Quantitative Risk Assessment Report

Engro Vopak Terminal Limited, Karachi.

SHEPHERD RISK

Safety, Risk & Loss Prevention Engineering

ENGRO VOPAK TERMINAL LTD.

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Executive Summary

As part of Hazards and Effects Management Process, Engro Vopak Terminal Limited (EVTL) carried out Quantitative Risk Assessment (QRA) study of the Chemical & RLNG Terminal and Storage facility at Port Qasim Karachi. QRA was carried out by M/S Shepherd Risk consultants.

A Quantitative Risk Assessment (QRA) is used to make decisions for the terminal on whether or not it should consider alternatives to reduce the risk to meet the risk tolerance criteria.

A QRA is a method of translating the risks associated with running a technical process with hazardous substances into interpretable risk contours, thereby giving insight into the process safety risks. Acute hazards are the principle concern of a QRA.

Using a software program and based on mathematical and physical relations the consequences of incidents (loss of containment, explosions, fires etc.) can be quantified. The risk is presented graphically by means of individual risk contours, connecting points with the same risk level and the societal risk curve (F-N curve).

Risk Assessment Summary:

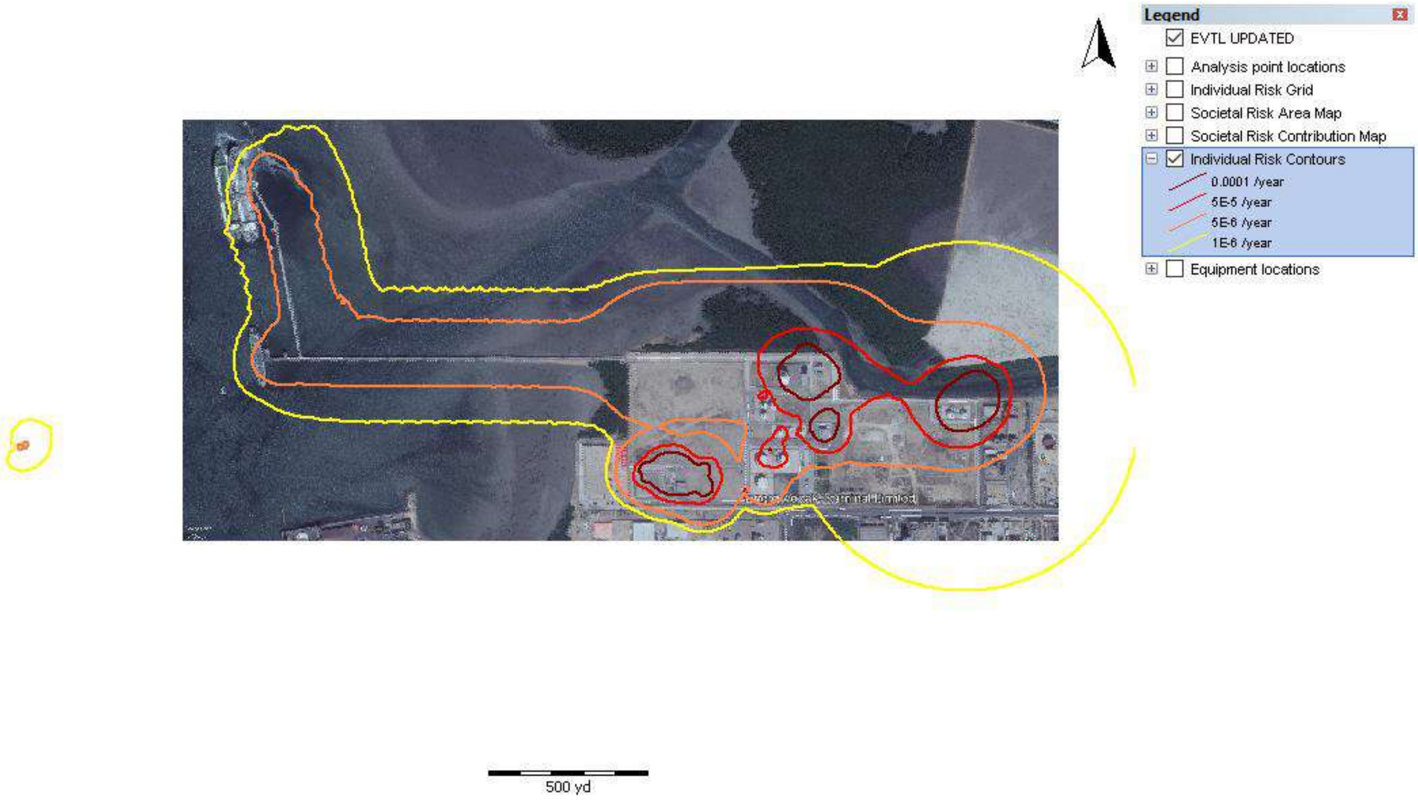
The base case risk assessment did not take credit of Fire & Gas detection and Emergency Shutdown System as 1) there is no comprehensive documented study on Fire & Gas detection mapping & coverage assessment; 2) SIL assessment & verification study has not been carried out and 3) no documented Human Factors Assessment made to demonstrate that ESD can be initiated manually within available safety times; due to these factors risk mitigation factor of F&G detection and ESD system cannot be quantified hence not included in risk calculations. A hypothetical scenario has been run to assess the impact of F&G detection and ESD system on risk, based on an assumed risk reduction factor.

Base case – without credit for ESD system:

Individual risk results are shown in table below.

Individual Fatality Risk (IR) contour	Limit	Extent	Satisfy Individual Risk Criteria, Y/N
$5x10^{-5}$/yr	Should not extend beyond Facility Battery limit	Extends slightly beyond facility fence on to neighboring industry	N
$5x10^{-6}$/yr	Extends to industrial developments only	Extends to industrial developments	Y
$1x10^{-6}$/yr	Extends to commercial and industrial developments only	Extends to industrial and port developments	Y

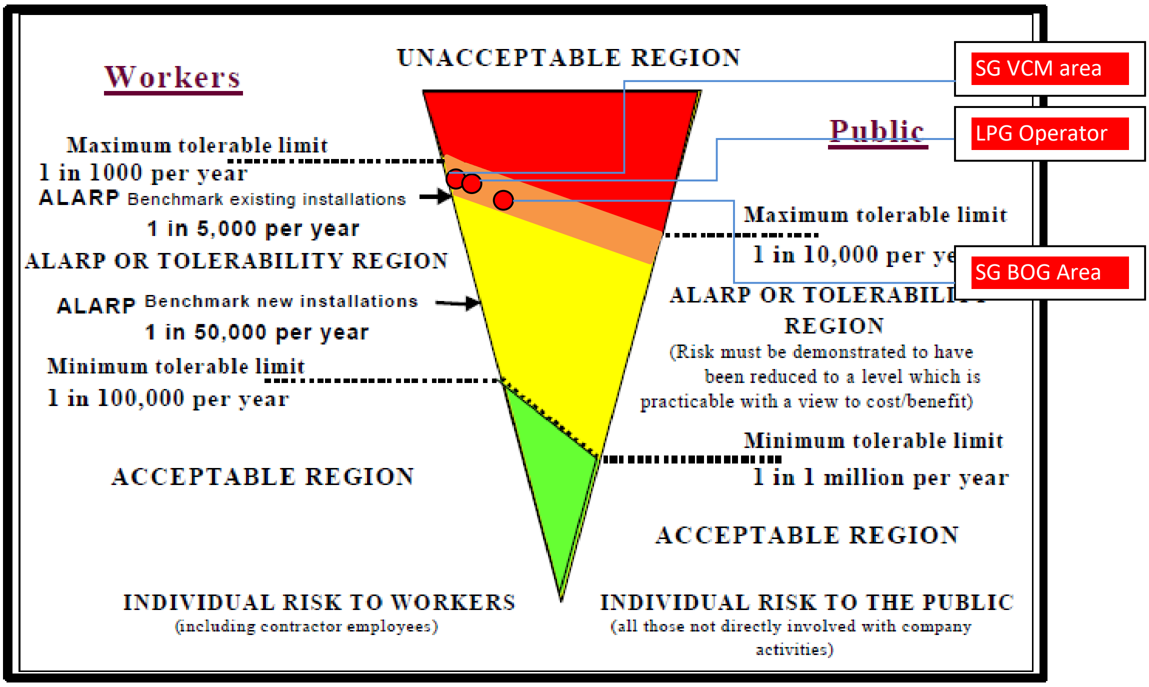
Individual risk: Risk graph shows some high Individual Risk areas (> $1x10^{-4}$per yr) within plant site. Risk to some of the operations personnel is <u>unacceptable</u> per risk acceptance criterion; this is due to very high exposures of these personnel within high risk areas.



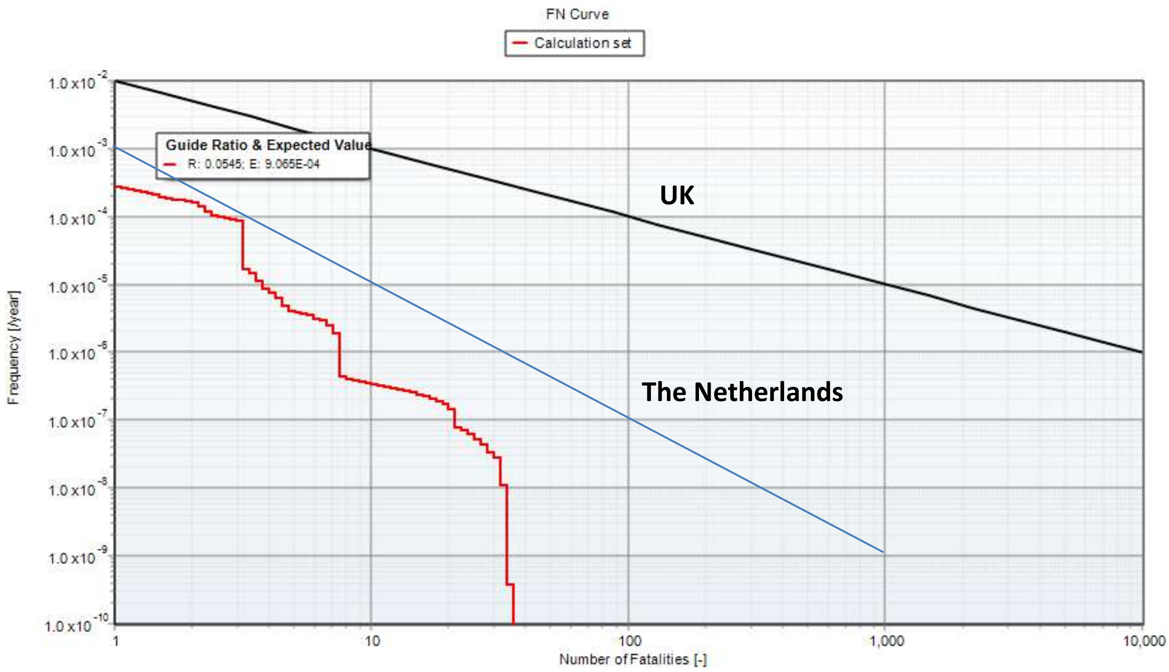
Risks to LPG operator, Security Guard at VCM Storage area and Security Guard at BOG area are unacceptable per risk acceptance criteria of $2x10^{-4}$/yr for onsite workers, risk is only acceptable if occupancy of personal decrease as per table given below:

Group name		Max allowable occupancy, %
CP3	SG VCM area	50
CP2	SG BOG area	80
BL03	LPG operator	50

Risks to third party personnel i.e. Bowser drivers is within acceptable limits per risk acceptance criteria of 1x10-4/yr for third party/public.



Societal risk graph shows risk is below upper acceptable line per UK HSE criterion, while as per Dutch criterion societal risk is slightly above the line. EVTL follows UK risk criteria.

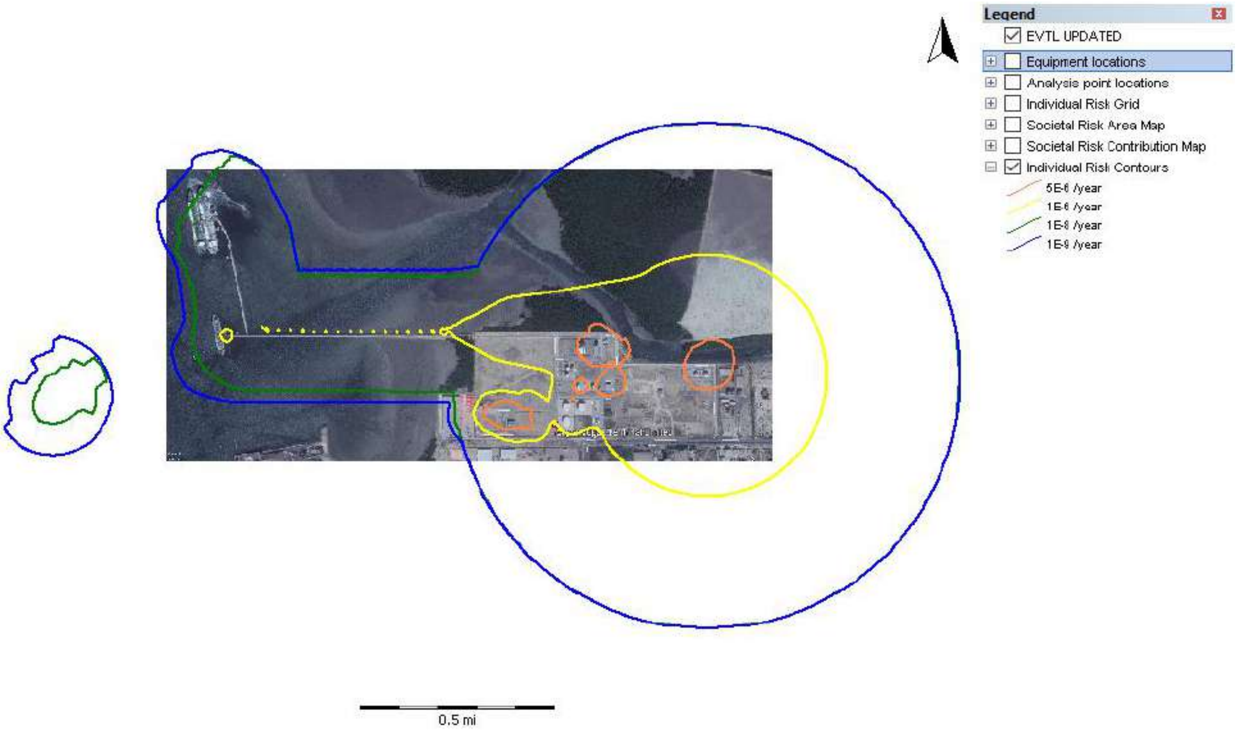


Consequence models show Vopak criteria are not complied for radiations level beyond facility fence and on onsite occupied buildings. Jet fire scenarios at Chemical Jetty or RLNG line are likely to damage FW pump house.

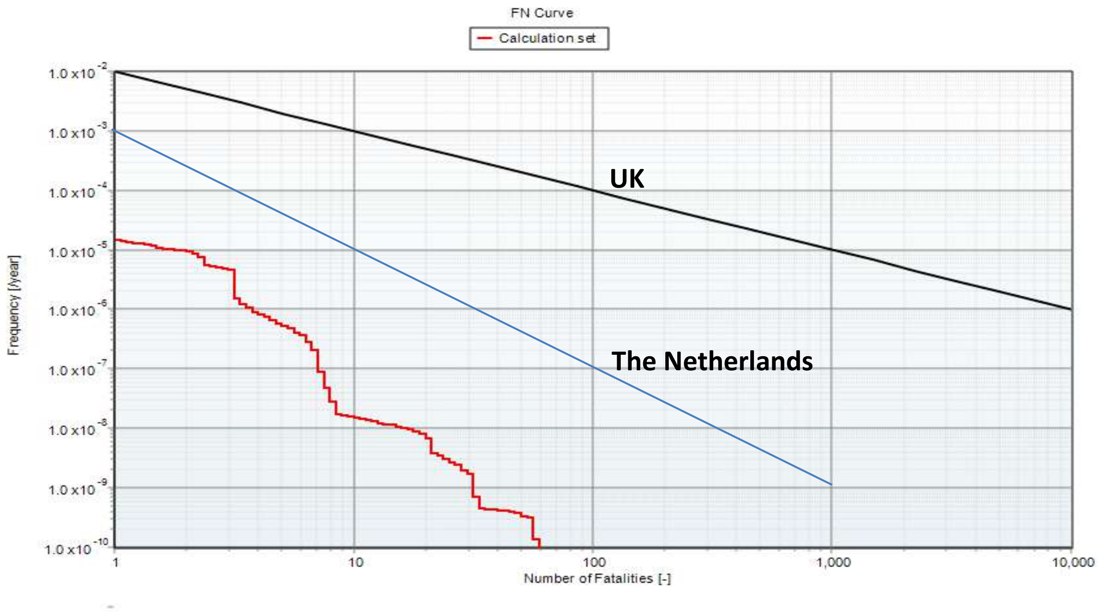
Radiation level	Criteria	Criteria Met Y/N	Comments
$3Kw/m^2$	Should not exceed facility battery limits.	No	$3Kw/m^2$ exceeds facility battery limits
	Firefighting equipment shall not be located within $3K/m^2$ contour	No	Most of the firefighting equipment (hydrants, monitors, valves) are located within 3 Kw/m^2 contour.
	Manned buildings (offices, control room shall be outside 3kw/m2 contour)	No	Office building/CR is within $3kw/m^2$ contour. Distance between P-Xylene tank and Office/Control room building is less than 50m (from center of tank) and less than 15m from dyke edge which is less than minimum spacing per most of industry spacing guidelines; Exxon (120m), Shell/GAPS (75m)
$10Kw/m^2$	Tanks within 10Kw/m2 contour shall be cooled by fixed system	Yes	All tanks require fixed cooling system as they fall within 10 kw/m2 contour from fires other than on equipment itself.

Risk Analysis with ESD Credit – a hypothetical scenario has been evaluated to assess the risk if Fire & Gas detection and ESD system provide adequate scenario coverage and isolation within reasonable time – 120 sec.

Results show significant risk reduction, Criteria is met for 5×10^{-5}/yr Individual risk contours not stretching beyond facility battery limits and there is no high risk ($> 1 \times 10^{-4}$) area within the plant site.



Societal risk curve shows the risk line stays well below The Netherlands risk criteria.



Conclusions & Recommendations

QRA results show that EVTL/Vopak societal risk criteria is in acceptable range but unmitigated risk criteria for Individual Risk are not met. Iso Risk Contour of $5x10^{-5}$/yr exceed beyond fence over neighboring industry, risk to security guards at VCM storage area, Ethylene storage area and LPG is unacceptable per company risk acceptance criteria, risk can be reduced by decreasing occupancy, for detail see section 3.1 and recommendation 5 & 6. Radiation contours of 3kW/m^2 and 10kW/m^2 exceed facility battery limits and Occupied Buildings siting criteria. Risk Assessment with credit for certain risk mitigations such as F&G detection system and automatic ESD show significant risk reduction.

Following risk mitigation measures have been suggested. Implementation should be subject to cost benefits analysis based on QRA.

1. Develop 3D mapping for installation of F&G detectors at locations not covered in previous mapping studies.
2. Review and update ESD philosophy, consideration shall be given to automatic ESD upon gas or fire detection to achieve the objective of isolation and blow-down within 120 seconds.
3. Develop and implement plan for SIL studies with HAZOP revalidation cycle. Implement IEC-61511 Safety Instrumented System lifecycle requirements to ensure all safety instrumented functions including F&G detection system achieve minimum SIL 1 for all safety functions throughout project life.
4. All ESD valves shall be fire proofed. Develop and implement plan for replacement of MOVs with ESD valves as per maintenance/obsolesce need; all new and existing ESD valves shall be fire proofed.
5. Security check post near Ethylene storage and VCM storage shall be relocated to a safer location outside $1x10^{-4}$/yr risk contour, refer to Figure 12 (if recommendation 1 - 4 are implemented, then this recommendation can be dropped as in case of ESD credit, risk at subject security post is acceptable) or limit the occupancy of the security guards to the maximum of 12 hr per day.
6. Operator cabin at Ethylene area shall be designated unoccupied and preferably demolished as it is no more functional as operator cabin.
7. All fixed Fire monitors shall have remotely operated valves (from control room).
   If this recommendation can be implemented with total spending not exceeding values given in Cost-benefits-Analysis sheet in Annex-4 than implement the recommendation else additional spending on risk mitigation is not justified. If the cost of implementation of this recommendation exceeds values given in Annex-4 then;
   Provide NFPA/ASTM rated fire fighters suits to fire responders suitable for fire radiations up to 12.5Kw/m2 for 60 seconds.
8. FW pump house shall be protected from fire impact either by relocating to outside 3kW/m^2 radiation contour or providing fire rated walls. It is better to relocate to a safer location so that room is approachable by operator in case of fire, refer to Figure 22.
   Refer to Annex-4, Risk of consequential damages is extremely low and acceptable per EVTL risk acceptance criteria hence on risk basis this recommendation can be dropped.
9. Relocate Assembly point to a safe location, out of 1.6Kw/m^2 contours.
10. Designate the Office Building/Control Room as Shelter-in-Place for the duration of event. This would require assurance on fire radiation (10 KW/m2) resistance of building structure for the duration of event; further study is required to upgrade the building as Shelter-in-Place. Based on QRA, risk to Office building personnel is 1.08E-06 which is acceptable, hence on risk basis no action is required, for detail see section 4.3.
11. Review and update ERP in light of QRA report; develop scenario based pre plans.

