[10]) gives as terminal operation limit for the FSRU and LNG carrier berthing manoeuvres a mean wind speed of 20 knots. So that, the manoeuvring simulations will be carried out with a constant wind speed of 20 knots with gusting (30 and 60 seconds of gust will be considered in the simulation runs).
As per available information, the main incoming wind direction are SW and NE. The prevailing direction is SW which is also the most demanding one, even though also NE direction due to monsoon winds will be taken into account in some simulation runs.

4.5 ANALYSIS ASSUMPTIONS

4.5.1 Berth Locations

The proposed location for the LNG terminal to be investigated in the present navigation study is along the Chann Waddo Channel that is currently not operational.

The site to be investigated during the navigation study is the one shown in the following figure.

Figure 4.2: Site Location

4.5.2 Berth Orientation and Layout

The overall layout of the jetty, including loading platform, breasting structures and mooring dolphins will be modelled inside the different scenarios according to the drawing provided by the Client.

The terminal orientation (approx. 080 N°) will be considered along to the navigational direction at the specific proposed location at the minimum distance from the shore-line in accordance with PQA recommendations regarding the minimum channel width and center channel line required for the safety navigation of the Chann Waddo Channel.
As per information provided by Client, the minimum distance to be kept between the center of the channel and the LNGC manifold is 250 meters. This value will be consider for the development of the area to be used during the simulation session.

4.5.3 Ship and Tugs models

In accordance with Client request, for the present study the following ship models will be considered for the simulations.

The main data reported below are relevant to ships available in RINA library already tested and reliable.

Table 4.1: LNG Carrier Moss Type 170k m^3 – main particulars

Ship type – Main Characteristics		Moss 170k m^3
Length Overall	L_{OA} [m]	299.98
Length between perpendicular	L_{BP} [m]	286.00
Beam	B [m]	52.00
Depth	D [m]	28.00
Draught (Full Load)	T_{AM} [m]	11.55
Draught (Ballast)	T_{AM} [m]	9.50
Gas Capacity	[m^3]	177,422
Displacement (Full Load)	Δ [ton]	124,700
Displacement (Ballast)	Δ [ton]	81,550

Table 4.2: LNG Carrier Membrane Type 130k m^3 – main particulars

Ship type – Main Characteristics		Membrane 130k m^3
Length Overall	L_{OA} [m]	274.34
Length between perpendicular	L_{BP} [m]	260.56
Beam	B [m]	43.30
Depth	D [m]	25.40
Draught (Full Load)	T_{AM} [m]	10.86
Draught (Ballast)	T_{AM} [m]	9.50
Gas Capacity	[m^3]	130,300
Displacement (Full Load)	Δ [ton]	89,640
Displacement (Ballast)	Δ [ton]	67,600

Table 4.3: LNG Carrier Membrane Type 260k m^3 – main particulars

Ship type – Main Characteristics		Membrane 260k m^3
Length Overall	L_{OA} [m]	345.00
Length between perpendicular	L_{BP} [m]	332.00
Beam	B [m]	53.80
Depth	D [m]	27.00
Draught (Full Load)	T_{AM} [m]	12.00
Draught (Ballast)	T_{AM} [m]	9.60
Gas Capacity	[m^3]	266,000
Displacement (Full Load)	Δ [ton]	171,300
Displacement (Ballast)	Δ [ton]	142,000

The FSRU will be a membrane type 170,000 m^3 LNG carrier and for all simulations it will be assumed already berthed to the jetty.

Furthermore, the tug fleet available at Port Qasim will be considered during the simulations.

Two different type of tugs are available at Port Qasim and they are involved in different steps of the manouvers depending on their bollard pull capacity.

Lamnalco Mukalla, Lamnalco Hodeidah and Lamnalco Sana'a main characteristics are reported in Table 4.4 for tug type 1, Lamnalco Aden main characteristics are reported in Table 4.4 for tug type 2.

Table 4.4: Tug – main characteristics

Tug type – Main Characteristics		1	2
Length Overall	L_{OA} [m]	33.31	33.31
Beam	B [m]	14.5	14.5
Gross Tonnage	GT	724	724
Bollard Pull	[t]	75	85
Speed	[kn]	14	14
Installed Power	[kW]	6,120	6,120

In accordance with PQA recommendations, one tug will be escorting the LNGC at stern during arrival manoeuver starting from the entrance of the channel while the other three tugs will be involved in the manoeuvers when the LNGC is approaching the jetty only.

Since RINA is not able to predict which type of tugs will be involved in the manoeuvers, conservatively four ASD tugs with a bollard pull of 75 tons will be considered in the simulations.

4.5.4 Chann Waddo Channel Bathymetry

The Chann Waddo Channel is currently not operational because of low water depth level in some of its sections. Inside Model Wizard suite of software, Chann Waddo Channel configuration needs to be updated according to the latest information available.

The update bathymetric layout made available by the Client (Ref. [12]) will be imported in the main scenario built up with the Electronic Chart of the area.

In addition to the above, the definition of the minimum channel depth and width according to the main international standards (Ref. [5] to [8]) will be developed taking into account the size of ships that will sail into the channel.

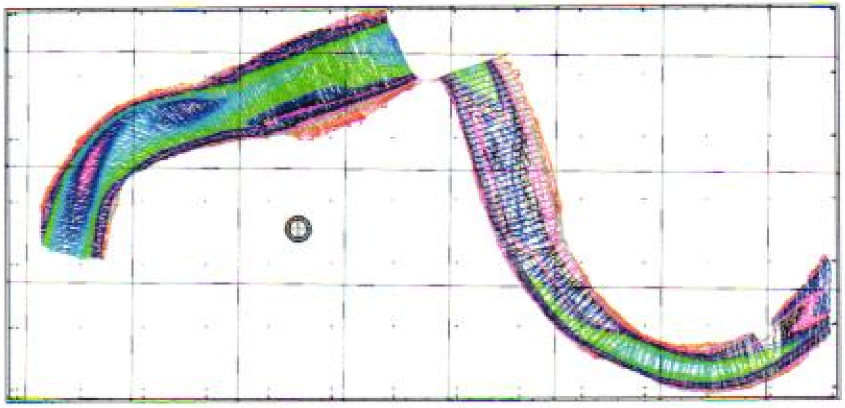


Figure 4.3: Bathymetric data

4.5.5 Navigation aids

Considering that the Channel is currently non-operational, no navigation aids are currently present, therefore, once the fairway dimension will be defined, the necessary Navigation Buoys will be placed all along the channel according to the applicable Standards (Ref.[9]).

Furthermore, the above mentioned navigation aids layout will be further discussed with the expert Ship Master that will be involved in the navigation simulation session in order to propose a tentative layout that not only is compliant with regulations but it is also supported by human LNG expert judgement.

4.6 PRELIMINARY RUNS MATRIX

4.6.1 Manoeuvring strategy

During the whole simulations the FSRU will be assumed already berthed to the jetty. The manoeuvres will be carried out with the ship models of LNG carriers reported in Section 4.5.3.

As general approach already in use at Port Qasim for handling LNG Traffic, the manoeuvring strategy foresees that the LNG carried should arrive in theoretical optimum conditions in the turning basin with high water slack current condition.

However, considering that this is highly theoretical and in order to properly take into account random variables affecting the scheduling of ships, scenario of high water +1/-1 h. will be considered.

The above described manoeuvering strategy is, theoretically, currently applied by PQA for the existing LNG Terminals, nevertheless also some particular cases at low tide will be performed during the simulation session.

4.6.2 Simulation Matrix

Table below reports an example of simulation matrix that may be considered as reference.

The final simulation matrix will be provided and agreed with the Client before starting the simulation session.

Table 4.5: Simulation Matrix example

Test no.	Description	Arrival / Departure	Ship type	Wind		Current		Failures
				[°]	[kts]	[°]	[kts]	
1	LNG carrier navigation from outside to the turning basin & evolution in the turning basin	Arrival	Membrane 130k m^3	SW	Strong (*)	Flood	Strong (*)	(**)
2	LNG carrier arrival/departure to/from mooring platform	Departure	Q-Max 260k m^3	NE	Strong (*)	Ebb	Strong (*)	(**)

(*) to be agree before starting the simulation session according to available metocean data and contributions from the team. Typical value might be 20 knots with gusts up to 30 knots.

(**) manoeuver repetitions with failures will be agreed during the study, based on captain feedbacks and contributions from the team. Typical failures simulated are (1) tug, (2) steering, (3) black-out.

REFERENCES

[1] OGP, 2010, "Process Release Frequencies", Risk Assessment Data Directory, Report No.434-1;

[2] DNV, 2010; RP-F107, "Risk Assessment of Pipeline protection";

[3] IP-UKOOA, 2006, "Ignition probability review, model development and look-up correlations", January;

[4] DNV, "PHAST", Version 6.7 (Theory Manual and Validation report);

[5] PIANC, 2014, "Harbour Approach Channels Design Guidelines", Report No 121;

[6] PIANC, 1997, "Approach Channel A Guide for Design", June;

[7] SIGTTO, "Site Selection and Design for LNG Ports and Jetties" Information Paper N°14;

[8] SIGTTO, 2003, "LNG Operations in Port Areas";

[9] IALA, 2011, "The use of Aids to Navigation in the Design of Fairways" Edition 1, June;

[10] Port Qasim Authority, Standard Operating Procedures for Operating Conventional LNG Carriers, PQA Notice SOP/ Conv 001/16 Dated 30th April, 2016;

[11] JGC Corporation – General Plot Plan for Jetty and Onshore Facility [dwg. no. D-000-1225-001];

[12] CW-Jhari 13th June bathymetry Chann Waddo Channel;

[13] P0009270-1-A2 Minute of Meeting relevant to Clarification Meeting held on 9th July 2018.

592

APPENDIX B

Appendix B

Event Trees

Doc. No. P0009270-1-H2 Rev. 4 – November 2018

RINA

F94

JGC Corporation
Karachi, Pakistan

QRA and Navigation Simulations for LNG terminal at Port Qasim

Appendix B: Event Tree Analysis

Doc. No. P0009270-1-H2 Rev. 4 – November 2018

Rev.	4
Description	Editorial modification
Prepared by	I. Mazza
Controlled by	M. Pontiggia
Approved by	G. Uguccioni
Date	21/11/2018

5995

QRA and Navigation Simulations for LNG terminal at Port Qasim

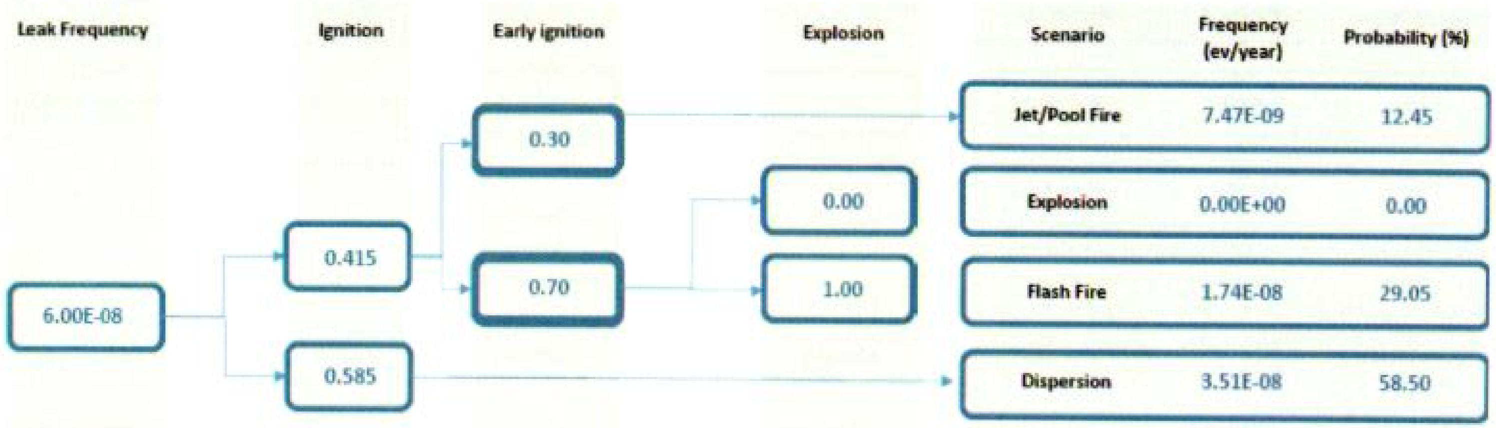
Appendix B: Event Tree Analysis

Rev.	Description	Prepared by	Controlled by	Approved by	Date
4	Editorial modification	I. Mazza	M. Pontiggia	G. Uguccioni	21/11/2018
3	Fourth Issue	M. Di Francesco	M. Pontiggia	G. Uguccioni	31/10/2018
2	Third Issue	M. Di Francesco	M. Pontiggia	G. Uguccioni	14/09/2018
1	Second Issue	M. Di Francesco	M. Pontiggia	G. Uguccioni	03/08/2018
0	First Issue	M. Di Francesco	M. Pontiggia	G. Uguccioni	20/07/2018

1 EVENT TREES

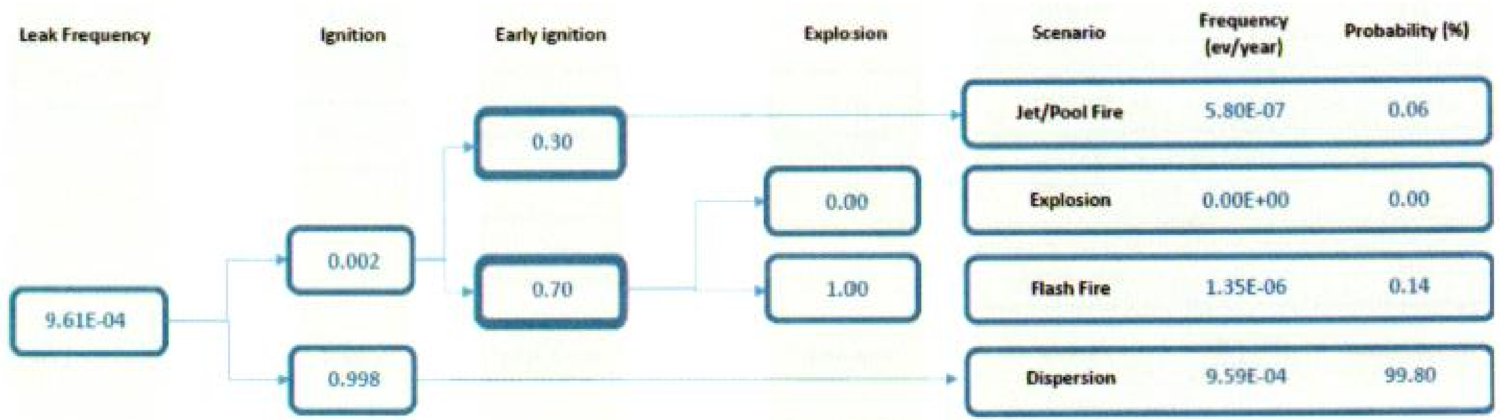
Event	1
Rupture size	>150 mm
Event Frequency	6.00E-08

Liquid release		**Event**	
Type of release	Large Plant Liquid	Type of release	Small Plant Gas LPG
Flowrate [kg/s]	0.0	Flowrate [kg/s]	302.13
Ign. Probability	0	Ign. Probability	0.415