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Definitions

BLEVE	BLEVE is defined as a sudden loss of containment of a pressure-liquefied gas existing above its normal atmospheric boiling point at the moment of its failure, which results in rapidly expanding vapor and flashing liquid. The release of energy from these processes (expanding vapor and flashing liquid) creates a pressure wave
Blast	A rapidly propagating pressure of shock-wave in atmosphere with high pressure, high density and high particle velocity
Confinement	A qualitative or quantitative measure of the enclosure or partial enclosure areas where vapors cloud may be contained.
Congestion	A qualitative or quantitative measure of the physical layout, spacing, and obstructions within a facility that promote development of a vapor cloud explosion.
Consequence	A measure of the expected effects of an incident outcome case.
Effect zone	For a loss of containment incident producing thermal radiation effects, the area over which a particular incident outcome case produces an effect based on a specified thermal damage criterion.
Event sequence	A specific unplanned sequence of events composed of initiating events and intermediate events that may lead to an incident.
F/N Curve	The two-dimensional relationship between frequency and cumulative severity of outcome.
Frequency	A number of occurrences of an event per unit of time.
Hazard	A chemical or physical condition that has the potential for causing damage to people, property, or the environment.
Incident	The loss of containment of material or energy.
Incident outcome	The physical manifestation of the incident; e.g. for flammable materials, the incident outcome, could be a flash fire, jet fire, vapour cloud explosion, etc.
Initiating event	The first event in an event sequence (e.g., corrosion resulting in leak/rupture of a pipeline).
Likelihood	A measure of the expected probability or frequency of occurrence of an event. It may be expressed as a frequency (e.g., events/year), a probability of occurrence during some time interval, or a conditional probability (i.e. probability of occurrence given that a precursor event has occurred)
Probability	The expression for the likelihood of occurrence of an event or an event sequence during an interval of time or the likelihood of occurrence of the Success or failure of an event on test or demand. By definition, the Probability must be expressed as a number ranging from 0 to 1.
Risk	A measure of human injury, environmental damage or economic loss regarding both the incident likelihood and the magnitude of the loss or injury
Risk analysis	The development of a quantitative estimate of risk based on engineering evaluation and mathematical techniques for combining estimates of incident consequences and frequencies.
Risk assessment	The process by which the results of a risk analysis are used to make decisions, either through a relative ranking of risk reduction strategies or comparison with risk targets.
Vapour Cloud Explosion	The explosion resulting from an ignition of a pre-mixed cloud of flammable vapour, gas or spray with air, in which flames accelerate to sufficiently high velocities to produce significant overpressure.

Abbreviations

BLEVE	Boiling Liquid Expanding Vapour Explosion
ESD	Emergency Shut Down system
FBR	Full Bore Rupture
FF	Flash Fire
IRPA	Individual Risk per Annum
JF	Jet Fire
LFL	Lower Flammability limit
LPG	Liquified Petroleum Gas
LSIR	Location Specific Individual Risk
P&ID	Piping and Instrumentation Diagram
PF	Pool Fire
QRA	Quantitative Risk Assessment
RLNG	Liquefied Natural Gas
VCE	Vapour Cloud Explosions

1 Introduction

As part of Hazards and Effects Management Process, Engro Vopak Terminal Limited (EVTL) carried out Quantitative Risk Assessment (QRA) study of the Chemical & RLNG Terminal and Storage facility at Port Qasim Karachi. QRA was carried out by M/S Shepherd Risk consultants.

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1.1 Scope

Scope of this QRA includes

- Chemical Storage terminal
- Chemical & LPG Jetty
- LPG storage and loading facility
- LPG Expansion Project (future)
- RLNG Jetty & Pipeline
- RLNG Jetty & Pipeline -Future

1.2 Process Description

There are three main processes at the EVTL Terminal.

- Chemical unloading/loading jetty and Chemical Storage and shipping;
- RLNG Jetty and pipeline and
- LPG Storage.

Chemical Jetty & Storage: The Chemical Jetty & Storage comprises of, Ethylene, Vinyl Chloride Monomer (VCM), Ethylene Di Chloride (EDC), Paraxylene, Mono Ethylene Glycol and Acetic Acid unloading, storage and shipping operations. Ethylene and VCM are pumped to customer via pipeline while EDC, Paraxylene, MEG, Acetic Acid and Phosphoric Acid are shipped via. road tankers.

RLNG: RLNG operations comprise of an FSRU (not part of EVTL operations) RLNG Jetty (ESD Station) and pipeline. The FSRU is operated by a third party, hence not included in QRA scope.

A second RLNG jetty and pipeline will be added in near future. This expansion scope is included in QRA.

LPG: LPG operations included LPG mounded bullets and LPG shipment via. road tankers. There are total of 10 LPG Bullets and 04 tanker loading stations in operations. Four (04) bullets and two additional loading stations will be added to the LPG facility.

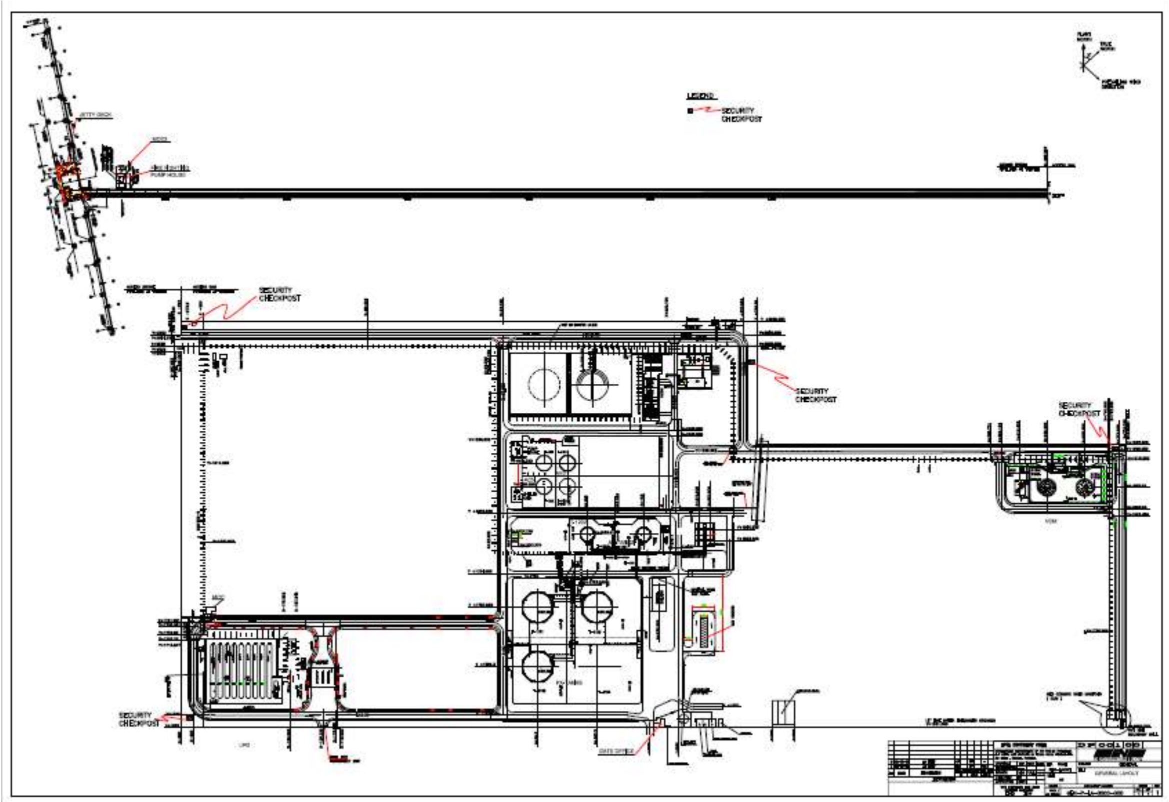


Figure 1: EVTL Plot Plan

Figure 2: EVTL Google earth view

2 Methodology

2.1 General

QRA has been conducted in line with VOPAK QRA Guidelines[1], CCPS Guidelines for Quantitative Risk Assessments[2], TNO Guideline[3] and industry practices.

Setting up a QRA is a specialist task requiring detailed knowledge as well as experience.

The classical quantitative risk analysis process has the following phases:

Hazard Identification

Identifies all potential hazards to personnel, assets, environment and loss of containment scenarios; especially those credible scenarios with off-site impacts.

Evaluation of Consequences and Impacts

The Consequence Evaluation determines hazard zones, considering all the different ways releases can develop. The Impact Evaluation determines the impacts of these consequences on population.

Evaluation of Frequencies

Estimate the event frequency per year for credible incident scenarios based on relevant historical failure frequencies.

Risk Estimation

Frequency and impact information is combined

Assessment of the Risks

First compares the risks calculated with criteria fixed in advance so as to determine their acceptability.

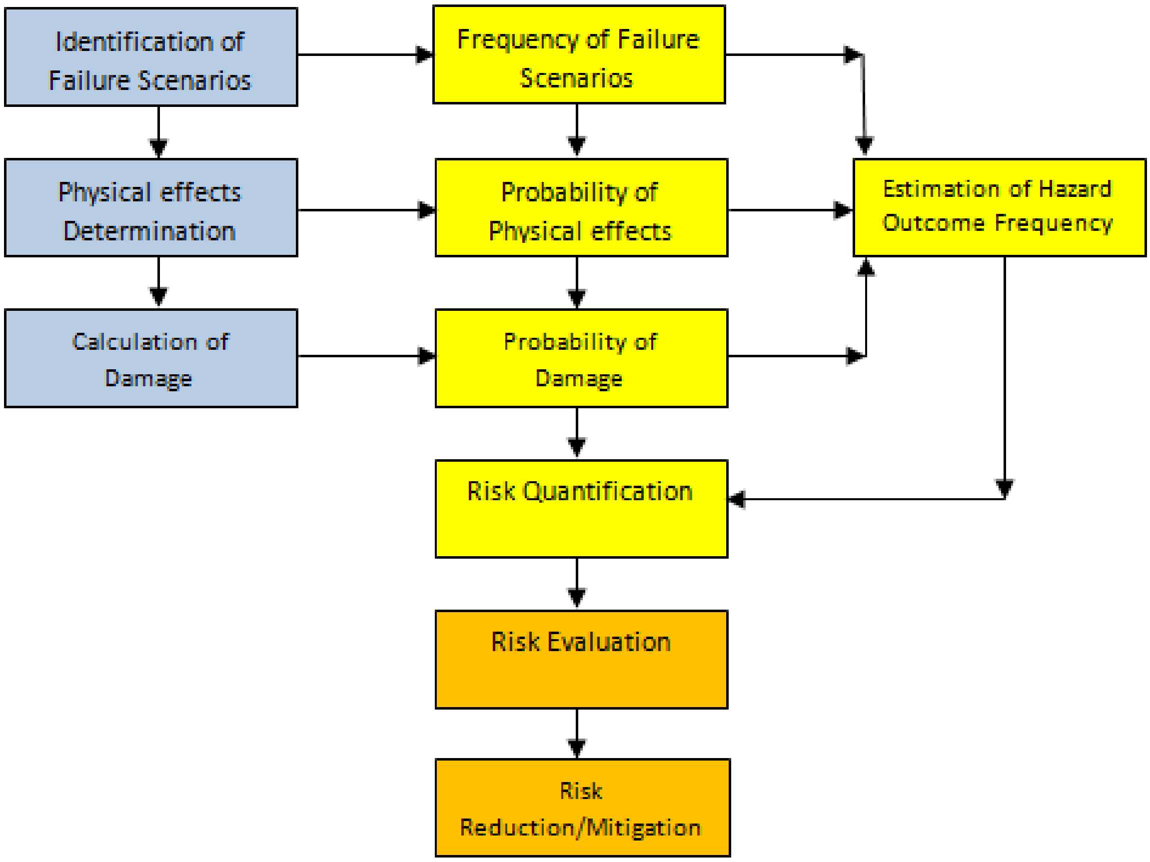


Figure 3: QRA Process

2.2 Hazard Identification

A Hazard Identification (HAZID) exercise has been carried out using a comprehensive generic HAZID checklist. This activity was conducted to provide the starting point for the QRA by identifying those hazards to be included in the assessment.

Table 1: Hazard Inventory

Chemical	UN/ IMO Hazard class	Major Hazards	Physical form	Type of Container	Unit Capacity of Container, MT	Max Qty. Stored On-Site, MT*2
AA	2789	PF	Liquid	Vertical Vessel (Cone roof)	2074	4148
Ethylene	1038	JF, FF, PF, EXP, BLEVE	Liquefied gas	Vertical Vessel (Cone roof)	6072.9536	6072
PX	1307	PF	Liquid	Vertical Vessel (Cone roof)	8160.96	24482
LPG	1075	JF, FF, PF, EXP, BLEVE	Liquefied gas	Horizontal Bullets	1201	8707
VCM	1086	JF, FF, EXP, BLEVE	Liquefied gas	Sphere	2682	5364
EDC*3	1184	PF	Liquid	Vertical Vessel (Cone roof)	3174.4	6348
MEG	3082	None	Liquid	Vertical Vessel (Cone roof)	3562	3561
Phosphoric Acid	1805	None	Liquid	Vertical Vessel (Cone roof)	-	-
Diesel*1	1202	PF	Liquid	Vertical Vessel	14	56

*1- due to small quantities, Diesel pool fire risks are not included in this QRA. *2- Max Qty. Stored On-Site is calculated by filling 80% of the storage tank volume. *3- As per Engro Vopak major risk assessment standard, section 6.1, EDC does not fall in toxic liquid categories, so toxic calculations are not evaluated in this study.

2.2.1 Loss of Containment Scenarios

To identify the loss of containment scenarios, the terminal process is divided into isolatable sections based on the isolation valves as indicated in the P&IDs and locations. These isolatable sections are further broken down into subsections based on the material types, phase and conditions of the material.

Consequence modeling is performed on TNO EFFECTS software. Consequence scenarios are developed based on event tree analysis. A basic event tree is shown in figure 4 below.

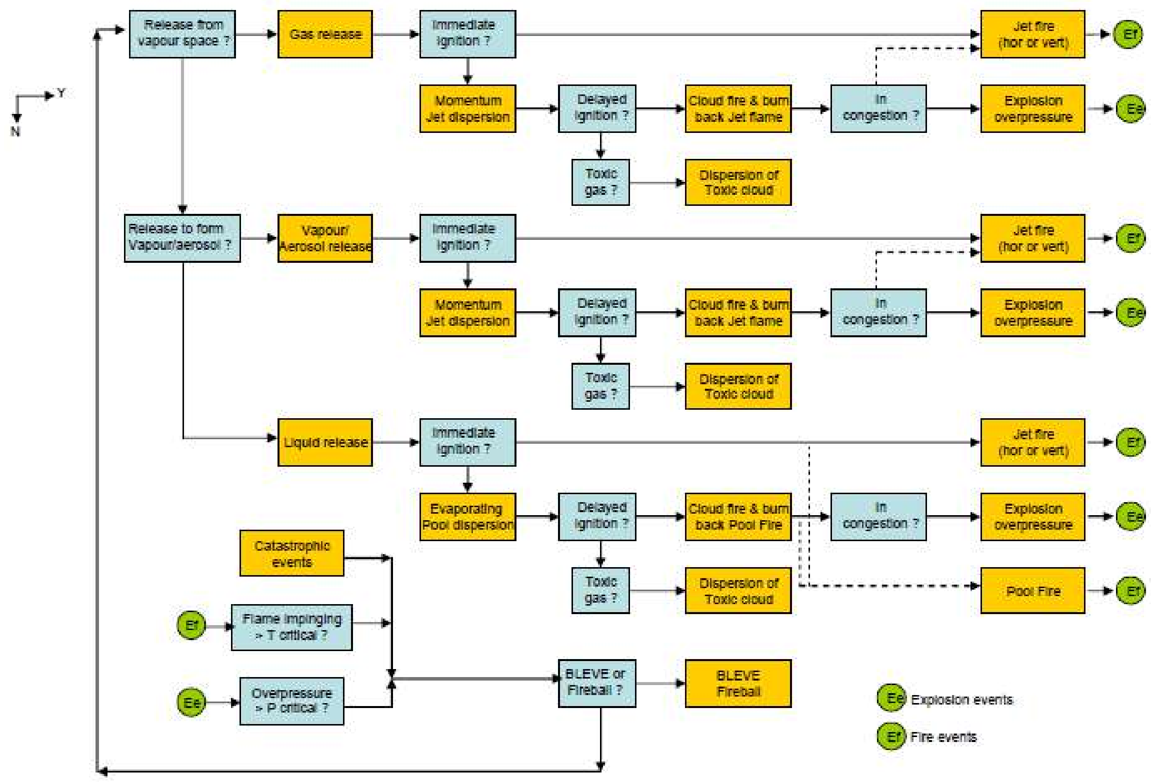


Figure 4: Event Tree

Based on the event tree models for each isolatable inventory and potential release points, the loss of containment scenarios are listed in Table 2. The consequences associated with each hazard scenario are discussed further in Section 4.3.1.

Table 2: HAZARD Scenario Sheet

ID	Material	Release Point	Line ID	Release Height, m	T, °C	P, barg	Phase	Isolatable Inventory, m3	Scenario
A01	AA	H20210	8" AA 2021 RHT	1.2	30	2.1	L	2500	PF
A02	AA	H20202	8" AA 2021 RHT	1	30	2	L	2559	PF
A03	AA	XV12611	8" AA 1211 RHT	1	30	0	L	2559	PF
A04	AA	PVRV	PVRV	15	29	0	V	2500	PF
A05	AA	T-1201	T-1201	0	29	0	L	2500	PF

A06	AA	XV-12621	8" AA 1221 RHT	1	31	0	L	2559	PF
A07	AA	PVRV	PVRV	15	27.7	0	V	2500	PF
A08	AA	T-1202	T-1202	0	27.7	0	L	2500	PF
A09	AA	XV12661	4" AA 2111 RHT	1	30	1.8	L	2500	PF
A10	AA	H21114	4" AA 2111 RHT	5	30	2.4	L	2500	PF
A11	AA	Pipework	8" AA 2021 RHT	1	30	2	L	2559	PF
E01	Ethylene	HV-1112	P-1001-8"-3A3-C100	0.8	-102	4	L	13050	PF
E02	Ethylene	HV-1114	P-1001-2"-3A3-C65	1	-102	4	L	3	PF
E03	Ethylene	MV-1025	P-1001-8"-3A3-C100	22	-102	4	L	13050	JF, FF
E04	Ethylene	PVRV 1226	N7B	22	10	0.1	0	13000	JF, FF
E05	Ethylene	PVRV-1224	N6A	22	10	0.1	0	13000	JF, FF
E06	Ethylene	MV-1062	P-1027-2"-3A3-C65	22	-102	22	L	13000	JF, FF
E07	Ethylene	V-1520	0	2	50	16	L	13000	JF, FF, BLEVE
E08	Ethylene	MV-1042	V-1015-10"-1A3-C100	22	-55	1.2	V	13009	JF, FF
E09	Ethylene	MV-1051	P-1016-3"-1A3-C75	22	-102	22	L	13001	PF, FF
E10	Ethylene	T-1501	T-1501	0	-102	0.2	L	13000	JF, FF
E11	Ethylene	MV-1336	P-1026-3"-3A3-C75	0.8	-102	22	L	13001	JF, FF
E12	Ethylene	MV-1319	V-1353-4"-3A3-C40	0.8	30	25	V	13001	JF, FF
E13	Ethylene	MV-1315	V-1355-4"-3A3-C40	0.8	30	25	V	13001	JF, FF
E14	Ethylene	V-1521	0	0	30	23	V	13001	JF, FF
E15	Ethylene	MV-2122	V-1356-6"-3A3-PP50	0.5	30	23	V	13099	JF, FF
E16a	Ethylene	MV-2146	V-1015-10"-1A3-C100	2	-50	0.2	V	13009	JF, FF
E16b	Ethylene	MV-2183	V-1077-10"-1A3-C100	2	-50	0.2	V	13009	JF, FF
E17a	Ethylene	MV-2159	V-1076-4"-3A3-PP50	2	140	25	V	13000	JF, FF

E17b	Ethylene	MV-2196	V-1093-4"-3A3-PP50	2	140	25	V	13000	JF, FF
E18a	Ethylene	MV-2209	P-1079-3"-3A3-C75	2	-30	21	L	13001	JF, FF
E18b	Ethylene	MV-2208	P-1095-3"-3A3-C75	2	-30	21	L	13001	JF, FF
E19	Ethylene	MV-2253	V-1101-4"-3A3-PP50	2	110	25	V	13001	JF, FF
E20	Ethylene	Pipework	P-1001-8"-3A3-C100	22	-102	4	L	13050	JF, FF
P01	PX	H-20110	12" PX 2011 RHT	1	30	2.8	L	12001	PF
P02	PX	H-20102	12" PX 2011 RHT	0	30	1.3	L	12125	PF
P03	PX	T-1101	T-1101	0	30	0.1	L	12000	PF
P04	PX	T-1102	T-1102	0	30	0	L	12000	PF
P05	PX	T-1103	T-1103	0	30	0.1	L	12000	PF
P6a	PX	XV 11611	12" PX 1111 RHT	1	30	1.3	L	12003	PF
P6b	PX	XV 11621	12" PX 1121 RHT	1	30	1.3	L	12007	PF
P6c	PX	XV 11631	12" PX 1131 RHT	1	30	1.3	L	12003	PF
P7a	PX	Y11101	PVRV	15	30	0.1	V	12000	PF
P7b	PX	Y11201	PVRV	15	30	0.1	V	12000	PF
P7c	PX	Y11301	PVRV	15	30	0.1	V	12000	PF
P8	PX	XV 11661	4" PX 1163 RHT	0	30	4.2	L	12003	PF
P09	PX	XV21621	4" PX 2121 RHT	5	30	4.2	L	12001	PF
P10	PX	Pipework	12" PX 2011 RHT	0	30	1.3	L	12125	PF
PL01	LPG	SDV201	12"-PL-BC2-2001	0.5	30	11	L	1207	JF, FF
PL02	LPG	HV201	12"-PL-BC2-2003	0	30	11	L	1207	JF, FF
PL03a	LPG	V-201B inlet valve	12"-PL-BA2-2005	5.5	30	11	L	1118	JF, FF
PL03b	LPG	V-201J Inlet valve	12"-PL-BA2-2168	5.5	30	11	L	1118	JF, FF
PL03c	LPG	V-202A Inlet Valve	12"-PL-BA2-2040	5.5	30	11	L	1116	JF, FF

PL04a	LPG	V-201B Outlet valve	10"-PL-BA2-2007	-1	30	11	L	1104	JF, FF
PL04b	LPG	V-201J Outlet valve	10"-PL-BA2-2122	-1	30	11	L	1101	JF, FF
PL04c	LPG	V-202A Outlet Valve	10"-PL-BA2-2042	-1	30	11	L	201	JF, FF
PL05	LPG	6" P-201A outlet valve	6"-PL-BA2-2024	0	30	11	L	1102	JF, FF
PL06a	LPG	3" Manual Valve	3"-PL-BA2-2045	0.3	30	11	L	1100	JF, FF
PL06b	LPG	3" Manual Valve	3"-PL-BA2-2047	0.3	30	11	L	1100	JF, FF
PL07	LPG	LPG BOUZER	LPG BOUZER	1	30	11	L	1100	FF, BLEVE
PV01a	LPG	6" Manual Valve	6"-PV-BA2-2080	5.5	30	9	V	1106	JF, FF
PV01b	LPG	6" Manual Valve	6"-PV-BA2-2107	5.5	30	9	V	1106	JF, FF
PV01c	LPG	6" Manual Valve	6"-PV-BA2-2075	5.5	30	9	0	1106	JF, FF
PV06a	LPG	2" Manual Valve	2"-PV-BA2-2068	0.5	30	9	V	1101	JF, FF
PV06b	LPG	2" Manual Valve	2"-PV-BA2-2070	0.5	30	9	V	1101	JF, FF
PLE03d	LPG	0301K	12"-PL-BD2-3012	6	30	11	L	3207	JF, FF
PLE04d	LPG	0232K	10"-PL-BD2-3025	-1	30	11	L	3101	JF, FF
PVE01d	LPG	BV0304K	6"-PV-BD2-3040	6	30	9	V	3100	JF, FF
PLE03e	LPG	0301M	12"-PL-BD2-3014	6	30	11	L	3100	JF, FF
PLE04e	LPG	0232M	10"-PL-BD2-3027	-1	30	11	L	3100	JF, FF
PVE01e	LPG	BV0304M	6"-PV-BD2-3040	6	30	9	V	3100	JF, FF
PLE06c	LPG	BV0243E	3"-PL-BD2-3020	0.5	30	11	L	3100	JF, FF
PVE06c	LPG	BV0251E	2"-PV-BD2-3046	0.5	30	9	V	3100	JF, FF
PL08	LPG	Pipework	12"-PL-BC2-2003	1	30	11	L	3207	JF, FF

V01	VCM	BV026	8"-VCL-AA2-1002	0.2	30	9	L	3819	JF, FF
V02	VCM	BV032	8"-VCL-AA2-1002	-1	30	9	L	3819	JF, FF
V03	VCM	BV-087	8"-VCL-AA2-1004	-1	30	9	L	3819	JF, FF
V04	VCM	BV110	10"-VCL-AA2-1007-HC	1	30	9	L	3751	JF, FF
V05	VCM	BV082	10"-VCL-AA2-1008-HC	1	30	9	L	3751	JF, FF
V06	VCM	BV053	6"-VCL-BA2-1012-PP	0	30	12	L	408313	JF, FF
V07	VCM	V-101A	V-101A	0	30	7	L	3750	JF, FF
V08	VCM	V101B	V101B	0	30	5	L	3750	JF, FF
V09a	VCM	PVRV	V-101A	20	50	10	V	3750	JF, FF
V09b	VCM	PVRV	V101B	20	50	10	V	3750	JF, FF
V10	VCM	Pipework	8"-VCL-AA2-1002	-1	30	9	L	3819	JF, FF
ED01	EDC	BV009	8"-EDL-AA2-3003	0.8	30	1.8	L	3200	PF
ED02	EDC	BV043	8"-EDL-AA2-3003 (H)	-1	30	1	L	3250	PF
ED03	EDC	BV206	8"-EDL-AA2-3011 (H)	0	30	1	L	3252	PF
ED04	EDC	BV210	8"-EDL-AA2-3008 (H)	0	30	1	L	3252	PF
ED05	EDC	BV063	4"-EDL-AA2-3009 (H)	0.8	30	1.8	L	3201	PF
ED06	EDC	BV089	4"-EDL-AA2-3015 (H)	5	30	1.8	L	3200	PF
ED07	EDC	T-1301		0	30	0.2	L	3200	PF
ED08	EDC	T-1302		0	30	0.2	L	3200	PF
ED09	EDC	Pipework	8"-EDL-AA2-3003 (H)	1	30	1	L	3250	PF
NG01	RLNG	ZV1053A	PH-1-0007-B4-300	1	10	100	G	2100	JF
NG02	RLNG	ZV3014	PH-3-00011-XXX-600	1	10	100	G	2100	JF
NGE01	RLNG	Future	Future	1	10	100	G	2100	JF

NG03	RLNG	Pipework from existing Jetty	PH-3-00011-XXX-600	1	10	100	G	2100	JF
NG04	RLNG	Pipework from new Jetty	PH-3-00011-XXX-600	1	10	100	G	2100	JF
NG05	RLNG	Buried RLNG pipeline to CTS	PH-3-00011-XXX-600	1	10	100	G	2100	FBR

*PLE03e, NGE01 “**E**” stand for expansion project

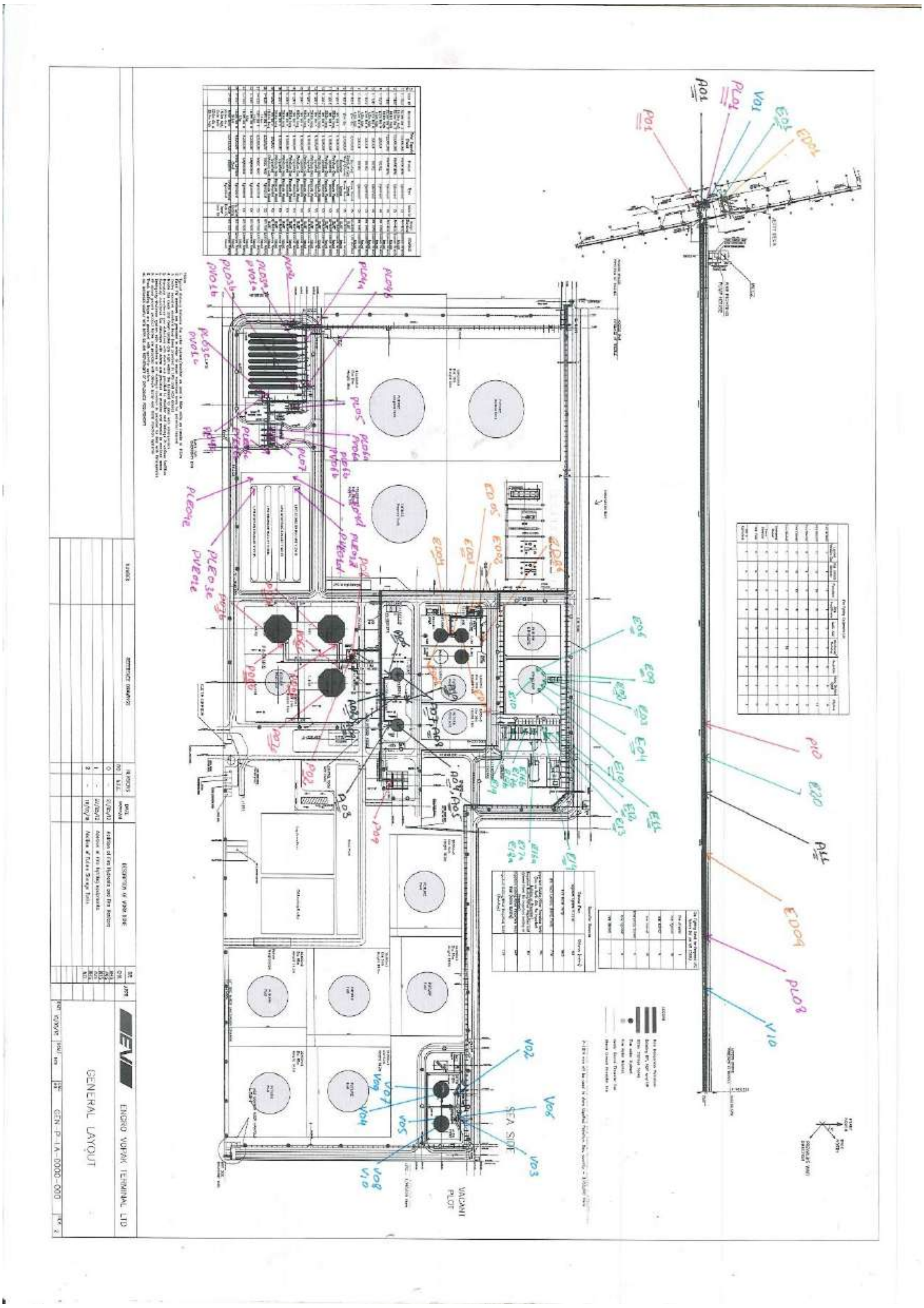


Figure 5: Release Locations

2.3 Consequence Analysis

This part of the analysis involves the following:

- Allocation of a release type (vapor, two phase etc) and hazard type (dispersion, fire, flash fire etc).
- Determination of release rate for each scenario. Release rates were calculated for small (10mm), medium (35mm) and large (100mm) holes.
- Association of each scenario with the type(s) of hazardous event that could occur should there be ignition (i.e. jet fire, flash fire etc).
- Determination of the consequences. Dispersion distances, distances to thermal radiation levels and distance to blast overpressure have been determined using TNO RISKCURVES software.

2.3.1 Consequence Scenarios

Hydrocarbon releases in the industry are either gaseous, mists or liquids and are either atmospheric releases or pressurized. Gas and mist releases are considered more significant since they are readily ignitable since they are in the gas state and due to the generation of vapour clouds which if ignited are instantly destructive in a widespread nature versus liquid fires that may be less prone to ignition, generally localized and relatively controllable.

The cause of a release can be external or internal corrosion, internal erosion, equipment wear, metallurgical defects, operator errors third party damage or for operational requirements.

Generally releases are categorized as:

1. **Catastrophic Failure:** A vessel or tank opens completely immediately releasing its contents. The amount of release is dependent of the size of the container.

2. **Pipeline Rupture (Guillotine flow)** A section of pipe is removed leading to two sources of gas. Each section being vented in an opening whose cross sectional areas are equal to the cross sectional area of the pipe (e.g., pipeline external impact and a section is removed).

3. **Leak:** Leaks are typically developed from valve, flanges or pump seal packing failures, localized corrosion or erosion effects and are typically small (10mm), medium (35mm) and large (100mm) holes.

4. **Vents, Drains, Sample Ports Failures:** Small diameter piping or valves may be opened or fail which release vapours or liquids to the environment unexpectedly.

5. **Normal Operational Releases:** Process storage or sewer vents, relief valve outlets, tank seals, which are considered normal and acceptable practices that release to the atmosphere.

2.3.1.1 Gaseous Release

There are a number of factors that determine the release rate and initial geometry of a hydrocarbon gas release. The most significant is whether the gas is under pressure or released at atmospheric conditions.

Depending on the release source the escaping gas can last from several minutes or hours, until the supply is isolated, depleted or fully depressurized. Common long duration sources are massive storage equipment, or long pipelines without intermediate isolation capabilities.

If released under atmospheric conditions the gas will either rise or fall depending on its vapour density and will be directed in the path of the prevailing wind. In the absence of a wind, heavier gases will collect in low points in the terrain. Normally atmospheric gas releases are dispersed within relatively close distances to their point source, usually about 3 meters (10 ft.) These atmospheric releases, if ignited, will burn relatively close to the source point, normally in a vertical position with flames of short length.

For gases released under pressure, there are a number of determining factors that influence the release rates and initial geometry of the escaping gases. The pressurized gas is released as gas jet and depending on the nature of the failure may be directed at any direction. All or part of a gas jet may be deflected by surrounding structures or equipment.

If adequate isolation capabilities are available and employed, the initial release will be characterized by high flow and momentum which decreases as isolation is applied or supplies are exhausted.

Within a few pipe diameters of the release point, the pressure of released gases decreases. Escaping gases are normally very turbulent and air will immediately be drawn into the mixture. The mixing of air will also reduce the velocity of the escaping gas jet. Obstacles such overhead platforms or structures will disrupt momentum forces of any pressurized release. These releases will generally produce a vapour cloud, which if not ignited will eventually disperse in the atmosphere. Where turbulent dispersion processes are prevalent (e.g., high pressure flow, winds, congestion, etc.), the gas will spread in both horizontal and vertical dimensions while continuing mixing with available oxygen in the air. Initially escaping gases are above the UEL but with dispersion and turbulence effects they rapidly pass into the flammable limits. If not ignited and given an adequate distance they will eventually disperse below the LEL.

Generally most gases have a low vapour density and will rise. In any event, the height of a gas plume will mostly be limited by the ambient atmospheric stability and wind speed. If the gases are ignited, the height of the plume will rise due to the increased buoyancy of the high temperature gases from the combustion process.

2.3.1.2 Liquid Release

When a liquid is released from process equipment, several things may happen. If the liquid is stored under pressure at a temperature above its normal boiling point (superheated), it will flash partially to vapour when released to atmospheric pressure. The vapour produced may entrain a significant quantity of liquid as droplets. Some of this liquid may rainout onto the ground, and some may remain suspended as an aerosol with subsequent possible evaporation. The liquid remaining behind is likely to form a boiling pool which will continue to evaporate, resulting in additional vapour loading into the air. An example of a superheated release is a release of liquid LPG from a pressurized container stored at ambient temperature.

2.3.1.3 Toxic Gas release

The inhalation of toxic gases can give rise to effects, which range in severity from mild irritation of the respiratory system to death. Lethal effects of inhalation depend on the concentration of the gas to which people are exposed and on the duration of exposure. Mostly this dependence is non linear; as the concentration increases, the time required to produce a specific injury decreases rapidly.

Immediately dangerous to life and health (IDLH) is defined as a condition that poses immediate danger to life or health, or a condition that poses a threat of severe exposure.

Two factors are considered when establishing the IDHL limits:

- Personnel must be able to escape such an environment without suffering permanent health damage,
- Personnel must be able to escape without severe eye or respiratory tract irritation or other condition that might impair their escape.

Immediately Dangerous to Life and Health: (IDLH) is an atmospheric concentration of any toxic, corrosive, or asphyxiate substance that poses an immediate threat to life or would cause irreversible or delayed adverse health effects or would interfere with an individual’s ability to escape from a dangerous atmosphere.

2.3.1.4 Fire

The combustion process: Fire, or combustion, is a chemical reaction in which a substance combines with oxygen and heat is released. Usually fire occurs when a source of heat comes into contact with a combustible material. If a combustible liquid or solid is heated it evolves vapour, and if the concentration of vapour is high enough it forms a flammable mixture with the oxygen of the air. If this flammable mixture is then heated further to its ignition point, combustion starts. Similarly, a combustible gas or vapour mixture burns if it is heated to a sufficiently high temperature.

Thus there are three conditions essential for a fire: (1) fuel, (2) oxygen, and (3) heat. These three conditions are often represented as the fire triangle.

If one of the conditions is missing, fire does not occur and if one of them is removed, fire is extinguished.

Normally the heat required is initially supplied by an external source and then provided by the combustion process itself. The amount of heat needed to cause ignition depends on the form of the substance. A gas or vapour may be ignited by a spark or small flame.

Ignition of a combustible gas or vapour mixture may occur in two ways. In the first the energy for ignition is supplied by a local source such as a spark or small flame at a point within the mixture. In the second the bulk gas mixture is heated up to its ignition temperature.

Fire growth and spread: Fire normally grows and spreads by direct burning, which results from impingement of the flame on combustible materials, by heat transfer or by travel of the burning material.

The three main modes of heat transfer are (1) conduction, (2) convection and (3) radiation. All these modes are significant in heat transfer from fires.

Conduction is important particularly in allowing heat to pass through a solid barrier and ignite material on the other side.

Most of the heat transfer from fires, however, is by convection and radiation. It is estimated that in most fires some 75% of the heat emanates by convection. On open plant much of the heat is dissipated into the atmosphere, but in steel structures it is transferred to the steel supports.

Radiation is the other main mode of heat transfer. Although it usually accounts for a smaller proportion of the heat issuing from the fire, radiated heat is transferred directly to nearby objects, does not go preferentially upwards and crosses open spaces. For these reasons it is generally the most significant mode of transfer on open plant.

Combustion of a flammable gas/air mixture occurs if the composition of the mixture lies in the flammable range and if the conditions exist for ignition. As already mentioned, ignition may result from either (1) bulk gas temperature rise or (2) local ignition.

The combustion of the mixture occurs if the bulk gas is heated up to its auto-ignition temperature. Alternatively, combustion occurs if there is applied to the mixture a source of ignition which has sufficient energy to ignite it.

Flammability limits: A flammable gas burns in air only over a limited range of composition. Below a certain concentration of the flammable gas, the lower flammability limit, the mixture is too `lean', while above a certain concentration, the upper flammability limit; it is too `rich'.

The concentrations between these limits constitute the flammable range. The lower and upper flammability limits (LFL and UFL) are also sometimes called, respectively, the lower and upper explosive limits (LEL and UEL). They are distinct from the detonability limits.

Flammability limits are affected by pressure, temperature, direction of flame propagation and surroundings.

2.3.1.4.1 Flash Fire

A flash fire would result if a flammable vapour cloud builds up and engulfs a source of ignition, or an ignition source is introduced. The volume of the combustion products are approximately 8 times the volume of the vapour cloud, hence a flash fire would be much larger than the initial un-ignited vapour cloud. Although a flash fire can cause fatalities by flame impingement, it would be of insufficient duration to cause escalation unless it develops significant overpressure. It would then be termed a vapour cloud explosion.

Due to the short duration of a flash fire, fatalities are considered to occur only within the flame itself. The size of the vapour cloud depends on:

- Release rate;
- Composition;
- Wind conditions.

Dispersion calculations should be performed to estimate the maximum gas cloud sizes within the LFL. These have been based upon horizontal releases into open air in the same direction as the wind for various wind speeds.

The results of the gas dispersion calculations shall be represented graphically. These results will be used to assess the potential for an ignition source to be engulfed in a vapour cloud, the extent of potential flash fires and the potential for explosion.

The dispersion calculations are valid for open area releases. Releases in congested areas will not disperse so readily and this will be taken into account in the assessment of effects on personnel and asset.

The conclusions from the dispersion calculations are:

- the heavier gases, propane and butane, produce similar size gas clouds for the same releases rate;
- methane gas tends to rise more rapidly due to buoyancy, particularly in light wind conditions;
- The larger the gas cloud, the greater the size of the flash fire and potential explosion overpressure upon ignition.

2.3.1.4.2 Unobstructed Jet Fires

Gas or vapor releases from holes in high-pressure hydrocarbon inventories give rise to turbulent jet fires if ignited. With this fire type pure fuel is released through an orifice and the air required for combustion is entrained from the surrounding atmosphere. At high release rates, the jet becomes highly turbulent, entrains more air and burns hotter.

The jet lengths have been modeled using TNO EFFECTS software.

Releases from the liquid phase of a process vessel (e.g. separator) will typically be driven by the vapor pressure of the liquid. Once the gas/liquid interface falls below the level of the leak a gas jet fire release will ensue driven by the pressure of the gas in the system.

High-pressure condensate releases will atomise due to the momentum of release and vaporize due to the heat from the fire and burn as a self sustaining jet, some heavier fractions can drop out when the pressure drops to below approximately 5 bar(a), resulting in surface pool fire forming below the jet fire.

Thermal radiation isopleths are proportional to the size of the jet fire. The dimensions of 3kW/m^2 and 37.5 kW/m^2 isopleths shall be calculated and included on the graph to facilitate assessment of effects on personnel and impairment of safety critical systems.

The unobstructed jet fires will only occur from ignited releases originating from inventories at the edge of the process area and orientated outboard. These are less likely to cause damage or fatalities.

Due to the congestion presented by the equipment and pipe work, the majority of potential process fires on the process area will be obstructed. These obstructed jet fires will result in a fireball type of fire, instead of a jet fire.

For jet fires, the fire fighting systems (firewater or other fire fighting agents) are not efficient to fight such types of fires due to the high momentum release initiating such jet fires. Hence, the only way to control jet fires is to limit the isolatable inventory feeding the jet flame.

The jet fire will deplete by time due to the decrease in driving force across the release point "the hole", consequently the jet flame is expected to be reduced by time.

For jet fires, it is essential to predict the approximate jet fire time duration in order to assess the extent of the hazardous consequences. Based on the isolatable section inventory within the system and the assumption that all operators are aware and trained to deal with such emergency situations, the approximate jet fire duration can be estimated as short duration fires.

If the ESD system shall operate effectively in such cases; hence the approximate jet fire durations can be estimated as too short to cause fatality, injury or massive damage to equipment.

2.3.1.4.3 Obstructed Jet Fires

Most jet fires will be obstructed due to the relatively congested layouts. These will burn as a continuous fireball. The diameter of these fireballs and the associated thermal radiation isopleths are calculated by considering the thermal radiation levels surrounding the fire.