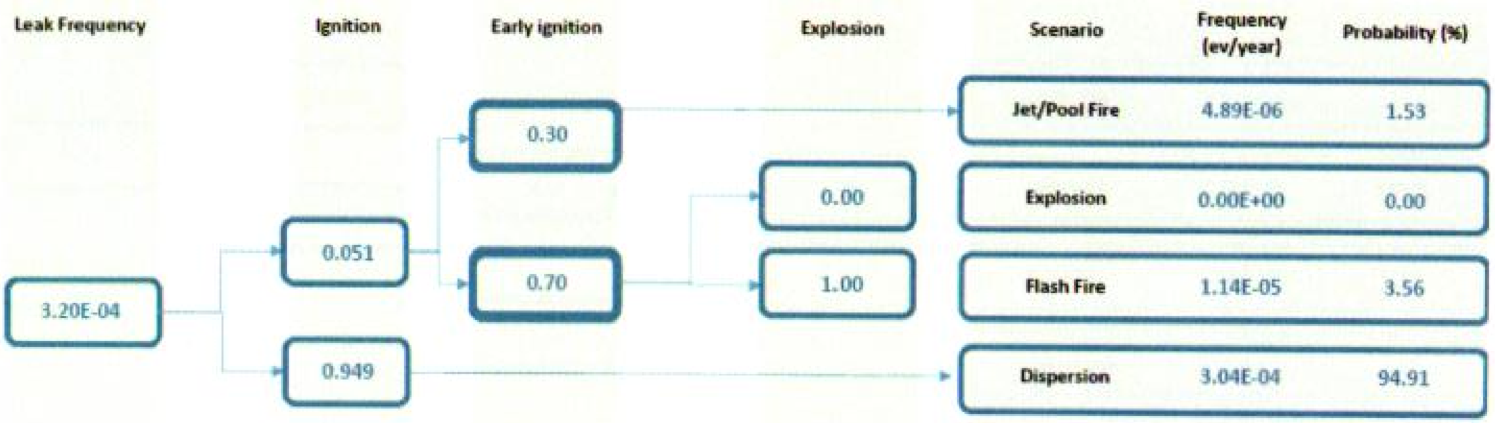
Event	2
Rupture size	10 mm
Event Frequency	9.61E-04

Liquid release		Event	
Type of release	Large Plant Liquid	Type of release	Small Plant Gas LPG
Flowrate [kg/s]	0.0	Flowrate [kg/s]	0.65
Ign. Probability	0	Ign. Probability	0.002



Event	2
Rupture size	50 mm
Event Frequency	3.20E-04

Liquid release		**Event**	
Type of release	Large Plant Liquid	Type of release	Small Plant Gas LPG
Flowrate [kg/s]	0.0	Flowrate [kg/s]	17.40
Ign. Probability	0	Ign. Probability	0.051

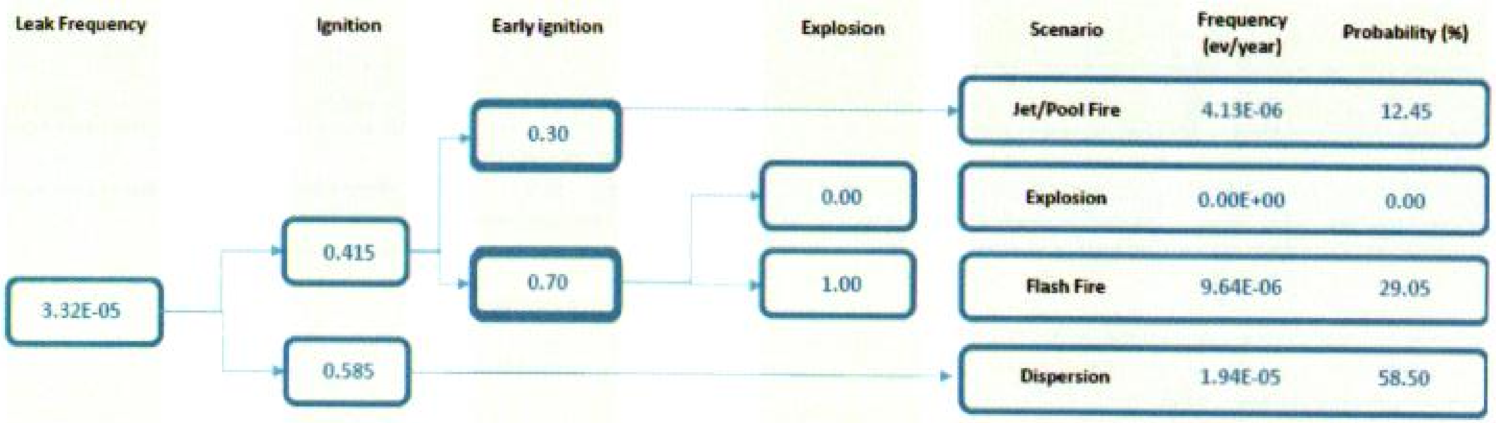


Event	2
Rupture size	150 mm
Event Frequency	3.32E-05

Liquid release		**Event**	
Type of release	Large Plant Liquid	Type of release	Small Plant Gas LPG
Flowrate [kg/s]	0.0	Flowrate [kg/s]	162.40
Ign. Probability	0	Ign. Probability	0.263

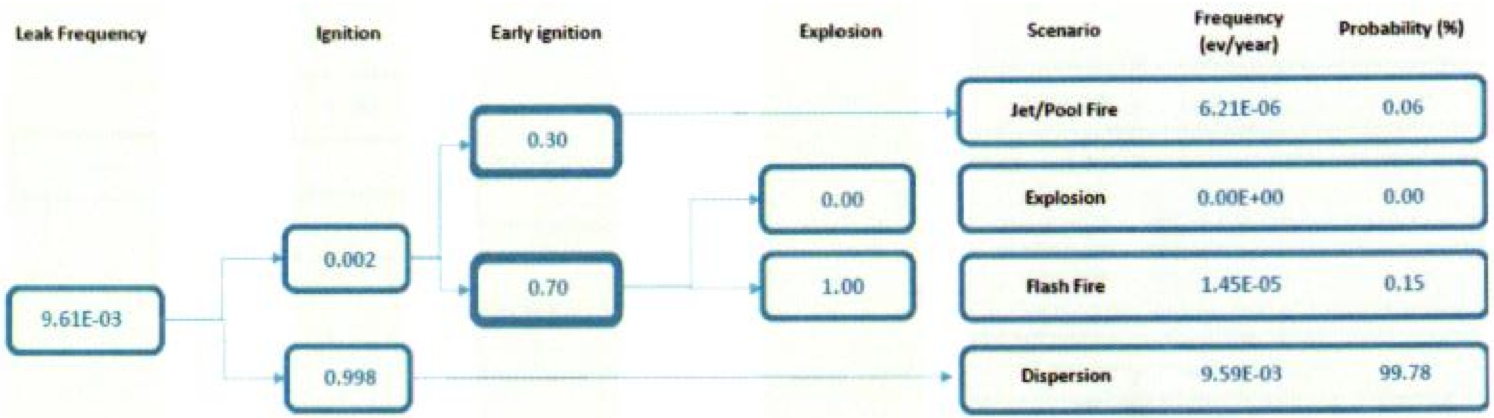
Event	2
Rupture size	>150 mm
Event Frequency	3.32E-05

Liquid release		**Event**	
Type of release	Large Plant Liquid	Type of release	Small Plant Gas LPG
Flowrate [kg/s]	0.0	Flowrate [kg/s]	302.10
Ign. Probability	0	Ign. Probability	0.415