For fires above single grade level, the radiation isopleths are in the shape of a hemisphere. The heat radiated through the hemispherical skin is assumed to be equal to the heat generated by the burning as follows:

Surface area of a hemisphere, A = 2πr2
Hence Q.(2.π.r2) = m.H.p
And r = v(m.H.p/2.π.Q) Where Q = Heat flux (kW/m2)
p = Proportion of heat radiated (typically 20%) H = Heat of Combustion (kJ/kg)
m = Burning Rate (kg/s) (equivalent to release rate) r = Radius (m)

The actual fireball radius is estimated based on setting Q at 150 kW/m2, which gives a conservative fire size. Curves are also calculated for the 4 and 37.5 kW/m2 isopleths.

For fires between multiple levels structure, the radiation isopleth is assumed to be in the shape of a cylinder, the height of which is the distance between decks.

The equilibrium equation for this case is calculated as follows: Surface area of a cylinder (excluding ends), A = 2. π.r

Hence Q.(2. π.h.r) = m.H.p
And r = (m.H.p/2. π.h.Q)
Where h = Height (or length) of cylinder (m)

For instance, a fireball in the centre of the deck level associated with a release rate greater than approximately 5 kg/s would produce fatal radiation levels to a distance about 20m from the fire source. In reality, the fire would soon become ventilation limited and would tend to fill the area with flames lapping out around the perimeter.

For this QRA since there are are no major obstruction, there is no process plant involved hence obstructed fires are not considered.

2.3.1.4.4 Buried Pipeline Rupture

For buried underground pipelines, the rate of release from a full bore guillotine rupture (i.e., release from both sides of the pipeline) should be calculated.

Gas and vapour releases that have to break out of the ground should be modelled as a vertical release from a crater in the ground.

This will have the effect of reducing the velocity of the material released from the crater. The crater diameter should be calculated using the following correlation:

$$W = 1{,}78(D)^{1{,}266}(P)^{0{,}5744}$$

Where:

W is the crater width (m).
D the pipeline diameter (m).
P the pipeline pressure (bar).

(Refer BP ETP 48-50)

2.3.1.4.5 Pool Fires

Liquid pool fires may occur on ground floors or elevated plated levels or plated decks or in bunded areas due to:

- Rain-out from ignited liquid releases at pressures under approximately 3 to 5 bar(g);
- Delayed ignition of higher pressure liquid releases; or
- Ignition of low pressure liquid releases (e.g. from storage tanks at atmospheric pressure).

Liquid rain out from high pressure jet fires will be relatively small and will not be assessed as the resulting pool fire would have no additional consequences to the coincident jet fire.

A high pressure liquid release would spray over a wide area and create a large flammable vapour cloud. Upon ignition, the fire would rapidly flash back to the source of the leak and burn as a liquid jet fire until the fuel is exhausted.

A low pressure release of flammable liquid will drain into the drip pans located under vessels and tanks containing liquid inventories. These will be drained to the hazardous open drains system. Ignition would result in a pool fire in the drip pan under the vessel.

The risk from pool fires to personnel or the asset is much less significant when compared to the jet fire or explosion hazards present on the facility and can be reasonably screened out from further assessment.

2.3.1.5 Explosion

A vapor cloud explosion is the result of a release of flammable material in the atmosphere, a subsequent dispersion phase, and, after some delay, an ignition of the vapor cloud. A flame must propagate at a considerable speed to generate blast, especially for 2-D (double-plane configurations) and 3-D (dense-obstacle) environments.

Figure 3 illustrates the relationship between flame speed and overpressure for three different geometries. In order to reach these speeds, either the flame has to accelerate or the cloud has to be ignited very strongly, thereby producing direct initiation of a detonation. Flame acceleration is only possible:

- in the presence of outdoor obstacles, for example, congestion due to pipe racks, weather canopies, tanks, process columns, and multilevel process structures;
- in a high-momentum release causing turbulence, for example, an explosively dispersed cloud or jet release;
- in combinations of high-momentum releases and congestion.

Historically, this phenomenon was referred to as "unconfined vapor cloud explosion," but, in general, the term "unconfined" is a misnomer. It is more accurate to call this type of explosion simply a "vapor cloud explosion."

A typical vapour cloud explosion on a process plant would start as a slow laminar flame ignited by a weak ignition source such as a spark. As the gas mixture burns, hot combustion products are created that expand to approximately the surrounding pressure. As the surrounding mixture flows past the obstacles (vessels, piping, structures etc) within the gas cloud turbulence is created. This turbulence increases the flame surface area and the combustion rate. This further increases the velocity and turbulence in the flow field ahead of the flame leading to a strong positive feedback mechanism for flame acceleration and high explosion overpressures.

For this QRA only confined spaces are below Ethylene storage tank bottom space, VCM Storage tank dyke and LPG Loading station.

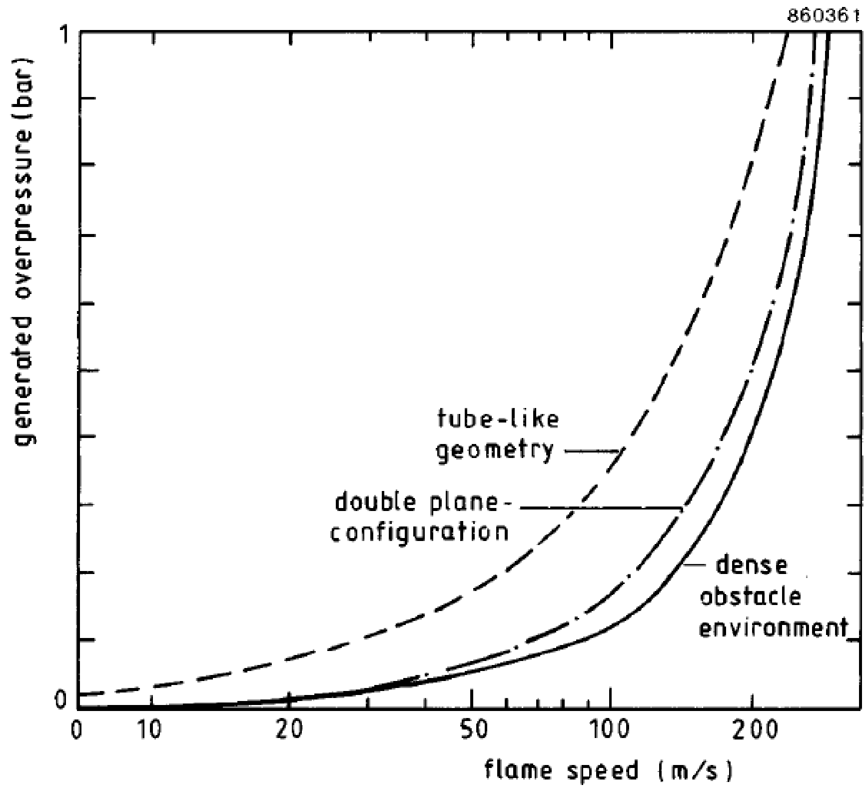


Figure 6: Overpressure as a function of flame speed for three geometries (Source: CCPS Guidelines for Evaluating the Characteristics of Vapor Cloud Explosions, Flash Fires, and BLEVEs)

2.3.2 Data and Assumptions

The quality of the predictions of the QRA depends on the quality and relevance of the data sources and assumptions used. It is therefore important that appropriate sources of historical data are used, that the data is correctly applied and that realistic, yet conservative, assumptions are made based on best practice and experience available from other similar risk assessments.

The data sources and assumptions used are described in the following sections.

2.3.2.1 Hole Size

Release rates are calculated for three (03) scenarios, small (10mm), medium (35mm) and large (100mm) holes.

2.3.2.2 Release Conditions

All releases were calculated at normal operating temperature and pressures.

2.3.2.3 Release Orientation

Release orientation is considered to be evenly distributed in all directions however, for consequence calculations purpose releases were modeled at 45° orientation.

2.3.2.4 Release Duration

Maximum release duration is taken as 30 minutes (1800 sec). Conditional credit of operator response and emergency Isolation, depressurization and existing active fire protection is considered in QRA. Refer discussion below.

2.3.2.5 Risk Mitigation Credit

In QRA limited credit for risk mitigation measures can be taken provided the safeguards are reliable (designed for worst scenario), survivable (in fire or explosion) and available (PFDavg or SIL quantified) i.e. release or fire is detected and ESD is uninitiated within available process safety time (time before damage occurs) . Credit for safeguards can be taken either as reduction in release duration (ESD activation) or reduction in frequency of event or both.

In summary:

- Hardware safeguards (for examples automated trip such as on high tank level) are accounted for quantitatively as they generally reduce event frequencies, credit is taken if site has implemented IEC_61511 Safety Instrumented System lifecycle (SIL assessment and verification).
- Automatic shutdowns based on fire or gas detection or lone worker systems are accounted for quantitatively as they generally reduce event severity by limiting the duration and quantity of a loss of containment, credit for risk reduction by F&G detection system is taken based on scenario coverage calculated in a 3D mapping study.
- Operator initiated shutdown may be accounted for in some events, provided there is sufficient response time and the operator is likely to be unaffected by the event or there are multiple personnel on attendance (such as ship unloading). Refer to Table 3 for typical safety times based on DNV data.
- Procedures and management systems (e.g. training, maintenance practices) are generally not accounted for quantitatively. Data used to estimate event frequencies in a QRA is largely based on generic historical information from a variety of plants and processes with different standards, designs and management systems, hence this will always lag the implementation of better engineering or procedural controls in particular industries. Therefore the use of statistical data is conservative in that it will overstate the risk from modern, well managed installations but may understate the risk from older or poorly managed facilities.
- Fire protection systems may be accounted for in some events to prevent escalation, for example escalation of a rim seal fire (localised consequence) to a full tank surface fire (larger consequence, potential offsite effects) may be prevented by application of foam, provided that there is adequate detection and remote activation of fire protection systems.
- Response by Emergency Services is not accounted for. This will generally take some time (of the order of 15 minutes or more) after an initial event. Attendance by the Emergency Services prevents further escalation and additional asset damage, as well as management of evacuations

For base case QRA credit for existing detection and isolation is not taken due to following factors:

- Comprehensive F&G Mapping study is not available, scenario coverage/risk reduction factor achieved from fire & Gas detection is unknown, hence, credit for gas or fire detection is not taken.
- ESD is initiated manually; no comprehensive Human Factors Engineering assessment is made to determine probability and time of successful ESD based on human response.

- Probability of Survival of ESD valves in case of fire or explosion scenarios is low as determined in section 4 consequence analysis shows ESD valves are likely to be engulfed in fire and explosion envelopes leading to failure of the valves.
- Credit for operator response is not taken as operator is not present in the process area most of the time for timely action to process upsets such as high level. For tanker loading operation operator is present during loading but availability and reliability of emergency isolation on tanker is not confirmed hence again credit of emergency isolation by operator is not considered.
- Credit for fixed fire water protection on tanks is not taken as reliability, availability and effectiveness factor of fire water system is not established.
- Credit for Ethylene tank design with double containment is taken and BLEVE is not taken as credible scenario. Similarly credit of mounding of LPG vessels is taken and BLEVE is not taken as credible scenario for LPG vessels.

A hypothetical case QRA is done taking credit of following safeguards to establish residual risk if the safeguards are effective.

- Automatic ESD upon gas or fire detection limiting release duration to 120 sec.
- Assumption that ESD system will survive initial fire & explosion effects.
- Sprinkler system will mitigate/prevent BLEVE of VCM spheres.

Table 3: Response Times based on DNV data

Description	Duration for Detection and Isolation [s]
Gas detector which auto closes ESD/automatic valve (XSFV).	120
Gas detector with isolation by manual valve closure.	960
Gas detector with isolation by remotely operated closure of control valve.	660
Detection by operator and initiation of ESD & Blowdown System	600
Gas detector with isolation by remotely operated closure of ESD.	360
Process trip which auto closes ESD.	360
Process alarm with isolation by manual valve closure.	1200
Process alarm with isolation by remotely operated closure of control valve.	900
Process alarm with isolation of feed by remotely operated closure of control valve. Duration determined by either inventory of material (max 1800s) or valve closure time (900s).	max. 1800
Process alarm with isolation of feed by remotely operated closure of ESD. Duration determined by either inventory of material (max 1800s) or valve closure time (600s).	max. 1800
Process alarm with isolation by remotely operated closure of ESD.	600
Detection by field operator, remote area, with manual isolation.	2700
Detection by field operator, remote area, with isolation by remotely operated control valve.	2400
Detection by field operator, remote area,, with isolation by remotely operated ESD.	2100
Detection by field operator routine patrol, with manual isolation.	1500
Detection by field operator routine patrol, with isolation by remotely operated control valve.	1200
Detection by field operator routine patrol, with isolation by remotely operated control valve. Duration determined by either inventory of material (max 1800s) or valve closure time.	1200
Detection by field operator on routine patrol with isolation of feed by remotely operated closure of ESD. Duration determined by either inventory of material (max 1800s) or valve closure time.	900
Detection by field operator on routine patrol, with isolation by remotely operated ESD.	900

2.3.2.6 Escalation

Risk calculations do not take into account probability of escalation of initial small event into a major event e.g. a small bore fire impinging on piping and structure is likely to damage pipe work and structure if fire is not controlled timely by Emergency Shutdown, However, estimating likelihood of escalation is complex and depends on various qualitative factors, hence not taken in QRA.

2.3.3 Meteorological Conditions, P_w

The two most significant variables, which would affect the dispersion calculations, are: Wind speed and atmospheric stability.

Wind Speed:

Wind rose data of Karachi was used. Wind speed and directions data of 5 years average has been used.

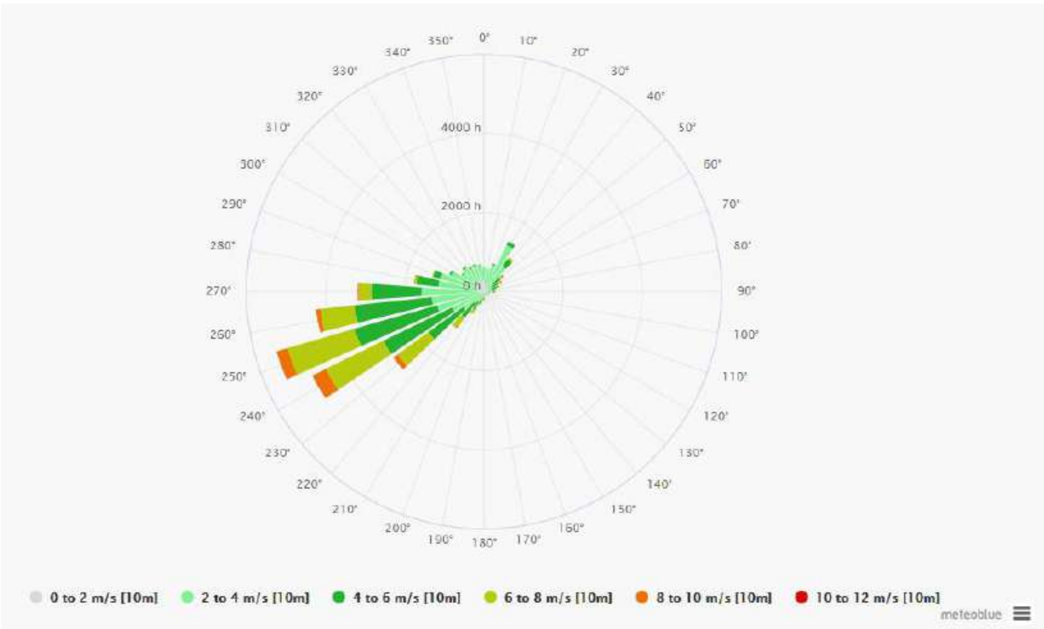


Figure 7: Karachi wind speed data (5yrs avg.)

Stability Categories:

The stability class is a measure of the atmospheric turbulence caused by thermal gradients. Pasquill Stability identifies six main categories, which are shown in the Table 5.

Table 4: Pasquill Stability Classes

A	B	C	D	E	F
Very Unstable	Unstable	Moderately Unstable	Neutral	Moderately Stable	Stable

Neutral conditions correspond to a vertical temperature gradient of about 1 (°C) per 100m.

Table 5 below gives relationship between wind speed and stability class.

Table 5: Relationship between Wind speed and Stability

Wind Speed	Day Time Solar Radiation			Night Time Cloud Cover		
m/s	Strong	Medium	Slight	Thin <3/8	Medium > 3/8	Overcast >4/5
<2	A	A-B	B	-	-	D
2-3	A-B	B	C	E	F	D
3-5	B	B-C	C	D	E	D
5-6	C	C-D	D	D	D	D
>6	C	D	D	D	D	D

At night, the ground is often cooler than the air if the sky is clear, and this gives rise to the most stable conditions and potentially the greatest effect distances.

Fig.4 shows the criteria used for the selection of weather parameters used for the consequences modeling for this study.

Based on VOPAK QRA guideline following sets of weather classes have been used in this QRA

	Set 1	Set 2	Set 3
Wind Speed, m/s	1	2	3
Pasquill Stability	F	B	C

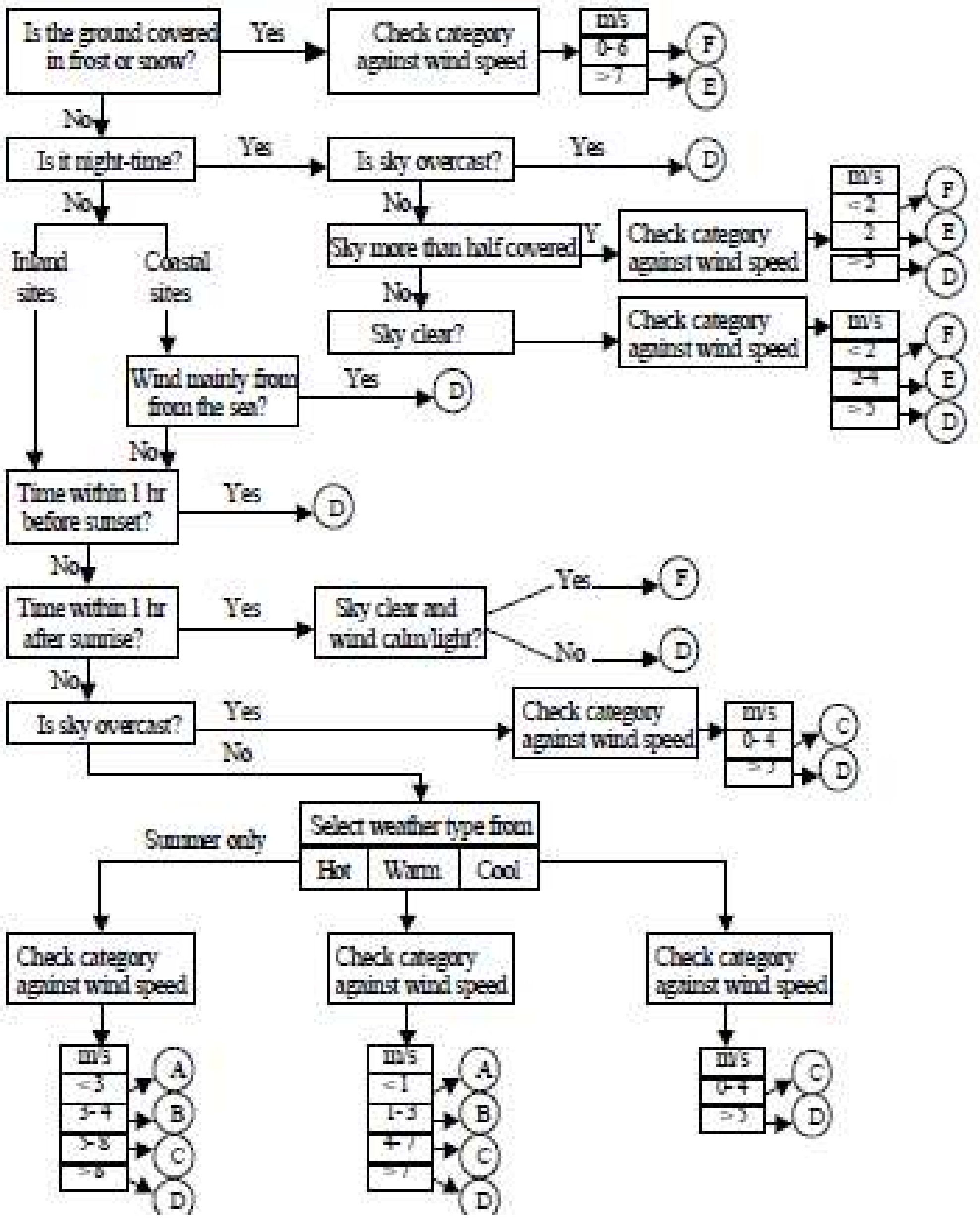


Figure 8: Determination of Modified Pasquill Stability Classes

2.3.4 Consequence analysis results

Consequence modeling results are summarized in table 6 below.

Table 6: Consequence Analysis Results

ID	Hole size, mm	Release rate, kg/s	Mass Released, kg	Event*(Note 01)		Consequence Distance, m		
						1F	2B	3C
A01	10	1.21	2189	PF	37.5 kW/m²	-	-	0
					3 kW/m²	-	-	12
					3% Fatality	-	-	11
	35	14.8	2.65E+04	PF	37.5 kW/m²	-	-	0
					3 kW/m²	-	-	34
					3% Fatality	-	-	29
	100	120.17	196000	PF	37.5 kW/m²	-	-	0
					3 kW/m²	-	-	35
					3% Fatality	-	-	30
A02	10	1.23	2219	PF	37.5 kW/m²	-	-	0
					3 kW/m²	-	-	12
					3% Fatality	-	-	10
	35	15	2.68E+04	PF	37.5 kW/m²	-	-	0
					3 kW/m²	-	-	34
					3% Fatality	-	-	29
	100	119.37	199000	PF	37.5 kW/m²	-	-	0
					3 kW/m²	-	-	47
					3% Fatality	-	-	40
A03	10	0.73	1319	PF	37.5 kW/m²	-	-	0
					3 kW/m²	-	-	10
					3% Fatality	-	-	8
	35	8.9	1.61E+04	PF	37.5 kW/m²	-	-	0
					3 kW/m²	-	-	27
					3% Fatality	-	-	23
	100	71.7	130000	PF	37.5 kW/m²	-	-	0
					3 kW/m²	-	-	47
					3% Fatality	-	-	40
A05	Rupture		2.07E+06	PF	37.5 kW/m²	-	-	0
					3 kW/m²	-	-	47
					3% Fatality	-	-	40
A06	10	0.73	1319	PF	37.5 kW/m²	-	-	0
					3 kW/m²	-	-	9

					3% Fatality	-	-	8
	35	8.9	1.61E+04	PF	37.5 kW/m^2	-	-	0
					3 kW/m^2	-	-	27
					3% Fatality	-	-	23
	100	71.7	128000	PF	37.5 kW/m^2	-	-	0
					3 kW/m^2	-	-	47
					3% Fatality	-	-	40
A08	Rupture		2.07E+06	PF	37.5 kW/m^2	-	-	0
					3 kW/m^2	-	-	47
					3% Fatality	-	-	40
A09	10	1.21	2190	PF	37.5 kW/m^2	-	-	0
					3 kW/m^2	-	-	12
					3% Fatality	-	-	10
	35	14.31	2.63E+04	PF	37.5 kW/m^2	-	-	0
					3 kW/m^2	-	-	34
					3% Fatality	-	-	29
	100	94.28	1.58E+05	PF	37.5 kW/m^2	-	-	0
					3 kW/m^2	-	-	47
					3% Fatality	-	-	40
A10	10	1.21	2189	PF	37.5 kW/m^2	-	-	0
					3 kW/m^2	-	-	12
					3% Fatality	-	-	11
	35	14.72	2.63E+04	PF	37.5 kW/m^2	-	-	0
					3 kW/m^2	-	-	34
					3% Fatality	-	-	23
	100	92.5	156000	PF	37.5 kW/m^2	-	-	0
					3 kW/m^2	-	-	51
					3% Fatality	-	-	40
A11	10	1.21	2189	PF	37.5 kW/m^2	-	-	0
					3 kW/m^2	-	-	12
					3% Fatality	-	-	11
	35	14.8	26463	PF	37.5 kW/m^2	-	-	0
					3 kW/m^2	-	-	34
					3% Fatality	-	-	29
	100	120.17	196000	PF	37.5 kW/m^2	-	-	0
					3 kW/m^2	-	-	35
					3% Fatality	-	-	30
E01	10	1.167	2096	FF	Distance to LFL, m	45	28	28
				JF	37.5 kW/m2	4	5	6
					3 kW/m2	26	26	26

					3% Fatality	22	21	21
	35	14.6	2.61E+04	FF	Distance to LFL, m	164	95	97
				JF	37.5 kW/m2	-	19	23
					3 kW/m2	73	85	84
					3% Fatality	113	69	68
	100	120.5	210000	FF	Distance to LFL, m	685	285	290
				JF	37.5 kW/m2	73	64	71
					3 kW/m2	217	226	222
					3% Fatality	178	149	182
E02	10	2.1	4101	FF	Distance to LFL, m	55	36	36
				JF	37.5 kW/m2	2	4	9
					3 kW/m2	34	33	33
					3% Fatality	28	27	27
	35	25.9	50218	FF	Distance to LFL, m	253	133	134
				JF	37.5 kW/m2	28	25	30
					3 kW/m2	105	106	104
					3% Fatality	86	86	85
E03	10	1.137	2029	FF	Distance to LFL, m	0	37	40
				JF	37.5 kW/m2	0	0	0
					3 kW/m2	0	0	0
					3% Fatality	0	0	0
	35	14.6	2.61E+04	FF	Distance to LFL, m	164	99	100
				JF	37.5 kW/m2	0	0	0
					3 kW/m2	73	74	73
					3% Fatality	113	55	56
	100	120.5	210000	FF	Distance to LFL, m	695	296	303
				JF	37.5 kW/m2	0	0	0
					3 kW/m2	211	216	213
					3% Fatality	389	172	170
E06	10	2.933	5594	FF	Distance to LFL, m	55	0	65
				JF	37.5 kW/m2	0	0	0
					3 kW/m2	0	0	0
					3% Fatality	0	0	0
	35	36	67615	FF	Distance to LFL, m	218	147	149

				JF	37.5 kW/m2	0	0	0
					3 kW/m2	110	112	110
					3% Fatality	87	89	87
E07	10	1.83	724	FF	Distance to LFL, m	23	17	17
				JF	37.5 kW/m2	0	0	9
					3 kW/m2	33	33	32
					3% Fatality	27	27	27
	35	22.46	724	FF	Distance to LFL, m	94	70	75
				JF	37.5 kW/m2	31	30	33
					3 kW/m2	105	105	102
					3% Fatality	85	86	84
	100	183.4	724	FF	Distance to LFL, m	141	121	136
				JF	37.5 kW/m2	95	93	95
					3 kW/m2	267	279	271
					3% Fatality	219	229	221
	BLEVE			BLEVE	5 psi			8
					1 psi			34
					0.5 psi			61
					3% Fatality			34
E08	10	0.011	20.02	FF	Distance to LFL, m	0	0	0
				JF	37.5 kW/m2	0	0	0
					3 kW/m2	0	0	0
					3% Fatality	0	0	0
	35	0.136	240	FF	Distance to LFL, m	0	0	0
				JF	37.5 kW/m2	0	0	0
					3 kW/m2	0	0	0
					3% Fatality	0	0	0
	100	1.07	1588	FF	Distance to LFL, m	0	0	0
				JF	37.5 kW/m2	0	0	0
					3 kW/m2	0	0	0
					3% Fatality	0	0	0
E09	10	1.86	3552	FF	Distance to LFL, m	46	0	52
				JF	37.5 kW/m2	0	0	0
					3 kW/m2	0	0	0
					3% Fatality	0	0	0

	35	23.53	44446	FF	Distance to LFL, m	196	121	124
				JF	37.5 kW/m2	0	0	0
					3 kW/m2	91	92	92
					3% Fatality	72	72	72
E10	Rupture		5.78E+06	FF	Distance to LFL, m	1266	407	736
				PF	37.5 kW/m2	46	49	52
					3 kW/m2	170	175	178
					3% Fatality	137	145	148
E11	10	0.89	1688	FF	Distance to LFL, m	0	0	0
				PF	37.5 kW/m2	0	0	0
					3 kW/m2	9	9	9
					3% Fatality	7	8	8
				JF	37.5 kW/m2	4	4	5
					3 kW/m2	23	23	23
					3% Fatality	20	19	19
	35	11.67	22127	FF	Distance to LFL, m	42	34	36
				PF	37.5 kW/m2	0	0	5
					3 kW/m2	18	19	19
					3% Fatality	14	16	16
				JF	37.5 kW/m2	17	17	20
					3 kW/m2	76	76	75
					3% Fatality	61	61	61
E12	10	0.286	517	FF	Distance to LFL, m	0	0	0
				JF	37.5 kW/m2	0	2	2
					3 kW/m2	10	10	10
					3% Fatality	9	9	9
	35	3.42	6136	FF	Distance to LFL, m	59	22	23
				JF	37.5 kW/m2	0	0	0
					3 kW/m2	32	32	32
					3% Fatality	27	27	26
	100	14	24411	FF	Distance to LFL, m	163	50	52
				JF	37.5 kW/m2	0	0	0
					3 kW/m2	63	63	62
					3% Fatality	52	52	51
E13	10	0.286	517	FF	Distance to LFL, m	0	0	0

				JF	37.5 kW/m2	0	2	2
					3 kW/m2	10	10	10
					3% Fatality	9	9	9
	35	3.5	6273	FF	Distance to LFL, m	70	23	24
				JF	37.5 kW/m2	0	0	0
					3 kW/m2	33	33	32
					3% Fatality	27	27	27
	100	25.8	43775	FF	Distance to LFL, m	461	88	96
				JF	37.5 kW/m2	0	0	0
					3 kW/m2	82	83	82
					3% Fatality	67	67	67
E14	10	0.23	39.8	FF	Distance to LFL, m	0	0	0
				JF	37.5 kW/m2	0	1	1
					3 kW/m2	9	9	9
					3% Fatality	8	8	8
	35	2.8	39.8	FF	Distance to LFL, m	0	0	0
				JF	37.5 kW/m2	0	0	0
					3 kW/m2	30	30	30
					3% Fatality	25	25	24
	100	17.52	39.8	FF	Distance to LFL, m	87	55	62
				JF	37.5 kW/m2	0	0	0
					3 kW/m2	79	79	78
					3% Fatality	64	65	64
E15	10	0.26	473	FF	Distance to LFL, m	0	0	0
				JF	37.5 kW/m2	2	2	2
					3 kW/m2	10	10	10
					3% Fatality	8	8	8
	35	3.2	5743	FF	Distance to LFL, m	35	19	19
				JF	37.5 kW/m2	0	0	0
					3 kW/m2	31	31	31
					3% Fatality	26	26	26
	100	25.45	43007	FF	Distance to LFL, m	463	88	96
				JF	37.5 kW/m2	0	0	0
					3 kW/m2	81	82	81
					3% Fatality	67	67	66

E16a	10	0.01	17.6	FF	Distance to LFL, m	0	0	0
				JF	37.5 kW/m2	0	0	0
					3 kW/m2	0	2	2
					3% Fatality	0	0	2
	35	0.12	211	FF	Distance to LFL, m	0	0	0
				JF	37.5 kW/m2	0	0	0
					3 kW/m2	8	8	8
					3% Fatality	6	7	7
	100	0.94	1353	FF	Distance to LFL, m	0	0	0
				JF	37.5 kW/m2	0	0	0
					3 kW/m2	22	22	22
					3% Fatality	18	18	18
E16b	10	0.01	17.6	FF	Distance to LFL, m	0	0	0
				JF	37.5 kW/m2	0	0	0
					3 kW/m2	0	2	2
					3% Fatality	0	0	2
	35	0.12	211	FF	Distance to LFL, m	0	0	0
				JF	37.5 kW/m2	0	0	0
					3 kW/m2	8	8	8
					3% Fatality	6	7	7
	100	0.94	1353	FF	Distance to LFL, m	0	0	0
				JF	37.5 kW/m2	0	0	0
					3 kW/m2	22	22	22
					3% Fatality	18	18	18
E17a	10	0.23	415.36	FF	Distance to LFL, m	0	0	0
				JF	37.5 kW/m2	0	0	0
					3 kW/m2	9	9	9
					3% Fatality	7	7	7
	35	2.8	5008	FF	Distance to LFL, m	0	0	0
				JF	37.5 kW/m2	0	0	0
					3 kW/m2	29	29	29
					3% Fatality	24	24	23
	100	16.7	28467	FF	Distance to LFL, m	0	0	0
				JF	37.5 kW/m2	0	0	0

					3 kW/m2	67	67	66
					3% Fatality	55	55	54
E17b	10	0.23	415.36	FF	Distance to LFL, m	0	0	0
				JF	37.5 kW/m2	0	0	0
					3 kW/m2	9	9	9
					3% Fatality	7	7	7
	35	2.8	5008	FF	Distance to LFL, m	0	0	0
				JF	37.5 kW/m2	0	0	0
					3 kW/m2	29	29	29
					3% Fatality	24	24	23
	100	16.7	28467	FF	Distance to LFL, m	0	0	0
				JF	37.5 kW/m2	0	0	0
					3 kW/m2	67	67	66
					3% Fatality	55	55	54
E18a	10	0.625	1091	FF	Distance to LFL, m	0	0	0
				JF	37.5 kW/m2	0	0	0
					3 kW/m2	18	18	18
					3% Fatality	15	15	15
	35	8.1	14039	FF	Distance to LFL, m	42	34	35
				JF	37.5 kW/m2	0	0	13
					3 kW/m2	60	60	59
					3% Fatality	49	49	48
E18b	10	0.625	1091	FF	Distance to LFL, m	0	0	0
				JF	37.5 kW/m2	0	0	0
					3 kW/m2	18	18	18
					3% Fatality	15	15	15
	35	8.1	14039	FF	Distance to LFL, m	41	33	35
				JF	37.5 kW/m2	0	0	13
					3 kW/m2	60	60	59
					3% Fatality	49	48	48
E19	10	0.24	436	FF	Distance to LFL, m	0	0	0
				JF	37.5 kW/m2	0	0	0
					3 kW/m2	9	9	9
					3% Fatality	7	7	7
	35	2.94	5263	FF	Distance to LFL,	0	0	0

					m			
				JF	37.5 kW/m2	0	0	0
					3 kW/m2	29	29	29
					3% Fatality	24	24	24
	100	17.5	29926	FF	Distance to LFL, m	0	0	0
				JF	37.5 kW/m2	0	0	0
					3 kW/m2	69	69	68
					3% Fatality	56	56	55
E20	10	1.167	2096	FF	Distance to LFL, m	45	28	28
				JF	37.5 kW/m2	4	5	6
					3 kW/m2	26	26	26
					3% Fatality	22	21	21
	35	14.6	26070	FF	Distance to LFL, m	164	95	97
				JF	37.5 kW/m2	-	19	23
					3 kW/m2	73	85	84
					3% Fatality	113	69	68
	100	120.5	210000	FF	Distance to LFL, m	685	285	290
				JF	37.5 kW/m2	73	64	71
					3 kW/m2	217	226	222
					3% Fatality	178	149	182
P01	10	1.23	2219	PF	37.5 kW/m^2	-	-	7
					3 kW/m^2	-	-	18
					3% Fatality	-	-	16
	35	15	2.71E+04	PF	37.5 kW/m^2	-	-	20
					3 kW/m^2	-	-	54
					3% Fatality	-	-	46
	100	121.9	215000	PF	37.5 kW/m^2	-	-	37
					3 kW/m^2	-	-	93
					3% Fatality	-	-	84
P02	10	0.9352	1691.5	PF	37.5 kW/m^2	-	-	5
					3 kW/m^2	-	-	16
					3% Fatality	-	-	14
	35	11.45	2.07E+04	PF	37.5 kW/m^2	-	-	17
					3 kW/m^2	-	-	48
					3% Fatality	-	-	40
	100	93	165000	PF	37.5 kW/m^2	-	-	18
					3 kW/m^2	-	-	52

					3% Fatality	-	-	44
P03	Rupture	0	8.18E+06	PF	37.5 kW/m^2	-	-	78
					3 kW/m^2	-	-	214
					3% Fatality	-	-	179
P04	Rupture	0	8.18E+06	PF	37.5 kW/m^2	-	-	78
					3 kW/m^2	-	-	214
					3% Fatality	-	-	179
P05	Rupture	0	8.18E+06	PF	37.5 kW/m^2	-	-	78
					3 kW/m^2	-	-	214
					3% Fatality	-	-	179
P6a	10	0.9352	1691	PF	37.5 kW/m^2	-	-	5
					3 kW/m^2	-	-	16
					3% Fatality	-	-	14
	35	11.45	2.07E+04	PF	37.5 kW/m^2	-	-	17
					3 kW/m^2	-	-	48
					3% Fatality	-	-	40
	100	92.7	165000	PF	37.5 kW/m^2	-	-	42
					3 kW/m^2	-	-	118
					3% Fatality	-	-	99
P6b	10	0.9352	1691	PF	37.5 kW/m^2	-	-	5
					3 kW/m^2	-	-	16
					3% Fatality	-	-	14
	35	11.45	20663	PF	37.5 kW/m^2	-	-	17
					3 kW/m^2	-	-	48
					3% Fatality	-	-	40
	100	92.7	165000	PF	37.5 kW/m^2	-	-	42
					3 kW/m^2	-	-	117
					3% Fatality	-	-	99
P6c	10	0.9352	1691	PF	37.5 kW/m^2	-	-	5
					3 kW/m^2	-	-	16
					3% Fatality	-	-	14
	35	11.45	20663	PF	37.5 kW/m^2	-	-	17
					3 kW/m^2	-	-	48
					3% Fatality	-	-	40
	100	92.7	165000	PF	37.5 kW/m^2	-	-	42
					3 kW/m^2	-	-	117
					3% Fatality	-	-	99
P8	10	1.43	2595	PF	37.5 kW/m^2	-	-	4
					3 kW/m^2	-	-	15
					3% Fatality	-	-	13

	35	17.56	3.17E+04	PF	37.5 kW/m²	-	-	12
					3 kW/m²	-	-	42
					3% Fatality	-	-	35
	100	140.2	247000	PF	37.5 kW/m²	-	-	19
					3 kW/m²	-	-	64
					3% Fatality	-	-	53
P09	10	1.39	2508	PF	37.5 kW/m²	-	-	6
					3 kW/m²	-	-	15
					3% Fatality	-	-	13
	35	16.97	3.06E+04	PF	37.5 kW/m²	-	-	13
					3 kW/m²	-	-	42
					3% Fatality	-	-	35
	100	135.49	240000	PF	37.5 kW/m²	-	-	20
					3 kW/m²	-	-	62
					3% Fatality	-	-	53
P10	10	1.23	2219	PF	37.5 kW/m²	-	-	7
					3 kW/m²	-	-	18
					3% Fatality	-	-	16
	35	15	27098	PF	37.5 kW/m²	-	-	20
					3 kW/m²	-	-	54
					3% Fatality	-	-	46
	100	121.9	215000	PF	37.5 kW/m²	-	-	37
					3 kW/m²	-	-	93
					3% Fatality	-	-	84
PL01	10	0.622	1107.2	FF	Distance to LFL, m	7	6	0
				JF	37.5 kW/m²	2	5	7
					3 kW/m²	18	18	20
					3% Fatality	17	17	12
	35	8	1.42E+04	FF	Distance to LFL, m	37	31	33
				JF	37.5 kW/m²	17	19	22
					3 kW/m²	60	59	66
					3% Fatality	55	54	54
	100	66.3	115000	FF	Distance to LFL, m	145	105	110
				JF	37.5 kW/m²	61	57	60
					3 kW/m²	155	158	175
					3% Fatality	143	146	143
PL02	10	0.622	1107	FF	Distance to LFL, m	7	6	0

				JF	37.5 kW/m^2	2	5	7
					3 kW/m^2	18	18	20
					3% Fatality	17	17	17
	35	8	1.42E+04	FF	Distance to LFL, m	37	31	33
				JF	37.5 kW/m^2	17	19	22
					3 kW/m^2	60	59	66
					3% Fatality	55	54	54
	100	66.3	115000	FF	Distance to LFL, m	145	105	110
				JF	37.5 kW/m^2	61	57	60
					3 kW/m^2	155	158	175
					3% Fatality	143	146	143
PL03a	10	0.24	422	FF	Distance to LFL, m	0	0	0
				JF	37.5 kW/m^2	0	0	0
					3 kW/m^2	8	8	10
					3% Fatality	0	7	8
	35	3.84	6745.2	FF	Distance to LFL, m	0	0	0
				JF	37.5 kW/m^2	0	0	0
					3 kW/m^2	39	39	44
					3% Fatality	36	35	35
	100	34.8	60916	FF	Distance to LFL, m	67	51	51
				JF	37.5 kW/m^2	36	28	37
					3 kW/m^2	112	114	126
					3% Fatality	103	105	102
PL03b	10	0.24	422	FF	Distance to LFL, m	0	0	0
				JF	37.5 kW/m^2	0	0	0
					3 kW/m^2	8	8	10
					3% Fatality	0	7	8
	35	3.842	6744	FF	Distance to LFL, m	0	0	0
				JF	37.5 kW/m^2	0	0	0
					3 kW/m^2	39	39	44
					3% Fatality	36	35	35
	100	34.8	60916	FF	Distance to LFL, m	67	51	51

				JF	37.5 kW/m^2	36	28	37
					3 kW/m^2	112	114	126
					3% Fatality	103	105	102
PL03c	10	0.25	438	FF	Distance to LFL, m	0	0	0
				JF	37.5 kW/m^2	0	0	0
					3 kW/m^2	8	8	10
					3% Fatality	0	7	8
	35	4	6992	FF	Distance to LFL, m	0	0	0
				JF	37.5 kW/m^2	0	0	0
					3 kW/m^2	39	39	44
					3% Fatality	36	35	36
	100	36	62943	FF	Distance to LFL, m	67	51	51
				JF	37.5 kW/m^2	36	28	37
					3 kW/m^2	112	114	126
					3% Fatality	103	105	102
PL04a	10	0.37	651.35	FF	Distance to LFL, m	0	0	0
				JF	37.5 kW/m^2	2	4	6
					3 kW/m^2	14	14	16
					3% Fatality	13	13	13
	35	5.5	9692	FF	Distance to LFL, m	23	22	22
				JF	37.5 kW/m^2	12	15	18
					3 kW/m^2	50	49	54
					3% Fatality	46	45	45
	100	47.4	82875	FF	Distance to LFL, m	94	74	78
				JF	37.5 kW/m^2	50	48	51
					3 kW/m^2	132	135	149
					3% Fatality	122	124	121
PL04b	10	0.53	941	FF	Distance to LFL, m	0	0	0
				JF	37.5 kW/m^2	2	4	7
					3 kW/m^2	17	14	19
					3% Fatality	16	16	16
	35	7.18	1.27E+04	FF	Distance to LFL, m	33	28	29