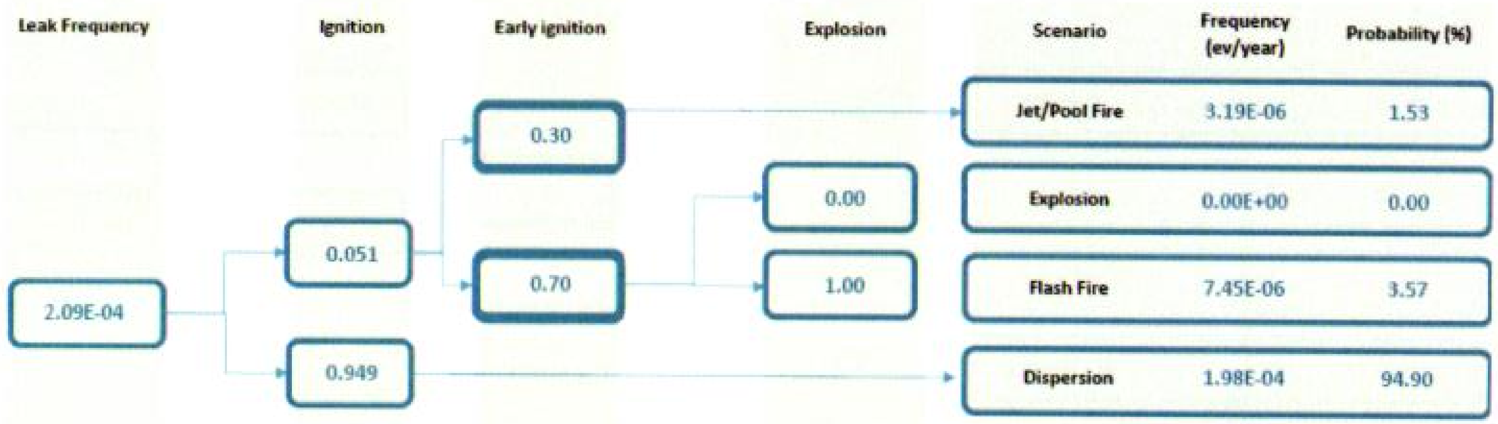
Event	3
Rupture size	10 mm
Event Frequency	9.61E-03

Liquid release		**Event**	
Type of release	Large Plant Liquid	Type of release	Small Plant Gas LPG
Flowrate [kg/s]	0.0	Flowrate [kg/s]	0.66
Ign. Probability	0	Ign. Probability	0.002



Event	3
Rupture size	50 mm
Event Frequency	2.09E-04

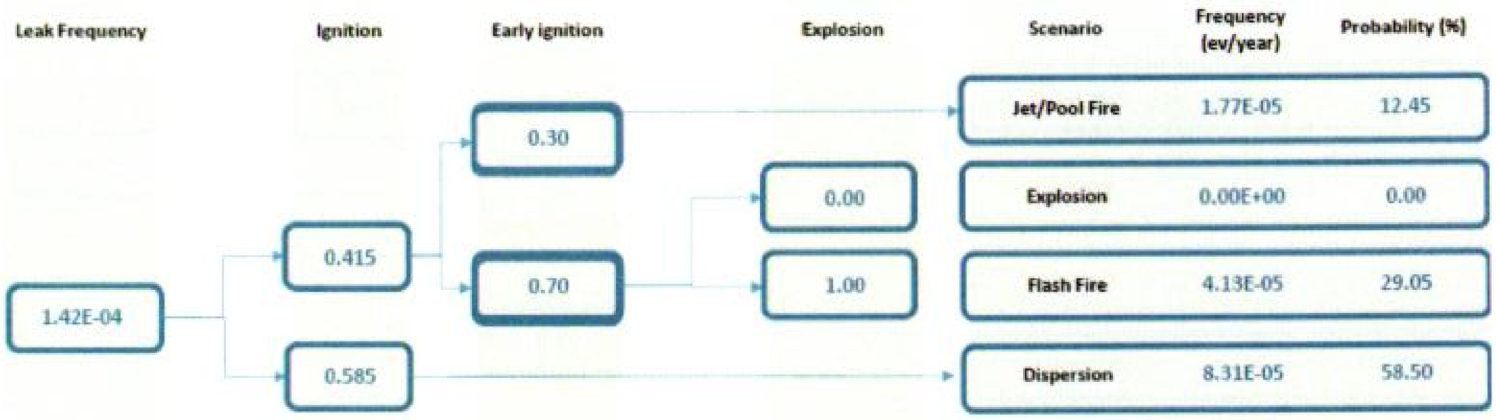
Liquid release		Event	
Type of release	Large Plant Liquid	Type of release	Small Plant Gas LPG
Flowrate [kg/s]	0.0	Flowrate [kg/s]	17.40
Ign. Probability	0	Ign. Probability	0.051



602

Event	3
Rupture size	150 mm
Event Frequency	1.42E-04

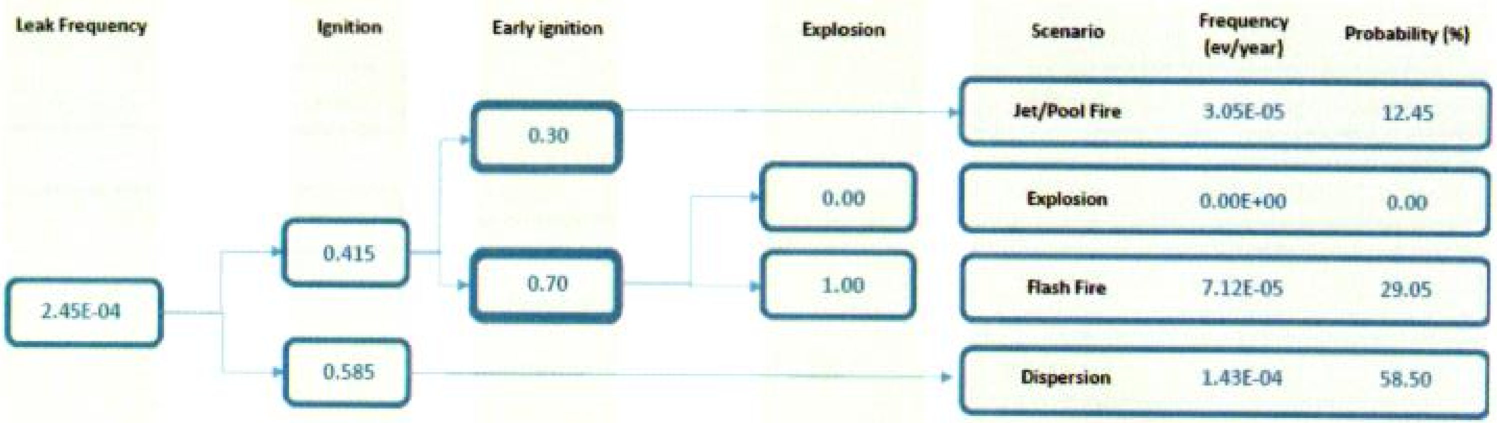
Liquid release		Event	
Type of release	Large Plant Liquid	Type of release	Small Plant Gas LPG
Flowrate [kg/s]	0.0	Flowrate [kg/s]	302.10
Ign. Probability	0	Ign. Probability	0.415



Event	3
Rupture size	>150 mm
Event Frequency	2.45E-04

Liquid release	
Type of release	Large Plant Liquid
Flowrate [kg/s]	0.0
Ign. Probability	0

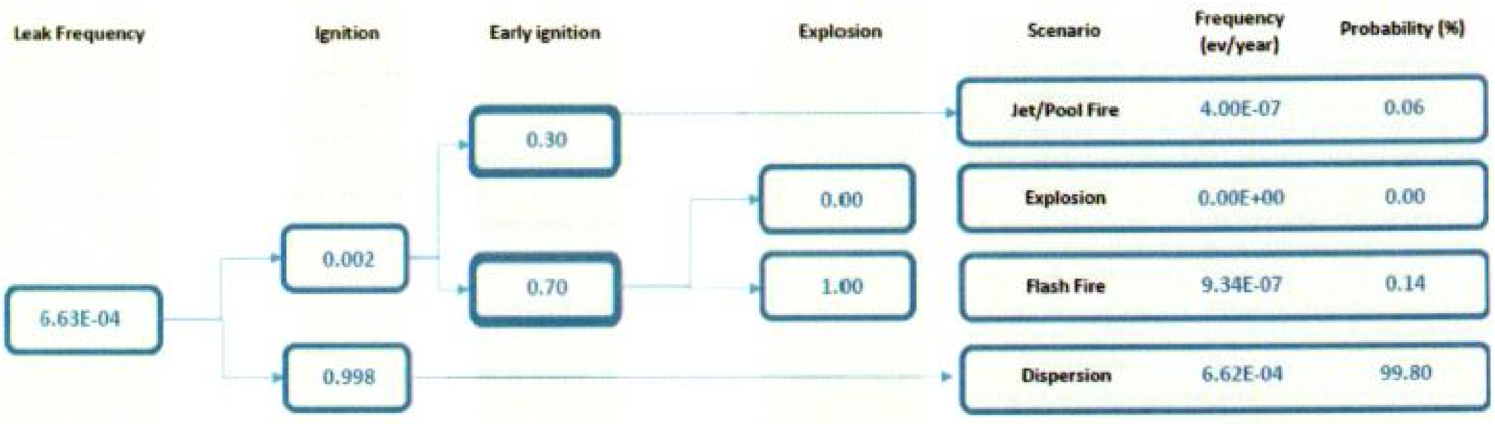
Event	
Type of release	Small Plant Gas LPG
Flowrate [kg/s]	302.10
Ign. Probability	0.415