				JF	37.5 kW/m²	15	18	20
					3 kW/m²	57	56	62
					3% Fatality	52	52	51
	100	60.1	110000	FF	Distance to LFL, m	129	95	100
				JF	37.5 kW/m²	58	54	58
					3 kW/m²	148	151	167
					3% Fatality	136	139	136
PL04c	10	0.53	941	FF	Distance to LFL, m	0	0	0
				JF	37.5 kW/m²	2	4	7
					3 kW/m²	17	14	19
					3% Fatality	16	16	16
	35	7.18	12721	FF	Distance to LFL, m	33	28	29
				JF	37.5 kW/m²	15	18	20
					3 kW/m²	57	56	62
					3% Fatality	52	52	51
	100	60.1	110000	FF	Distance to LFL, m	129	95	100
				JF	37.5 kW/m²	58	54	58
					3 kW/m²	148	151	167
					3% Fatality	136	139	136
PL05	10	0.31	544	FF	Distance to LFL, m	0	0	0
				JF	37.5 kW/m²	2	4	6
					3 kW/m²	13	13	14
					3% Fatality	12	12	12
	35	4.55	8004	FF	Distance to LFL, m	18	18	18
				JF	37.5 kW/m²	9	13	17
					3 kW/m²	46	45	50
					3% Fatality	42	41	41
	100	38.7	67726	FF	Distance to LFL, m	72	60	62
				JF	37.5 kW/m²	45	43	46
					3 kW/m²	120	122	133
					3% Fatality	110	113	109
PL06a	10	0.2384	421	FF	Distance to LFL, m	0	0	0

				PF	37.5 kW/m²	2	4	5
					3 kW/m²	11	11	13
					3% Fatality	10	10	11
	35	3.35	5928	FF	Distance to LFL, m	13	13	13
				PF	37.5 kW/m²	7	11	15
					3 kW/m²	39	38	43
					3% Fatality	36	35	35
PL06b	10	0.2384	421	FF	Distance to LFL, m	0	0	0
				JF	37.5 kW/m²	2	4	5
					3 kW/m²	11	11	13
					3% Fatality	10	10	11
	35	3.35	5928	FF	Distance to LFL, m	13	13	13
				JF	37.5 kW/m²	7	11	15
					3 kW/m²	39	38	43
					3% Fatality	36	35	35
PL07	BLEVE	0	22276	BLEVE	5 psi			27
					1 psi			109
					0.5 psi			196
					3% Fatality			249
PV01a	10	0.125	224	FF	Distance to LFL, m	0	0	0
				JF	37.5 kW/m²	0	0	0
					3 kW/m²	0	0	0
					3% Fatality	0	0	0
	35	1.52	2546	FF	Distance to LFL, m	0	0	0
				JF	37.5 kW/m²	0	0	0
					3 kW/m²	20	20	23
					3% Fatality	17	18	18
	100	8.9	10688	FF	Distance to LFL, m	206	44	47
				JF	37.5 kW/m²	0	0	0
					3 kW/m²	50	50	56
					3% Fatality	46	46	45
PV01b	10	0.125	224	FF	Distance to LFL, m	0	0	0

				JF	37.5 kW/m^2	0	0	0
					3 kW/m^2	0	0	0
					3% Fatality	0	0	0
	35	1.52	2546	FF	Distance to LFL, m	0	0	0
				JF	37.5 kW/m^2	0	0	0
					3 kW/m^2	20	20	23
					3% Fatality	17	18	18
	100	8.9	10688	FF	Distance to LFL, m	206	44	47
				JF	37.5 kW/m^2	0	0	0
					3 kW/m^2	50	50	56
					3% Fatality	46	46	45
PV01c	10	0.125	224	FF	Distance to LFL, m	0	0	0
				JF	37.5 kW/m^2	0	0	0
					3 kW/m^2	0	0	0
					3% Fatality	0	0	0
	35	1.52	2546	FF	Distance to LFL, m	0	0	0
				JF	37.5 kW/m^2	0	0	0
					3 kW/m^2	20	20	23
					3% Fatality	17	18	18
	100	8.9	10688	FF	Distance to LFL, m	206	44	47
				JF	37.5 kW/m^2	0	0	0
					3 kW/m^2	50	50	56
					3% Fatality	46	46	45
PV06a	10	0.123	221	FF	Distance to LFL, m	0	0	0
				JF	37.5 kW/m^2	1	1	2
					3 kW/m^2	7	7	8
					3% Fatality	7	7	7
	35	0.657	1149	FF	Distance to LFL, m	0	0	0
				JF	37.5 kW/m^2	0	0	0
					3 kW/m^2	16	16	18
					3% Fatality	15	15	15
PV06b	10	0.123	221	FF	Distance to LFL, m	0	0	0

				JF	37.5 kW/m^2	1	1	2
					3 kW/m^2	7	7	8
					3% Fatality	7	7	7
	35	0.657	1149	FF	Distance to LFL, m	0	0	0
				JF	37.5 kW/m^2	0	0	0
					3 kW/m^2	16	16	18
					3% Fatality	15	15	15
PLE03d	10	0.633	1135	FF	Distance to LFL, m	0	0	0
				JF	37.5 kW/m^2	0	0	0
					3 kW/m^2	16	16	19
					3% Fatality	14	14	15
	35	8.15	1.46E+04	FF	Distance to LFL, m	0	0	0
				JF	37.5 kW/m^2	0	0	12
					3 kW/m^2	58	58	65
					3% Fatality	53	53	52
	100	67.44	120000	FF	Distance to LFL, m	159	110	117
				JF	37.5 kW/m^2	56	51	55
					3 kW/m^2	155	158	175
					3% Fatality	142	145	143
PLE04d	10	0.61	1084	FF	Distance to LFL, m	7	0	0
				JF	37.5 kW/m^2	2	5	7
					3 kW/m^2	18	18	20
					3% Fatality	17	17	17
	35	7.9	1.40E+04	FF	Distance to LFL, m	37	31	32
				JF	37.5 kW/m^2	17	19	21
					3 kW/m^2	60	59	65
					3% Fatality	55	54	53
	100	65.3	114000	FF	Distance to LFL, m	143	32	109
				JF	37.5 kW/m^2	60	51	60
					3 kW/m^2	154	58	174
					3% Fatality	142	53	142
PVE01d	10	0.125	225.29	FF	Distance to LFL, m	0	0	0

				JF	37.5 kW/m^2	0	0	0
					3 kW/m^2	0	0	0
					3% Fatality	0	0	0
	35	1.53	2691	FF	Distance to LFL, m	0	0	0
				JF	37.5 kW/m^2	0	0	0
					3 kW/m^2	20	20	23
					3% Fatality	17	18	18
	100	12.3	18034	FF	Distance to LFL, m	283	54	58
				JF	37.5 kW/m^2	0	0	0
					3 kW/m^2	57	57	65
					3% Fatality	53	53	52
PLE03e	10	0.633	1135	FF	Distance to LFL, m	0	0	0
				JF	37.5 kW/m^2	0	0	12
					3 kW/m^2	16	16	65
					3% Fatality	14	14	52
	35	8.15	14576	FF	Distance to LFL, m	0	0	117
				JF	37.5 kW/m^2	0	0	55
					3 kW/m^2	58	58	175
					3% Fatality	53	53	143
	100	67.44	120000	FF	Distance to LFL, m	159	110	0
				JF	37.5 kW/m^2	56	51	7
					3 kW/m^2	155	158	20
					3% Fatality	142	145	17
PLE04e	10	0.61	1084	FF	Distance to LFL, m	7	0	32
				JF	37.5 kW/m^2	2	5	21
					3 kW/m^2	18	18	65
					3% Fatality	17	17	53
	35	7.9	13968	FF	Distance to LFL, m	37	31	109
				JF	37.5 kW/m^2	17	19	60
					3 kW/m^2	60	59	174
					3% Fatality	55	54	142
	100	65.3	114000	FF	Distance to LFL, m	143	32	0

				JF	37.5 kW/m^2	60	51	0
					3 kW/m^2	154	58	0
					3% Fatality	142	53	0
PVE01e	10	0.125	225.29	FF	Distance to LFL, m	0	0	0
				JF	37.5 kW/m^2	0	0	0
					3 kW/m^2	0	0	23
					3% Fatality	0	0	18
	35	1.53	2691	FF	Distance to LFL, m	0	0	58
				JF	37.5 kW/m^2	0	0	0
					3 kW/m^2	20	20	65
					3% Fatality	17	18	52
	100	12.3	18034	FF	Distance to LFL, m	283	54	58
				JF	37.5 kW/m^2	0	0	0
					3 kW/m^2	57	57	57
					3% Fatality	53	53	52
PLE06c	10	0.24	421	FF	Distance to LFL, m	0	0	0
				JF	37.5 kW/m^2	2	4	5
					3 kW/m^2	11	11	13
					3% Fatality	10	10	11
	35	3.35	5928	FF	Distance to LFL, m	13	13	13
				JF	37.5 kW/m^2	7	11	15
					3 kW/m^2	39	38	43
					3% Fatality	36	35	35
PVE06c	10	0.12	220.95	FF	Distance to LFL, m	0	0	0
				JF	37.5 kW/m^2	1	1	2
					3 kW/m^2	7	7	8
					3% Fatality	7	7	7
	35	0.614	1149	FF	Distance to LFL, m	0	0	0
				JF	37.5 kW/m^2	0	0	0
					3 kW/m^2	16	16	18
					3% Fatality	15	15	15
PL08	10	0.622	1107.2	FF	Distance to LFL, m	7	6	0

				JF	37.5 kW/m^2	2	5	7
					3 kW/m^2	18	18	20
					3% Fatality	17	17	12
	35	8	14176	FF	Distance to LFL, m	37	31	33
				JF	37.5 kW/m^2	17	19	22
					3 kW/m^2	60	59	66
					3% Fatality	55	54	54
	100	66.3	115000	FF	Distance to LFL, m	145	105	110
				JF	37.5 kW/m^2	61	57	60
					3 kW/m^2	155	158	175
					3% Fatality	143	146	143
V01	10	1.75	3168	FF	Distance to LFL, m	14	14	14
				JF	37.5 kW/m^2	5	4	5
					3 kW/m^2	22	22	25
					3% Fatality	20	20	20
	35	21.2	3.91E+04	FF	Distance to LFL, m	54	54	54
				JF	37.5 kW/m^2	20	16	20
					3 kW/m^2	70	71	79
					3% Fatality	64	65	64
	100	123	2.70E+05	FF	Distance to LFL, m	176	177	176
				JF	37.5 kW/m^2	63	56	63
					3 kW/m^2	186	189	209
					3% Fatality	171	173	171
V02	10	1.75	3168	FF	Distance to LFL, m	16	14	14
				JF	37.5 kW/m^2	2	4	5
					3 kW/m^2	22	22	25
					3% Fatality	21	20	20
	35	21.2	3.91E+04	FF	Distance to LFL, m	73	54	54
				JF	37.5 kW/m^2	17	16	20
					3 kW/m^2	70	71	79
					3% Fatality	64	65	64
	100	123	270000	FF	Distance to LFL, m	290	177	176

				JF	37.5 kW/m^2	68	56	63
					3 kW/m^2	184	189	209
					3% Fatality	169	173	171
V03	10	1.75	3168	FF	Distance to LFL, m	16	14	14
				JF	37.5 kW/m^2	2	4	5
					3 kW/m^2	22	22	25
					3% Fatality	21	20	20
	35	21.2	3.91E+04	FF	Distance to LFL, m	73	54	54
				JF	37.5 kW/m^2	17	16	20
					3 kW/m^2	70	71	79
					3% Fatality	64	65	64
	100	123	270000	FF	Distance to LFL, m	290	177	176
				JF	37.5 kW/m^2	68	56	63
					3 kW/m^2	184	189	209
					3% Fatality	169	173	171
V04	10	1.6	2913	FF	Distance to LFL, m	15	14	14
				JF	37.5 kW/m^2	3	4	5
					3 kW/m^2	21	21	24
					3% Fatality	20	19	19
	35	19.9	3.67E+04	FF	Distance to LFL, m	70	52	52
				JF	37.5 kW/m^2	16	16	19
					3 kW/m^2	68	68	76
					3% Fatality	62	63	62
	100	118.78	2.60E+05	FF	Distance to LFL, m	280	172	171
				JF	37.5 kW/m^2	65	54	61
					3 kW/m^2	179	184	203
					3% Fatality	164	168	166
V05	10	1.6	2913	FF	Distance to LFL, m	15	14	14
				JF	37.5 kW/m^2	3	4	5
					3 kW/m^2	21	21	24
					3% Fatality	20	19	19
	35	19.9	36741	FF	Distance to LFL, m	70	52	52

				JF	37.5 kW/m²	16	16	19
					3 kW/m²	68	68	76
					3% Fatality	62	63	62
	100	118.78	260000	FF	Distance to LFL, m	280	172	171
				JF	37.5 kW/m²	65	54	61
					3 kW/m²	179	184	203
					3% Fatality	164	168	166
V06	10	1.98	3621	FF	Distance to LFL, m	17	15	15
				JF	37.5 kW/m²	2	4	6
					3 kW/m²	24	23	26
					3% Fatality	22	21	21
	35	24.6	4.59E+04	FF	Distance to LFL, m	78	58	58
				JF	37.5 kW/m²	19	18	21
					3 kW/m²	75	75	84
					3% Fatality	69	69	68
	100	147.52	3.20E+05	FF	Distance to LFL, m	311	190	190
				JF	37.5 kW/m²	73	61	69
					3 kW/m²	196	202	223
					3% Fatality	180	185	182
V07	10	1.76	1.76	FF	Distance to LFL, m	13	12	12
				JF	37.5 kW/m²	2	4	6
					3 kW/m²	22	21	25
					3% Fatality	21	20	20
	35	22.5	2.25E+01	FF	Distance to LFL, m	59	47	47
				JF	37.5 kW/m²	16	16	19
					3 kW/m²	68	68	76
					3% Fatality	62	63	62
	100	184.7	184.7	FF	Distance to LFL, m	232	154	155
				JF	37.5 kW/m²	65	54	61
					3 kW/m²	178	182	202
					3% Fatality	163	167	165
V08	10	1.7462	3161	FF	Distance to LFL, m	13	12	12

				JF	37.5 kW/m^2	2	4	6
					3 kW/m^2	22	21	25
					3% Fatality	21	20	20
	35	20.703	37702	FF	Distance to LFL, m	59	47	47
				JF	37.5 kW/m^2	16	16	19
					3 kW/m^2	68	68	76
					3% Fatality	62	63	62
	100	141	274000	FF	Distance to LFL, m	232	154	155
				JF	37.5 kW/m^2	65	54	61
					3 kW/m^2	178	182	202
					3% Fatality	163	167	165
V09a	PVRV	22.815	41068	FF	Distance to LFL, m	0	0	0
				JF	37.5 kW/m^2	0	0	0
					3 kW/m^2	58	55	68
					3% Fatality	52	47	52
V09b	PVRV	22.815	41068	FF	Distance to LFL, m	0	0	0
				JF	37.5 kW/m^2	0	0	0
					3 kW/m^2	58	55	68
					3% Fatality	52	47	52
V10	BLEVE			BLEVE	5 psi	-	-	40
					1 psi	-	-	175
					0.5 psi	-	-	320
					3% Fatality	-	-	966
ED01	10	1.35	2440	PF	37.5 kW/m^2	-	-	0
					3 kW/m^2	-	-	12
					3% Fatality	-	-	11
	35	16.5	2.96E+04	PF	37.5 kW/m^2	-	-	0
					3 kW/m^2	-	-	35
					3% Fatality	-	-	30
	100	132	226000	PF	37.5 kW/m^2	-	-	0
					3 kW/m^2	-	-	38
					3% Fatality	-	-	33
ED02	10	1.16	2102	PF	37.5 kW/m^2	-	-	0
					3 kW/m^2	-	-	11
					3% Fatality	-	-	10
	35	14.22	2.56E+04	PF	37.5 kW/m^2	-	-	0

					3 kW/m^2	-	-	23
					3% Fatality	-	-	20
	100	102.41	1.96E+05	PF	37.5 kW/m^2	-	-	0
					3 kW/m^2	-	-	23
					3% Fatality	-	-	20
ED03	10	1.16	2102	PF	37.5 kW/m^2	-	-	0
					3 kW/m^2	-	-	12
					3% Fatality	-	-	10
	35	14.22	2.56E+04	PF	37.5 kW/m^2	-	-	0
					3 kW/m^2	-	-	33
					3% Fatality	-	-	28
	100	114.7	197000	PF	37.5 kW/m^2	-	-	0
					3 kW/m^2	-	-	51
					3% Fatality	-	-	44
ED04	10	1.16	2102	PF	37.5 kW/m^2	-	-	0
					3 kW/m^2	-	-	12
					3% Fatality	-	-	10
	35	14.223	2.56E+04	PF	37.5 kW/m^2	-	-	0
					3 kW/m^2	-	-	33
					3% Fatality	-	-	28
	100	114.74	198000	PF	37.5 kW/m^2	-	-	0
					3 kW/m^2	-	-	51
					3% Fatality	-	-	44
ED05	10	1.24	2240	PF	37.5 kW/m^2	-	-	0
					3 kW/m^2	-	-	12
					3% Fatality	-	-	10
	35	14.47	25986	PF	37.5 kW/m^2	-	-	0
					3 kW/m^2	-	-	24
					3% Fatality	-	-	20
	100	46.6	82190	PF	37.5 kW/m^2	-	-	0
					3 kW/m^2	-	-	24
					3% Fatality	-	-	20
ED06	10	1.35	2440	PF	37.5 kW/m^2	-	-	0
					3 kW/m^2	-	-	12
					3% Fatality	-	-	11
	35	16.27	2.92E+04	PF	37.5 kW/m^2	-	-	0
					3 kW/m^2	-	-	35
					3% Fatality	-	-	30
	100	80.3	140000	PF	37.5 kW/m^2	-	-	0
					3 kW/m^2	-	-	55

					3% Fatality	-	-	47
ED07	Rupture	0	3.20E+06	PF	37.5 kW/m^2	-	-	0
					3 kW/m^2	-	-	50
					3% Fatality	-	-	43
ED08	Rupture	0	3.20E+06	PF	37.5 kW/m^2	-	-	0
					3 kW/m^2	-	-	50
					3% Fatality	-	-	43
ED09	10	1.35	2440	PF	37.5 kW/m^2	-	-	0
					3 kW/m^2	-	-	12
					3% Fatality	-	-	11
	35	16.5	2.96E+04	PF	37.5 kW/m^2	-	-	0
					3 kW/m^2	-	-	35
					3% Fatality	-	-	30
	100	132	226000	PF	37.5 kW/m^2	-	-	0
					3 kW/m^2	-	-	38
					3% Fatality	-	-	33
NG01	10	1.1	1962	FF	Distance to LFL, m	0	0	0
				JF	37.5 kW/m^2	0	0	0
					3 kW/m^2	16	15	17
					3% Fatality	14	14	14
	35	13.3	2.38E+04	FF	Distance to LFL, m	324	65	71
				JF	37.5 kW/m^2	0	0	0
					3 kW/m^2	49	49	55
					3% Fatality	46	45	45
	100	108.6	179000	FF	Distance to LFL, m	1195	215	243
				JF	37.5 kW/m^2	0	0	0
					3 kW/m^2	129	130	145
					3% Fatality	118	120	118
NG02	10	1.1	1962	FF	Distance to LFL, m	0	0	0
				JF	37.5 kW/m^2	0	0	0
					3 kW/m^2	16	15	17
					3% Fatality	14	14	14
	35	13.3	23784	FF	Distance to LFL, m	324	65	71
				JF	37.5 kW/m^2	0	0	0
					3 kW/m^2	49	49	55

					3% Fatality	46	45	45
	100	108.6	179000	FF	Distance to LFL, m	1195	215	243
				JF	37.5 kW/m^2	0	0	0
					3 kW/m^2	129	130	145
					3% Fatality	118	120	118
NGE01	10	1.1	1962	FF	Distance to LFL, m	0	0	0
				JF	37.5 kW/m^2	0	0	0
					3 kW/m^2	16	15	17
					3% Fatality	14	14	14
	35	13.3	23784	FF	Distance to LFL, m	324	65	71
				JF	37.5 kW/m^2	0	0	0
					3 kW/m^2	49	49	55
					3% Fatality	46	45	45
	100	108.6	179000	FF	Distance to LFL, m	1195	215	243
				JF	37.5 kW/m^2	0	0	0
					3 kW/m^2	129	130	145
					3% Fatality	118	120	118
NG03	10	1.1	1962	FF	Distance to LFL, m	0	0	0
				JF	37.5 kW/m^2	0	0	0
					3 kW/m^2	16	15	17
					3% Fatality	14	14	14
	35	13.3	23784	FF	Distance to LFL, m	324	65	71
				JF	37.5 kW/m^2	0	0	0
					3 kW/m^2	49	49	55
					3% Fatality	46	45	45
	100	108.6	179000	FF	Distance to LFL, m	1195	215	243
				JF	37.5 kW/m^2	0	0	0
					3 kW/m^2	129	130	145
					3% Fatality	118	120	118
NG04	10	1.1	1962	FF	Distance to LFL, m	0	0	0
				JF	37.5 kW/m^2	0	0	0
					3 kW/m^2	16	15	17

					3% Fatality	14	14	14
	35	13.3	23784	FF	Distance to LFL, m	324	65	71
				JF	37.5 kW/m^2	0	0	0
					3 kW/m^2	49	49	55
					3% Fatality	46	45	45
	100	108.6	179000	FF	Distance to LFL, m	1195	215	243
				JF	37.5 kW/m^2	0	0	0
					3 kW/m^2	129	130	145
					3% Fatality	118	120	118

Note 01: For tabulation of consequence see VOPAK major hazard risk assessment, appendix 4 - QRA standards.