604

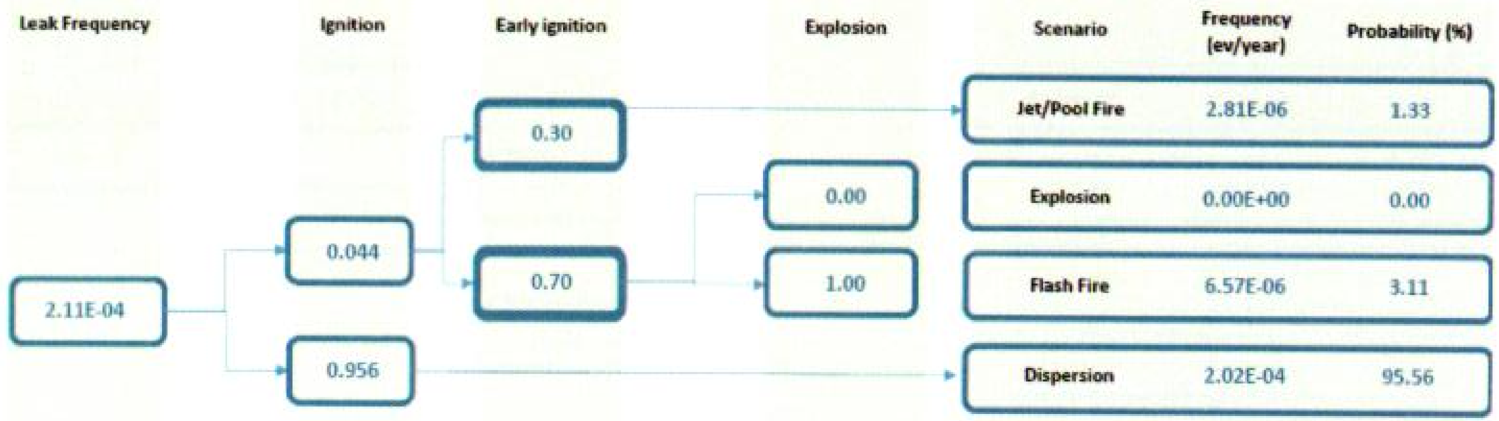
Event	4
Rupture size	10 mm
Event Frequency	6.63E-04

Liquid release		**Event**	
Type of release	Large Plant Liquid	Type of release	Small Plant Gas LPG
Flowrate [kg/s]	0.0	Flowrate [kg/s]	0.54
Ign. Probability	0	Ign. Probability	0.002



Event	4
Rupture size	50 mm
Event Frequency	2.11E-04

Liquid release		Event	
Type of release	Large Plant Liquid	Type of release	Small Plant Gas LPG
Flowrate [kg/s]	0.0	Flowrate [kg/s]	14.40
Ign. Probability	0	Ign. Probability	0.044



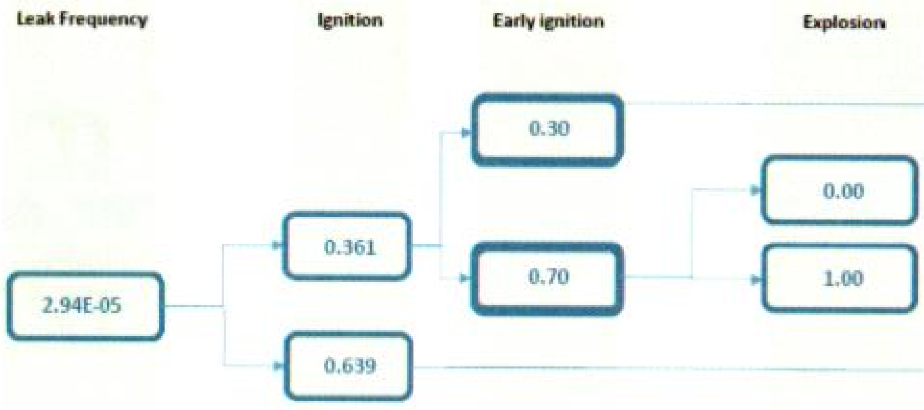
606

Event	4
Rupture size	150 mm
Event Frequency	3.00E-05

Liquid release		**Event**	
Type of release	Large Plant Liquid	Type of release	Small Plant Gas LPG
Flowrate [kg/s]	0.0	Flowrate [kg/s]	134.60
Ign. Probability	0	Ign. Probability	0.229

Event	4
Rupture size	>150 mm
Event Frequency	2.94E-05

Liquid release		Event	
Type of release	Large Plant Liquid	Type of release	Small Plant Gas LPG
Flowrate [kg/s]	0.0	Flowrate [kg/s]	250.30
Ign. Probability	0	Ign. Probability	0.361



Scenario	Frequency (ev/year)	Probability (%)
Jet/Pool Fire	3.18E-06	10.83
Explosion	0.00E+00	0.00
Flash Fire	7.43E-06	25.27
Dispersion	1.88E-05	63.90

608

608

610

APPENDIX C

Appendix C

Consequence Plots

Doc. No. P0009270-1-H2 Rev. 4 – November 2018

RINA

JGC Corporation
Karachi, Pakistan

QRA and Navigation Simulations for LNG terminal at Port Qasim

Appendix C: Consequence Plots

Doc. No. P0009270-1-H2 Rev. 4 – November 2018

Rev.	4
Description	Editorial modification
Prepared by	M. Di Francesco
Controlled by	M. Pontiggia
Approved by	G. Uguccioni
Date	21/11/2018

612

QRA and Navigation Simulations for LNG terminal at Port Qasim

Appendix C: Consequence Plots

Rev.	Description	Prepared by	Controlled by	Approved by	Date
4	Editorial modification	I. Mazza	M. Pontiggia	G. Uguccioni	21/11/2018
3	Fourth Issue	M. Di Francesco	M. Pontiggia	G. Uguccioni	31/10/2018
2	Third Issue	M. Di Francesco	M. Pontiggia	G. Uguccioni	14/09/2018
1	Second Issue	M. Di Francesco	M. Pontiggia	G. Uguccioni	03/08/2018
0	First Issue	M. Di Francesco	M. Pontiggia	G. Uguccioni	20/07/2018

1 CONSEQUENCE PLOTS

In the following plots, consequences for considered scenarios (Flash fire and Jet/pool fire) are graphically shown as contours over the layout. Given the map length scale, only worst case (that is, 150 mm hole size, 5/D meteo aggregation) has been plotted.