2.4 Frequency Evaluation

Consequence frequencies are estimated based on following factors:

$F_n = f_r \times P_w \times P_i \times O_F \times V_F$

Where:
F_n = Frequency of event n, e.g. fatality due to jet fire
F_r = Initial release frequency, based on site incident history or industry data
P_w = Probability of wind blowing in a particular direction based on site meteorological conditions
P_i = Probability of ignition
O_F = Occupancy Factor, hrs spent by a worker at a particular location per day
V_F = Vulnerability factor, probability of fatality of a person exposed to fire, radiation, toxic gas/vapors concentration or blast over pressure

2.4.1 Release frequencies, f_r

Historical data for release frequencies from piping and pipelines was taken from various credible sources. Vopak QRA guideline[1] provide some data on release frequencies, other credible sources are UK HSE, DNV[4], OREDA[5], TNO[6] API[7], UKOPA[8], EGIG[9] and industry data from Shell, BP and other operators. For this QRA DNV failure rate data which is adopted from UK HSE failure rate data is used, where any specific equipment or piping component failure rate is not available in DNV/UK HSE data then other data from other sources as mentioned above was used. Refer to **Annex-1** for failure frequency data used in this QRA.

2.4.2 Probability of Ignition, P_i

Ignition of a leak may occur either at the point of leak or at some distance from it. The cause of ignition may be the leak itself (e.g., static electricity) or an external source (hot surfaces, sparks, flames, electrical devices, vehicle motors, etc.). The ignition probability depends essentially on the flammability properties of the material being released, the process conditions, and the number and energy of the possible ignition sources encountered by the cloud: the larger the cloud the higher the probability of being ignited. In practice, ignition probability is often related to the discharge rate.

Historically, the causes of ignition of released flammable/combustible material in the oil and gas facilities have included:

- Flames/direct heat;
- Hot surfaces;
- Hot work (e.g. welding, flame cutting, grinding);
- Mechanical sparks;
- Electrical equipment not classified for hazardous areas;
- Faulty electrical equipment;
- Lightning;
- Engines;
- Distressed equipment (e.g. overheated bearings);
- Impact energy (e.g. tools, dropped objects, projectiles);
- Chemical energy;
- Static electricity;
- Illicit smoking; and
- Hot soot particles.

Total ignition probability is divided into immediate and delayed ignition probabilities; probability of delayed ignition is taken as 1/4th of total ignition probability (OGP). Immediate ignition will result in jet fire and delayed ignition will result in flash fire or Vapor Cloud Explosion depending on congestion and confinement. Ignition probabilities are taken from industrial data and OGP report.

Table 7: Probability of Ignition

	Release rate kg/s	Total	Immediate	Delayed
Small Release	< 1	0.01	0.0025	0.0075
Medium Release	< 50	0.07	0.0175	0.0525
Large Release	>50	0.3	0.075	0.225

2.4.3 Population Data/Occupancy Factor, O_f

The occupancy factor is the fraction of time a particular person spends in an area. e.g. RLNG operator spends 20 minutes every 2 hrs at RLNG jetty and remaining time in office. Hence Jetty occupancy is 20/120 = 0.16. Refer to Annex-2 for operator exposure in unloading & loading operations.

Table 8: Population data and occupancy factor

Group Name	Location	Number of people		Inside fraction	Occupancy factor O_f, days/year	
		Day	Night		Day	Night
CP1 – Security Guard	Jetty entrance	2	2	0	0.5	0.5
CP2 – Security Guard	Ethylene storage area	1	1	0	0.5	0.5
CP3 – Security Guard	VCM storage area	1	1	0	0.5	0.5
CP4 – Security Guard	MEG common user manifold	1	1	0	0.5	0.5
CP5 – Security Guard	LPG storage area	1	1	0	0.5	0.5
Jetty CP – Security Guard	water pump at jetty	1	1	0	0.5	0.5
Main gate CP – Security Guard	Main gate	8	8	0	0.5	0.5
Office Building Personnel	Office Building	23	5	0.95	0.3	0.5
Warehouse Personnel	Warehouse	16	2	0.95	0.3	0.5
BL01 - Operator*	Acetic acid bowser loading	2	2	0	0.05	0.05
BL02 - Operator	Para Xylene bowser loading	3	3	0	0.7	0.7
BL03 - Operator	LPG Bowser loading	5	5	0	0.25	0.25
BL04 - Operator*	EDC Bowser loading	2	2	0	0.04	0.04
BL05 - Operator	MEG	2	2	0	0.05	0.05
Chemical Jetty - Operator	Chemical Jetty	1	1	0	0.3	0.3
RRLNG Jetty - Operator	RRLNG Jetty	1	1	0	0.16	0.16
RRLNG new Jetty - Operator	RRLNG new Jetty	1	1	0	0.16	0.16
BOG - Operator	BOG	1	1	0.7	1	1
VCM Operator - Operator	VCM Operator	1	1	0	0.12	0.12

*BL01 and BL04 duties are performed by same person.

2.4.4 Vulnerability Criteria, V_f

In the determination of the hazardous envelope(s) associated with each scenario, consequence end points need to be defined for each hazard type. Vulnerability criteria of Humans to fire radiation, explosion over pressure and toxic exposure is defined in various publications including TNO Green Book (CPR 16E)[10], TNO Purple Book (CPR 18E)[3], CCPS Guidelines for QRA[2], and industry publications like OGP Risk Assessment Data Directory.

Human vulnerability is normally defined in terms of dose, Probit functions are used to convert dose into probability of fatality.

Probit is a function that relates lethality to the intensity or concentration of a hazardous effect and the duration of exposure. It typically takes the form:

$$Pr = a + b \ln V$$

where:

Pr = probit

a, b are constants

V = “dose”,

Typically:

For toxic materials:

$V = (c^n t)$ where c = concentration, n = constant, t = exposure duration

For thermal radiation:

$V = (I^{4/3} t)$ where I = thermal radiation, t = exposure duration

Values of constants a, b and n for fire and toxic chemicals are reported in literature (TNO, CCPS, OGP etc.).

In summary following are vulnerability limits for fire & explosion exposure:

- 100% lethality for people outdoors engulfed by a jet fire, pool fire or fireball
- 100% lethality for members of the public outdoors engulfed by a flash fire
- 50% to 100% lethality, depending on ease of escape, for workers wearing fire resistant clothing made from fabrics meeting the requirements of NFPA 2112 or equivalent.

Table 9: Human vulnerability Criteria - Fire radiation exposure

Radiation Level, kW/m²	Effect on Humans
1.2	**Received from the sun at noon in summer**
2	**Minimum to cause pain after 1 minute**
<5	**Will cause pain in 15 to 20 seconds and injury after 30 seconds’ exposure**
>6	**Pain within approximately 10 seconds; rapid escape only is possible**
>12.5	**Significant chance of fatality for medium duration exposure.** **• Thin steel with insulation on the side away from the fire may reach thermal stress level high enough to cause structural failure.** **• Wood ignites after prolonged exposure.**
>25	**Likely fatality for extended exposure.** **• Spontaneous ignition of wood after long exposure.** **• Unprotected steel will reach thermal stress temperatures that can cause failure.**

>35	**• Significant chance of fatality for people exposed instantaneously.** **• Cellulosic material will pilot ignite within one minute's exposure.**

Human vulnerability to explosion is summarized below:

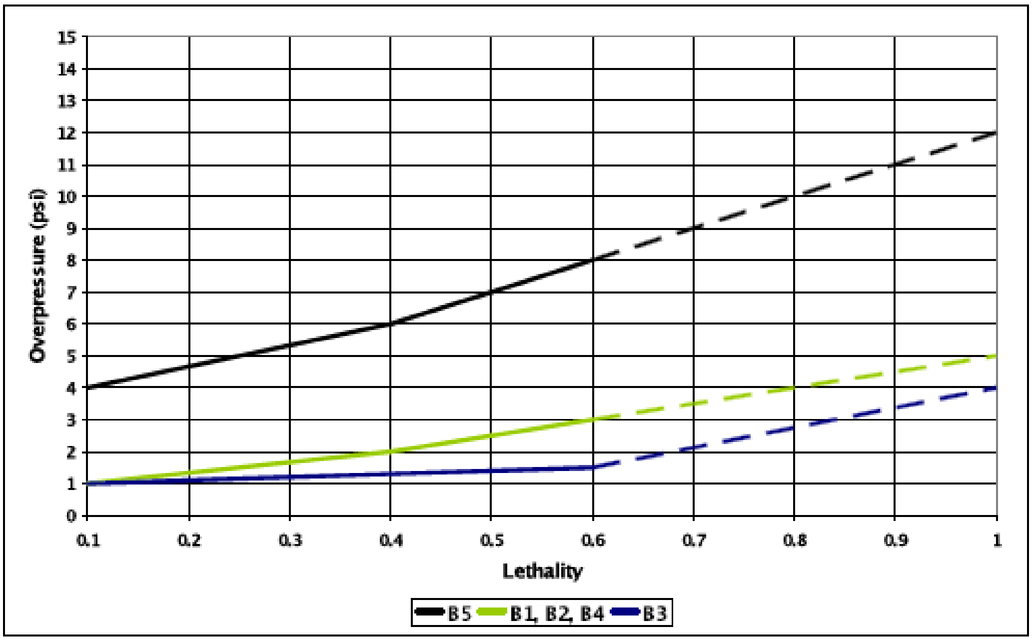
For people *onshore*, outdoors and in the open, the following lethality levels are recommended:

- 0.35 bar overpressure: 15% lethality for people outdoors, in the open
- 0.5 bar overpressure: 50% lethality for people outdoors, in the open

For people *onshore*, outdoors but adjacent to buildings or in unprotected structures (e.g. process units), the following lethality levels are recommended:

- 0.35 bar overpressure: 30% lethality for people outdoors
- 0.5 bar overpressure: 100% lethality for people outdoors

For people inside a building lethality is given below based on API-753 criteria.



Building Types

B1: Wood-frame trailer or shack.

B2: Steel-frame/metal siding or pre-engineered building.

B3: Unreinforced masonry bearing wall building.

B4: Steel or concrete framed with reinforced masonry infill or cladding.

B5: Reinforced concrete or reinforced masonry shear wall building.

Figure 9: Overpressure lethality relationship

For Structural, piping and equipment and buildings response to fire and explosion impact CCPS, TNO and OGP has published criteria.

Based on Vopak QRA guideline, following threshold limits have been used in QRA:

- 3 kW/m^2 radiation contour shall not exceed plant battery limits
- Normally manned offices, buildings, control rooms shall be located outside 3kW/m^2 contour
- Tanks within 10 kW/m^2 contour shall be cooled by fixed cooling system/deluge system
- Firefighting equipment and tie-ins shall be located outside 3kW/m^2 contour

2.5 Risk Representation

Quantitative representations of risk are commonly used to describe the risk level to the workforce and/or members of the public affected by industrial activities. These risk representations are normally calculated as, Individual Risk Per Anum (IRPA), Societal Risk, and potential risk of loss of life, and the resulting risk levels can then be compared with known fatality statistics.

For pipelines, in general only Risk Contours are used. F/N curves are not usually used as the risk, when depicted in this way, would become dependent on the length of the pipeline section considered and the location of individuals, all of which change greatly along the length of the pipeline – which makes this figure meaningless. Risk Transects show the effect of distance on risk frequency at 90 degrees to any point along the pipeline and are developed from a section or intersection through Risk Contours.

Risk Contours

The Risk Contour is an iso-risk line on the map at which a hypothetical individual staying at one point on this line unprotected and for 24 hours per day would be subjected to a defined probability of loss of life due to exposure to hazards induced by the industrial activity. This risk indicator is most frequently used to quantify the risk to the public around an industrial activity (in this case the gas pipeline) and is expressed as a risk of fatality on a per year basis.

Each point along the risk contour is specific to a certain point on the ground, and represents the sum of any risk scenarios which can affect that point. It is sometimes called the Location Risk. Another way to look at the definition above, is to say that a hypothetical individual is at the location and exposed whenever any of the risk scenarios manifests itself.

Although the hypothetical individual is exposed when the scenario occurs, it is normal to take account of human reaction. For example if the individual is in the heat radiation field of a big flame, then an exposure time is assumed from the time of the event until after the individual can reasonably be assumed to have taken cover or moved far enough away from the flame not to be at further risk.

It is possible to take account of the protection offered by buildings, so that the risk contour level inside a building is lower than outside. However this is not normal practice when calculating Risk Contours for land-use planning purposes and has not been undertaken for this analysis.

Individual Risk

The Individual Risk (IR) level is more specifically defined as the Individual Risk Per Annum (IRPA), which is the calculated annual risk loading to a specific individual or group of individuals. Clearly this depends on the amount of time in a year that the individual spends in different risk areas. The individual risk calculation takes account of the fact that people move from one place to another.

When calculating individual risk from major accident scenarios, it is normal to take account of protection by buildings.

Societal Risk Curves

Societal Risk is used in Quantified Risk Assessment (QRA) studies and is depicted on a cumulative graph called an F/N curve. The horizontal axis is the number of potential fatalities, N. The vertical axis is the frequency per year that N or more potential fatalities could occur, F. This risk indicator is used by authorities as a measure for the social disruption in case of large accidents.

Because it is a cumulative curve, the curve always drops away with increasing N. Normally the F/N curve has a lower frequency cut-off at one in a billion (1 x10-9/yr).

This type of curve is normal for plant type hazardous installations where a large group of people could be affected and their location is well established (housing estates, schools etc) relative to the event location (the plant).

2.5.1 Risk Acceptance Criteria

Individual Risk: EVTL adopts UK HSE Criteria for risk acceptance.

In the UK the “Control of Major Accident Hazards” (COMAH) regulations are in line with the latest EU “Seveso-2” Directive. A comprehensive treatment of the subject of tolerability of risk was given in a report titled “Reducing Risks Protecting People”. It accepted the concept of tolerable Individual Risk as being the dividing line between what is just tolerable and intolerable and set the upper tolerable limit for workforce fatalities at 10^{-3}/yr (1 in a thousand) for workers and 10^{-4}/yr (1 in 10 thousand) for members of the public. A level at which risks might be broadly acceptable but not altogether negligible was set at 10^{-6}/yr (1 in a million). The region in between would be controlled by the ALARP concept. Industry practice is to use a bench mark criteria of 1 in 5000yrs (2 x 10^{-4}/yr) criteria of ALARP for existing facilities.

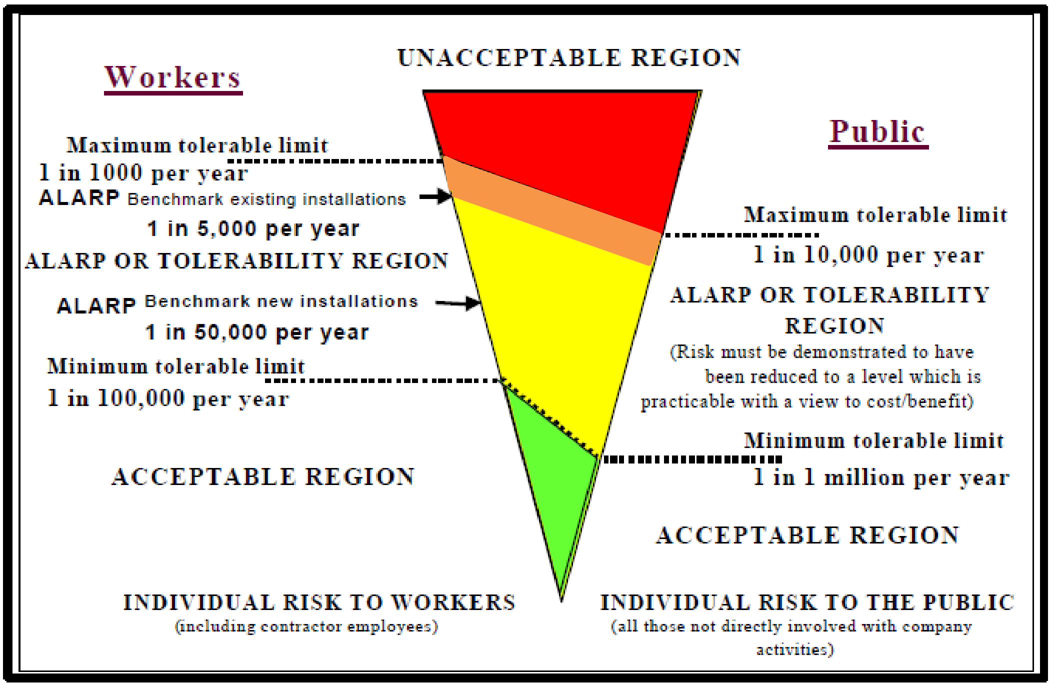


Figure 10: Risk Acceptance Criteria

Based on VOPAK QRA guidelines, following are risk acceptance criteria for individual risk.

Individual Fatality Risk (IR) contour	Limit
$5x10^{-5}$/yr	Should not extend beyond Facility Battery limit
$5x10^{-6}$/yr	Extends to industrial developments only
$1x10^{-6}$/yr	Extends to commercial and industrial developments only

Societal risk: There are various regional regulatory criteria for the societal risk acceptance. There is no regulatory risk acceptance criterion in Pakistan. Engro Vopak adopted UK societal risk criterion for bench marking. Other criteria are Dutch & Singapore. The Dutch criterion is so restrictive that it raises questions about its merit.

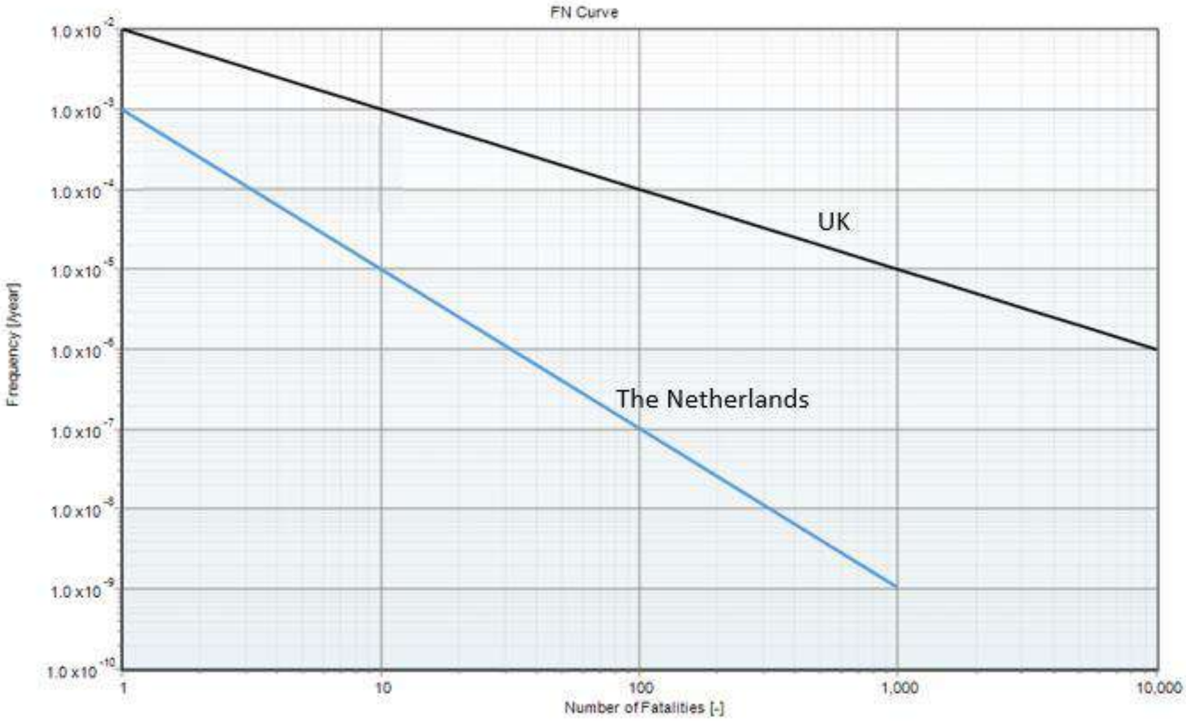


Figure 11: Regulatory upper tolerability F-N criteria

3 Risk Analysis Results

3.1 Base Case – No ESD Credit

Individual Risk

The individual fatality risk results are presented as cumulative contours (i.e. representing the sum of all risk contributors) of equal risk level on the map. In figure 9.

Individual risk results are shown in table 10 below. Contour of $5x10^{-5}$/yr extends slightly beyond facility battery limit into neighboring industrial facility. Only a small area of neighboring facility is within $5x10^{-5}$ /yr contour hence not a major concern.

Table 10: Individual Risk Contours

Individual Fatality Risk (IR) contour	Limit	Extent	Satisfy Individual Risk Criteria, Y/N
$5x10^{-5}$/yr	Should not extend beyond Facility Battery limit	Extends slightly beyond facility fence on to neighboring industry	N
$5x10^{-6}$/yr	Extends to industrial developments only	Extends to industrial developments	Y
$1x10^{-6}$/yr	Extends to commercial and industrial developments only	Extends to industrial and port developments	Y

Individual risk contours (Fig. 11) show that within plant site there are some high risk areas exceeding $1x10^{-4}$/yr risk levels. Due to operator exposure in these high risk areas, risk to some personnel is above acceptable limits.

Table 12 gives Individual Specific Risks. Risks to LPG operator and Security Guard at VCM Storage area are unacceptable per risk acceptance criteria of $2x10^{-4}$/yr for onsite workers. The high risk to LPG operator is due to very high exposure levels to Hazards i.e. high frequency of loading. Security Guard near VCM storage is exposed to high risk area. Risk to SG near Ethylene BOG Compressor is marginally below unacceptable limits due to high exposure in high risk area, risk is only acceptable if occupancy of personal decrease as per table given below:

Table 11: Need to decrease individual availability to achieve acceptable risk

Group name		Max allowable occupancy, %
CP3	SG VCM area	50
CP2	SG BOG area	80
BL03	LPG operator	50

Risks to third party personnel i.e. Bowser drivers is within acceptable limits per risk acceptance criteria of $1x10^{-4}$/yr for third party.