IS1
Hole diameter: 150 mm
Direction: H
Meteo: 5/D
Consequences:
Flash Fire

LFL
LFL/2
Source

IS1
Hole diameter: 150 mm
Direction: H
Meteo: 5/D
Consequences:
Jet Fire Radiation

- 3 kW/m2
- 5 kW/m2
- 7 kW/m2
- 12.5 kW/m2
- 37.5 kW/m2
- Source

519

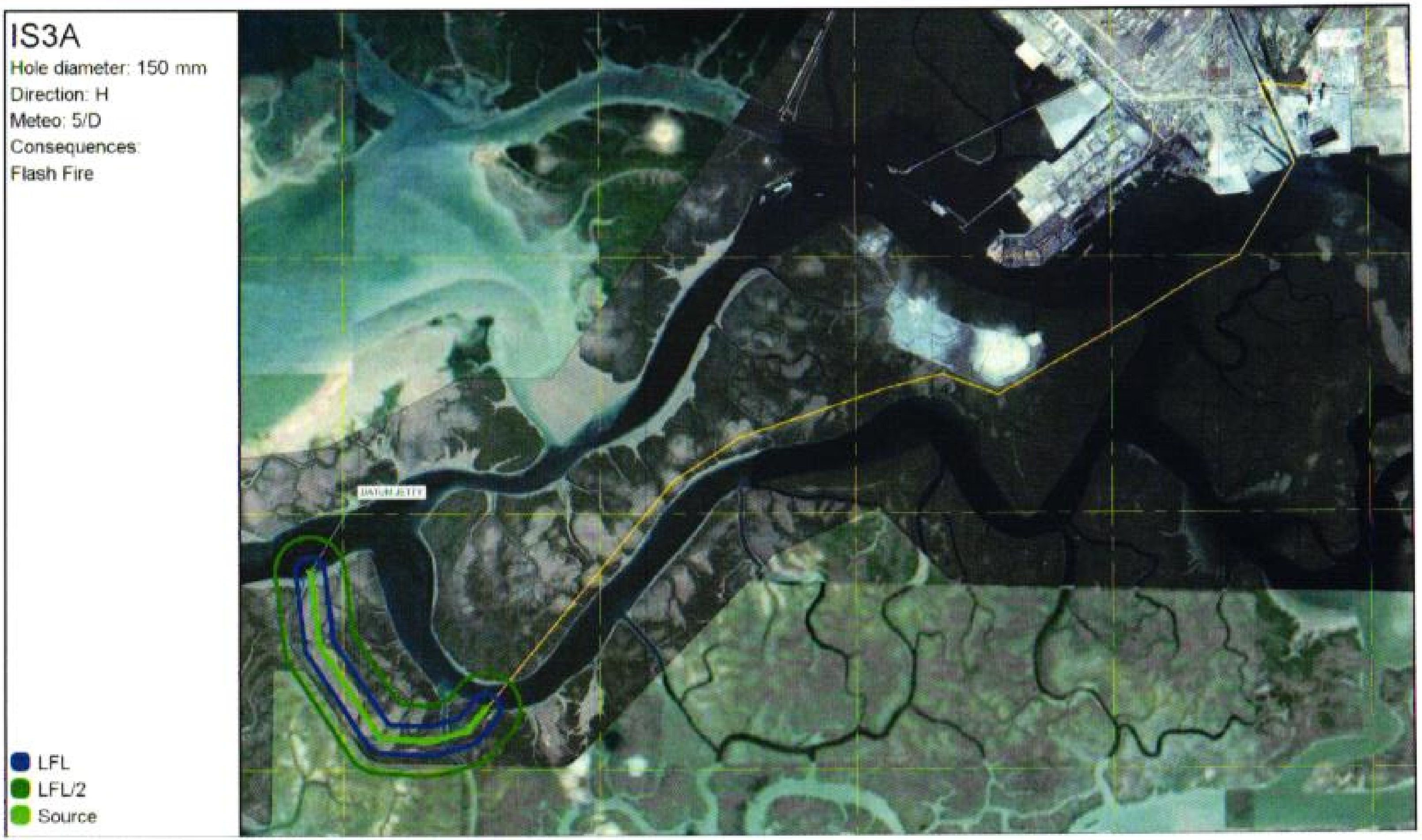
IS2

Hole diameter: 150 mm
Direction: H
Meteo: 5/D
Consequences:
Flash Fire

LFL
LFL/2
Source

IS2
Hole diameter: 150 mm
Direction: H
Meteo: 5/D
Consequences:
Jet Fire Radiation

- 3 kW/m2
- 5 kW/m2
- 7 kW/m2
- 12.5 kW/m2
- 37.5 kW/m2
- Source


IS3A
Hole diameter: 150 mm
Direction: H
Meteo: 5/D
Consequences:
Flash Fire
LFL
LFL/2
Source

IS3A

Hole diameter: 150 mm

Direction: H

Meteo: 5/D

Consequences:

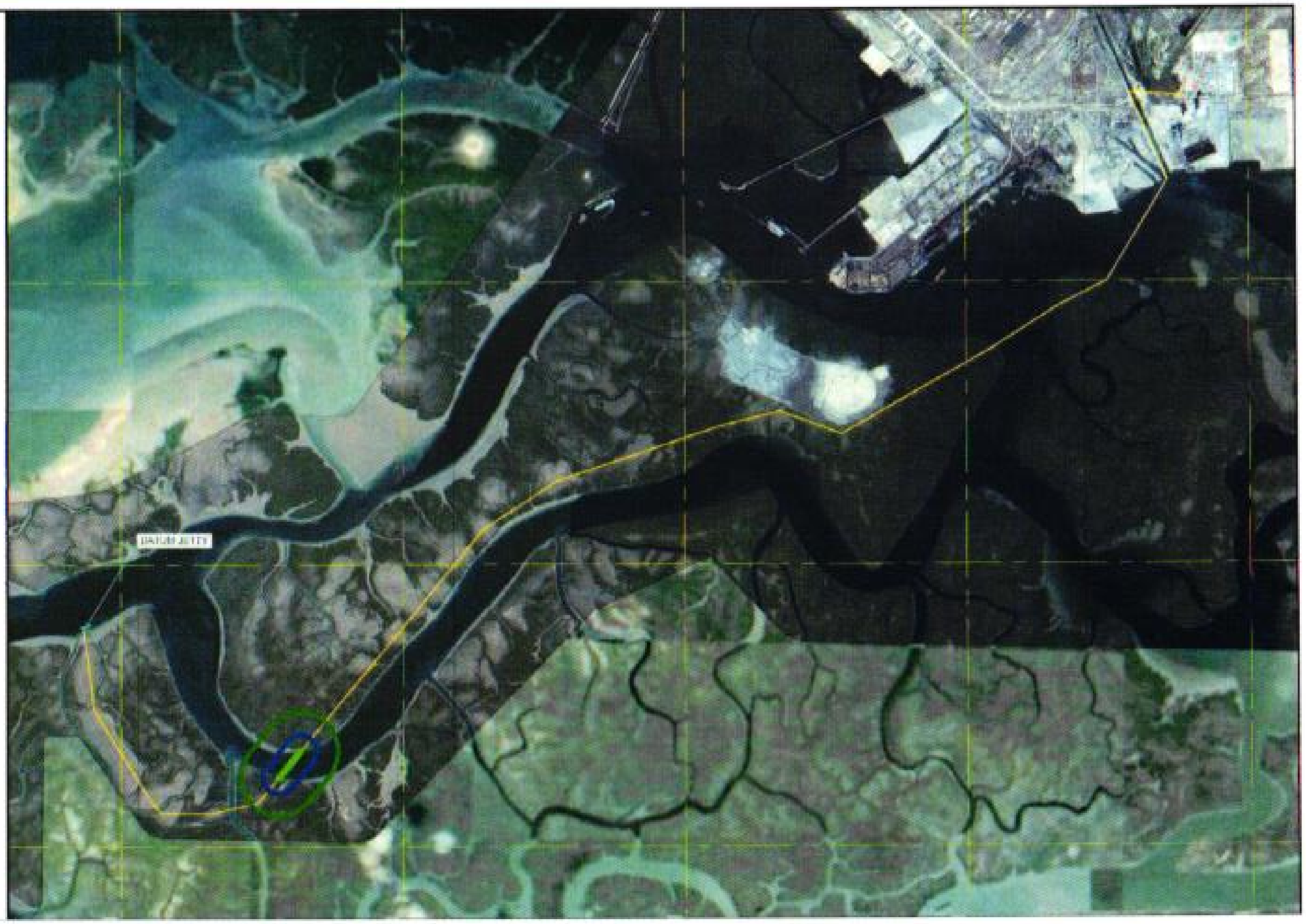
Jet Fire Radiation

- 3 kW/m2
- 5 kW/m2
- 7 kW/m2
- 12.5 kW/m2
- 37.5 kW/m2
- Source

618

IS3B

Hole diameter: 150 mm
Direction: H
Meteo: 5/D
Consequences:
Flash Fire



LFL
LFL/2
Source

IS3B
Hole diameter: 150 mm
Direction: H
Meteo: 5/D
Consequences:
Jet Fire Radiation

3 kW/m2
5 kW/m2
7 kW/m2
12.5 kW/m2
37.5 kW/m2
Source

620

IS3C

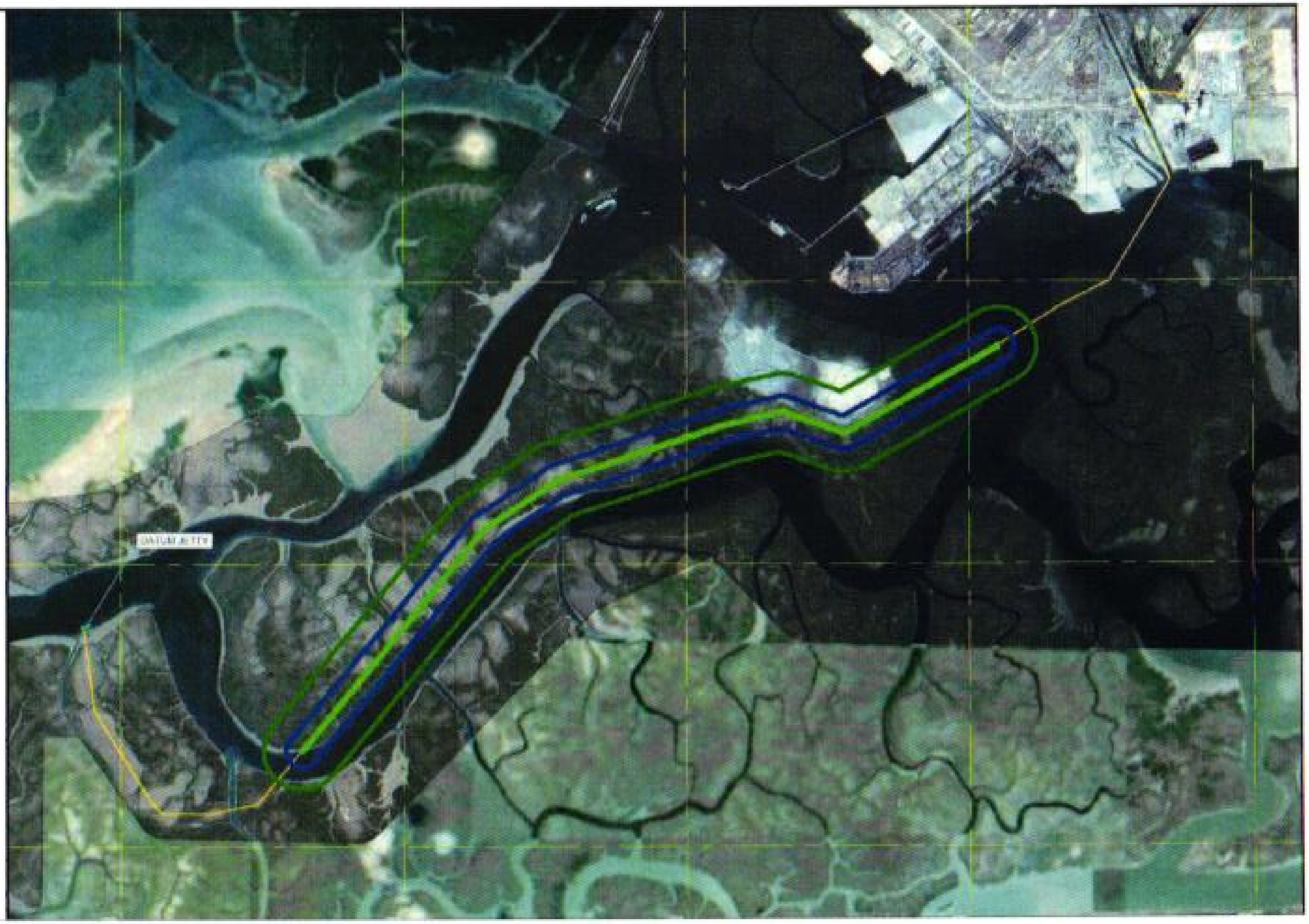
Hole diameter: 150 mm

Direction: H

Meteo: 5/D

Consequences:

Flash Fire



LFL

LFL/2

Source

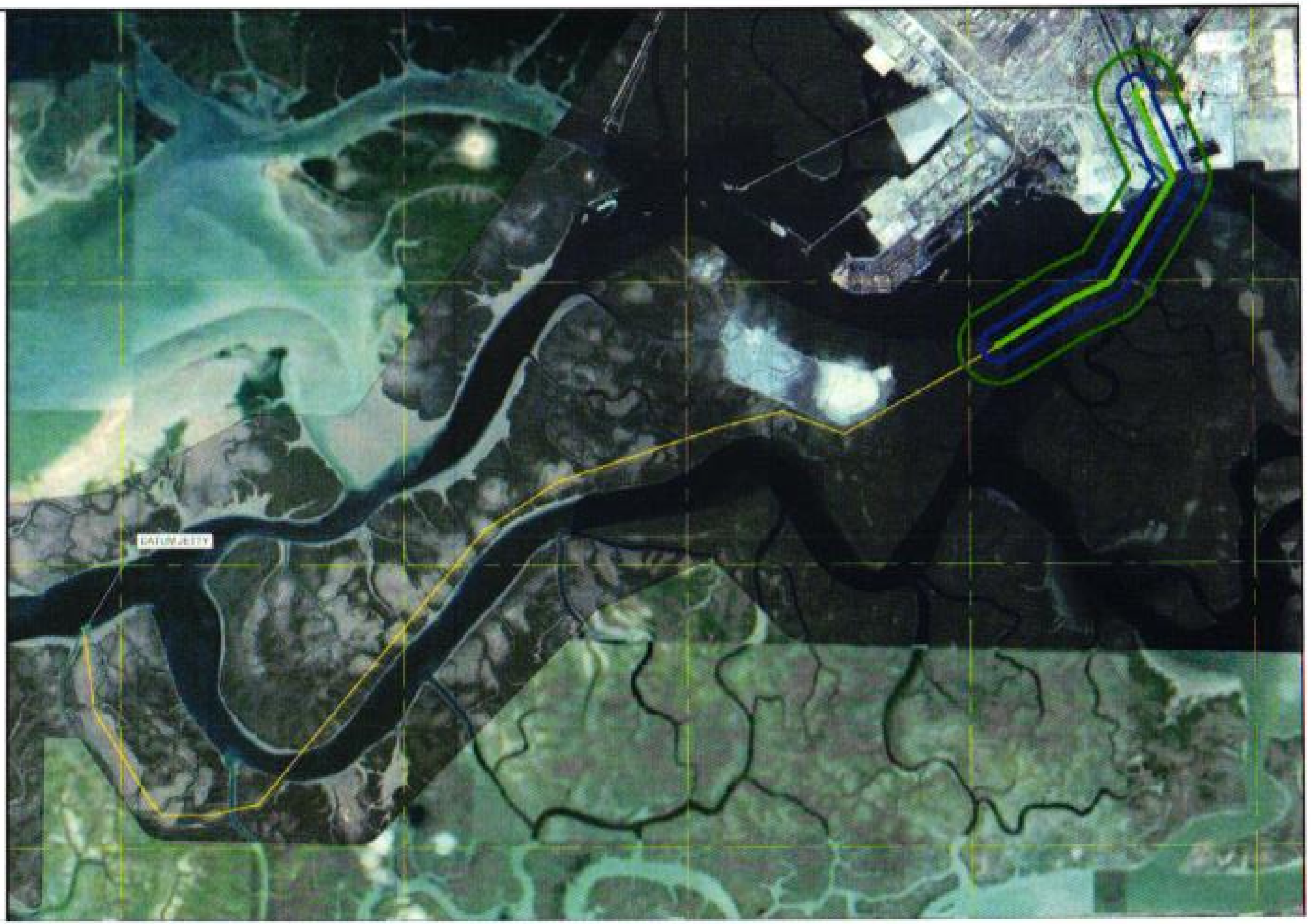
IS3C
Hole diameter: 150 mm
Direction: H
Meteo: 5/D
Consequences:
Jet Fire Radiation

- 3 kW/m2
- 5 kW/m2
- 7 kW/m2
- 12.5 kW/m2
- 37.5 kW/m2
- Source

622

IS3D

Hole diameter: 150 mm
Direction: H
Meteo: 5/D
Consequences:
Flash Fire



LFL
LFL/2
Source

IS3D

Hole diameter: 150 mm
Direction: H
Meteo: 5/D
Consequences:
Jet Fire Radiation

- 3 kW/m2
- 5 kW/m2
- 7 kW/m2
- 12.5 kW/m2
- 37.5 kW/m2
- Source

IS3E

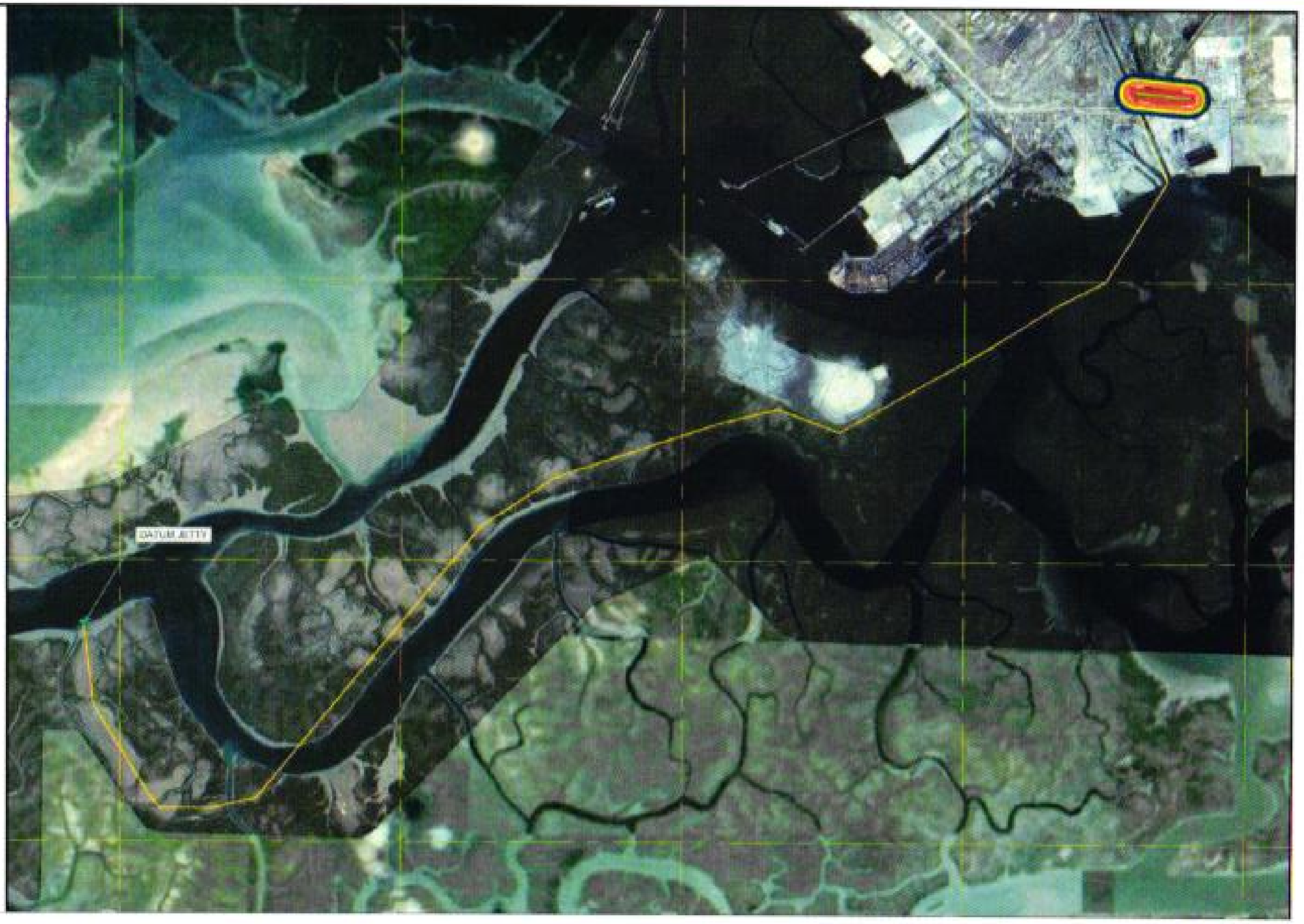
Hole diameter: 150 mm
Direction: H
Meteo: 5/D
Consequences:
Flash Fire

LFL
LFL/2
Source

IS3E

Hole diameter: 150 mm
Direction: H
Meteo: 5/D
Consequences:
Jet Fire Radiation

3 kW/m2
5 kW/m2
7 kW/m2
12.5 kW/m2
37.5 kW/m2
Source



IS4

Hole diameter: 150 mm

Direction: H

Meteo: 5/D

Consequences:

Flash Fire

- LFL
- LFL/2
- Source

678

RINA

RINA Consulting S.p.A. | Società soggetta a direzione e coordinamento amministrativo e finanziario del socio unico RINA S.p.A.
Via San Nazaro, 19 - 16145 GENOVA | P. +39 010 31961 | rinaconsulting@rina.org | www.rina.org
C.F./P. IVA/R.I. Genova N. 03476550102 | Cap. Soc. € 20.000.000,00 i.v.

JGC Corporation
Karachi, Pakistan

QRA and Navigation Simulations for LNG terminal at Port Qasim

Assumptions Sheet

Doc. No. P0009270-1-H1 Rev. 0 – July 2018

Rev.	1
Description	Issued after JGC comments and videoconference held on 09/07/2018
Prepared by	A. Rossi / I. Mazza / M. Pontiggia
Controlled by	S. Cappellozza
Approved by	C. Mordini
Date	13/07/2018

QRA and Navigation Simulations for LNG terminal at Port Qasim

Assumptions Sheet

Rev.	Description	Prepared by	Controlled by	Approved by	Date
0	First Issue	Andrea Rossi, Ilaria Mazza, Marco Pontiggia	Stefano Cappellozza	Claudio Mordini	06/07/2018
1	Issued after JGC comments and videoconference held on 09/07/2018	Andrea Rossi, Ilaria Mazza, Marco Pontiggia	Stefano Cappellozza	Claudio Mordini	13/07/2018

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

ABBREVIATIONS AND ACRONYMS

AIS	Automatic Identification System
ARPA	Automatic Radar Plotting Aid
ASD	Azimuth Stern Drive Tug
CLIENT	JGC Corporation
ECDIS	Electronic Chart Display and Information System
FSRU	Floating Storage Regasification Unit
HAZID	Hazard Identification Study
HAZOP	Hazard and Operability Study
HIPPS	High Integrity Pressure Protection System
HSE	Health Safety Environment
IRPA	
LNG	Liquefied Natural Gas
LNGC	LNG Carrier
LPG	Liquefied Petroleum Gas
LSIR	Location Specific Individual Risk
MAH	Major Accident Hazards
N	North
NE	North East
NG	Natural Gas
ORF	Onshore Receiving Facilities
PFD	Process Flow Diagram
PQA	Port Qasim Authority
QRA	Quantitative Risk Analysis
RADAR	Radio Detection and Ranging
R&D	Research and Development
SW	South West
S	South
TBD	To be discussed
UK	United Kingdom