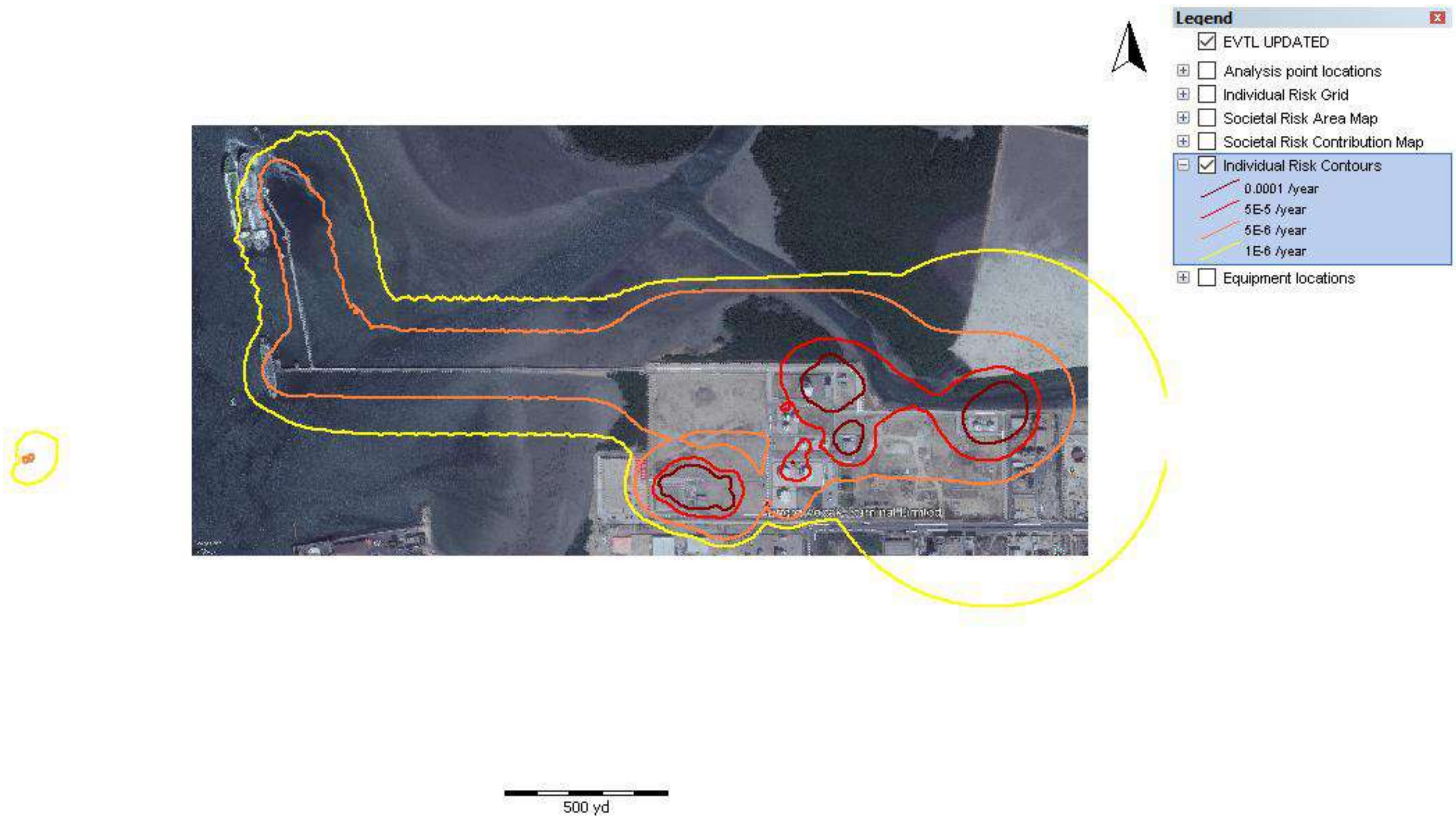


Figure 12: Individual Risk Map

Table 12: Individual Specific Risk

Group Name	Location	IRPA	Main Risk Contributors	Contribution factor, %	ALARP ($2x10^{-4}$/yr), Y/N
CP1 – Security Guard	Jetty entrance	4.87E-05	NG 05- RLNG Pipeline full bore rupture and fire	33	Y
			NG03- RLNG Pipeline fire at ESD valve near FW pump	22	
			NG04- RLNG Pipeline fire	22	
CP2 – Security Guard	Ethylene storage area	1.01E-04	NG 05- RLNG Pipeline full bore rupture and fire	51	N
			E07 – Loss of containment and fire at Ethylene refrigeration unit	45	
CP3 – Security Guard	VCM storage area	2.30E-04	V06 – Loss of containment and fire at VCM piping	63	N
			NG 05- RLNG Pipeline full bore rupture and fire	14	
CP4 – Security Guard	MEG common user manifold	1.50E-06	BLEVE of VCM Tank	100	Y
CP5 – Security Guard	LPG storage area	5.38E-06	PL-04a – LPG Loss of containment and fire at LPG bullet top inlet valve	45	Y
			PL-02 – LPG Loss of containment and fire at LPG Pig receiver	17	
Jetty CP – Security Guard	Water pump at jetty	1.29E-05	PL01- LPG Jetty	29	Y
			NG03- RLNG Pipeline fire at ESD valve near FW pump	29	
Main gate CP – Security Guard	Main gate	1.09E-06	BLEVE of VCM Tank	89	Y
Office Building Personnel	Office Workers	2.29-06	P06c - Para Xylene Pool fire at Tank Dyke	66	Y
	Control Room	2.08E-05	BLEVE of VCM Tank	16	
Warehouse Personnel	Warehouse	5.34E-07	BLEVE of VCM Tank	96	Y
BL01 - Operator	Acetic acid bowser loading	2.53E-05	P08- Loss of containment and pool fire at Para Xylene loading pump	36	Y
			E07 – Loss of containment and fire at Ethylene refrigeration	33	

			unit		
BL02 - Operator	Para Xylene bowser loading	2.71E-05	E07 – Loss of containment and fire at Ethylene refrigeration unit	53.7	Y
			NG 05- RLNG Pipeline full bore rupture and fire	21.1	
BL03 - Operator	LPG Bowser loading	2.10E-04	PL-05 – LPG Loss of containment and fire at LPG Loading station	42	N
			EXP 03 – VCE at LPG loading station	19	
			PL-04 – LPG Loss of containment and fire at LPG bullet bottom outlet valve	10	
BL05 - Operator	MEG Area	3.1E-05	NG 05- RLNG Pipeline full bore rupture and fire	40	Y
			E07 – Loss of containment and fire at Ethylene refrigeration unit	18	
Chemical Jetty - Operator	Chemical Jetty	1.85E-05	PL01 – LPG pipe work Loss of containment ad fire	46	Y
RLNG Jetty - Operator	RLNG Jetty	1.93E-05	NG03- Loss of containment and fire at RLNG piping	69	Y
BOG - Operator	BOG/Ethylene Area	4.39E-05	NG 05- RLNG Pipeline full bore rupture and fire	28	Y
			E07 – Loss of containment and fire at refrigeration unit	20	
			E09- loss of containment and fire at Ethylene Storage tank return line from economizer	15	
			Exp 03 – VCE at LPG loading area	13	
VCM Operator - Operator	VCM Operator	4.17E-05	V06- VMC Pumping area	64	Y

Table 13: Risk to third party

Group Name	Location	IRPA	Main Risk Contributors	Contribution factor, %	ALARP ($1x10^{-4}$/yr), Y/N
BL01A - Bowser Driver	Acetic acid bowser loading	2.15E-05	E07 – Loss of containment and fire at Ethylene refrigeration unit	57	Y
			A06 – Acetic Acid loss of containment and fire in dike area	15	
BL02A - Bowser Driver	Para Xylene bowser loading	2.71E-05	E07 – Loss of containment and fire at Ethylene refrigeration unit	54	Y
			NG 05- RLNG Pipeline full bore rupture and fire	21	
BL03A - Bowser Driver	LPG Bowser loading	8.47E-06	EXP 03 – VCE at LPG loading station	23	Y
			PL-05 – LPG Loss of containment and fire at LPG Loading station	20	
			PL-04 – LPG Loss of containment and fire at LPG bullet bottom outlet valve	12	
BL04A - Bowser Driver	EDC Bowser loading	4.46E-05	NG 05- RLNG Pipeline full bore rupture and fire	27	Y
			E07 – Loss of containment and fire at Ethylene refrigeration unit	21	
BL05A - Bowser Driver	MEG Area	6.15E-06	NG 05- RLNG Pipeline full bore rupture and fire	40	Y
			E07 – Loss of containment and fire at Ethylene refrigeration unit	18	

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Societal risk graph shows risk is below upper acceptable line per UK HSE criterion, while as per Dutch criterion societal risk is slightly above the line. EVTL follows UK risk criteria.

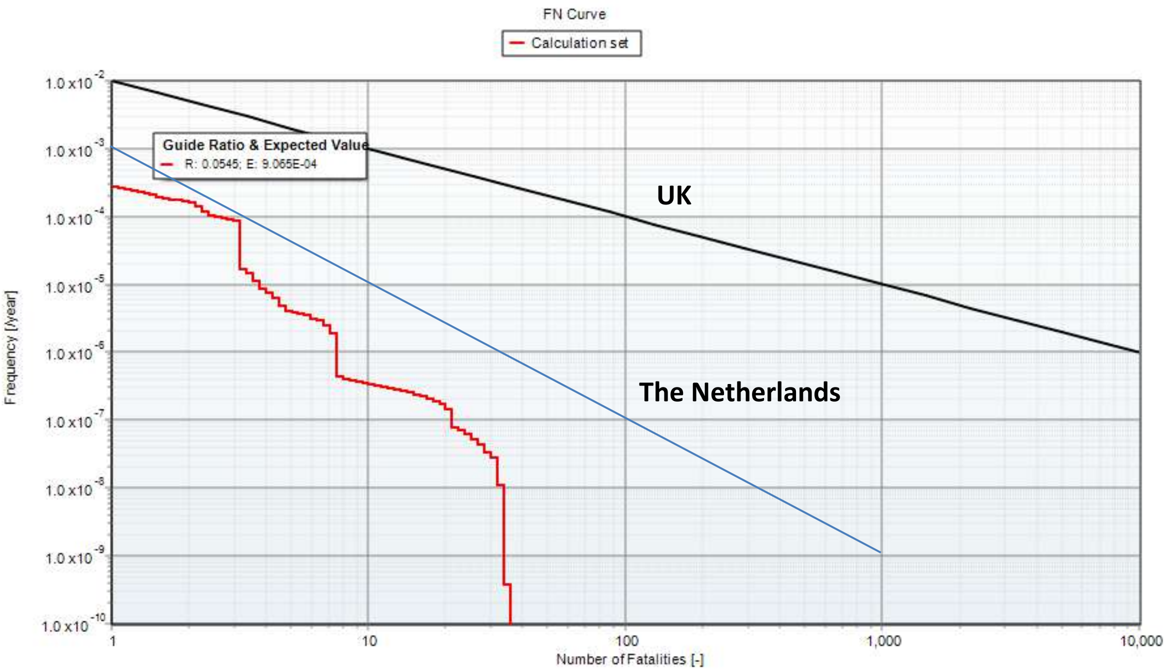

Figure 13: Societal Risk Curve

Societal risk area map shows that two most vulnerable areas are LPG loading area and office block, as shown in orange blocks on risk map.

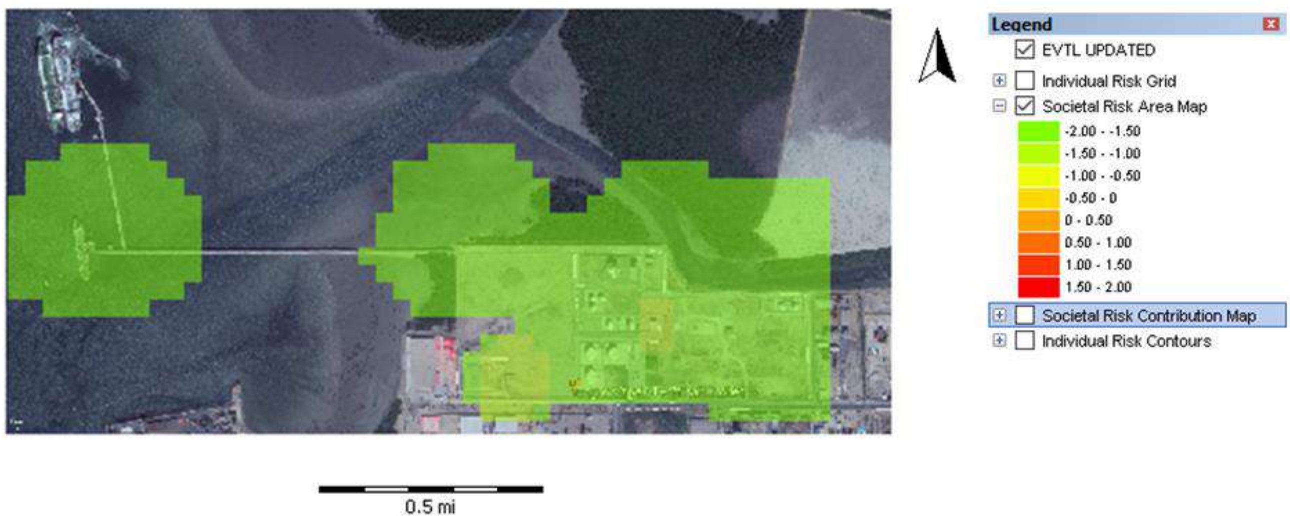

Figure 14: Societal Risk Area Map

Highest risk contributing events are Para Xylene pool fire at loading bay (37.3%) and VCE at LPG loading station (23%).

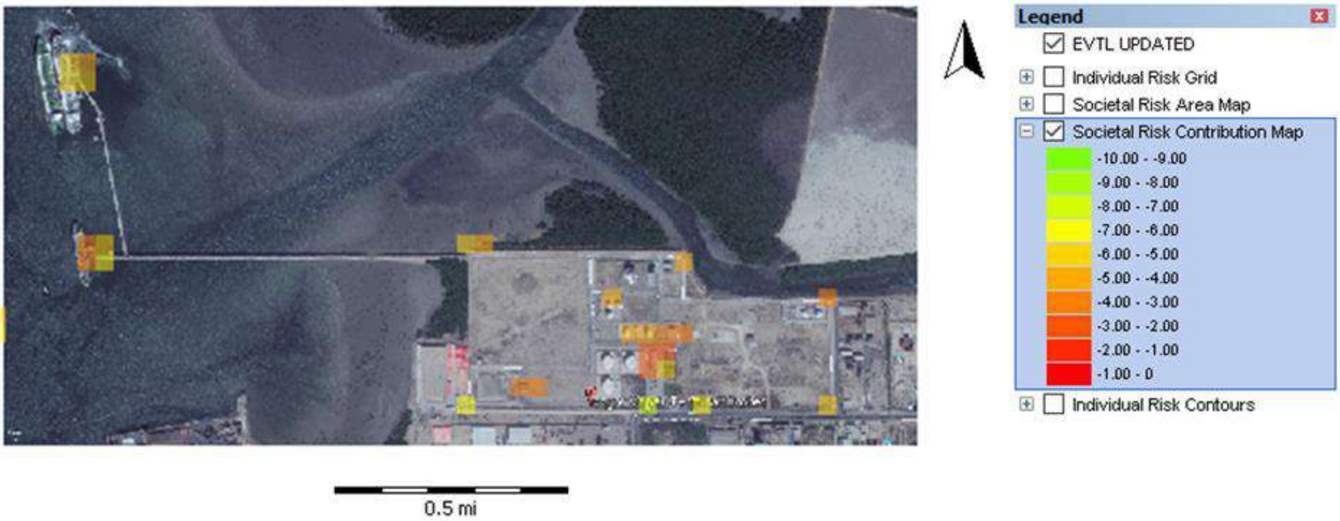

Figure 15: Societal Risk Contribution Map

3.1.1 Risk Contributors

Risk contributor's analysis identifies high risk operations and hence areas to focus in terms of risk reduction actions, inspection & maintenance plans and operations practices.

Table 14: Societal Risk Ranking to Expected Value.

Societal Risk Ranking to Expected Value		
Scenario	Contribution [%]	Value
EXP03 Explosion (Multi Energy model) Set Set (EXP03)	23.7	2.15E-04
100 mm, P09 Unified LOC scenario Set (P09)	20.7	1.87E-04
100 mm, PL05 Unified LOC scenario Set (PL05)	10.1	9.12E-05
100 mm, V06 Unified LOC scenario Set (V06)	8.49	7.70E-05
NG05, Jet Fire (Chamberlain model) Set (NG05)	6.77	6.13E-05
100 mm, E07 Unified LOC scenario Set (E07)	4.84	4.39E-05
35 mm, E09 Unified LOC scenario Set (E09)	3.03	2.75E-05
100 mm, P06c Unified LOC scenario Set (P06c)	2.8	2.54E-05
100 mm, PL04c Unified LOC scenario Set (PL04c)	2.73	2.47E-05
35 mm, P09 Unified LOC scenario Set (P09)	2.27	2.06E-05
100 mm, PLE04e Unified LOC scenario Set (PLE04e)	1.49	1.35E-05
100 mm, PLE04d Unified LOC scenario Set (PLE04d)	1.46	1.32E-05
100 mm, PL04b Unified LOC scenario Set (PL04b)	1.36	1.24E-05
100 mm, E20 Unified LOC scenario Set (E20)	1.34	1.21E-05
100 mm, NG03 Unified LOC scenario Set (NG03)	1.22	1.10E-05
35 mm, E06 Unified LOC scenario Set (E06)	1.03	9.30E-06
100 mm, PLE04d Unified LOC scenario Set (PLE04d)	0.915	8.30E-06
100 mm, V04 Unified LOC scenario Set (V04)	0.842	7.63E-06
35 mm, PL06a Unified LOC scenario Set (PL06a)	0.726	6.58E-06
100 mm, V05 Unified LOC scenario Set (V05)	0.682	6.18E-06

3.2 Risk Analysis with ESD Credit

In order to assess the benefit of F&G Detection and ESD an hypothetical case has been evaluated. It is assumed that F&G detectors are installed to provide 90% Fire & Gas scenario coverage and that combined process safety time for ESD actuation is 120 seconds. The system PFD (Probability of Failure upon Demand) is assumed to be equal to SIL 1 system. The F&G Scenario Coverage factor and the PFD value is used in Event tree to determine the frequency of event. Duration of release is taken as 120sec (vs. 3600 sec without ESD credit case).

The effect of activation of ESD within 120s is smaller footprints of consequence (gas dispersion, fire) and reduction in frequency of events.

Individual Risk

Individual risk contours show that 5 x 10^{-5}/yr contour do not exceed facility battery limits, there are no high risk areas within plant site (> 1 x10^{-4}/yr).

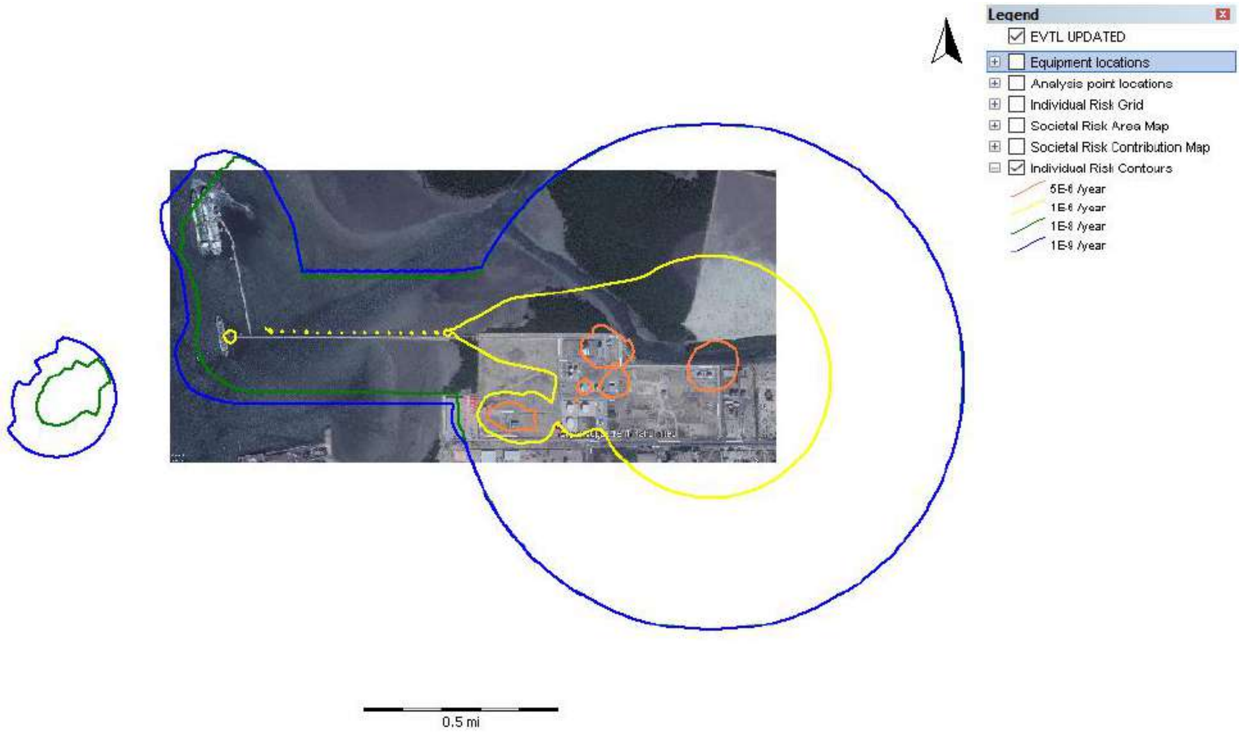

Figure 16: Individual risk contour - With ESD Credit

Individual specific risks are within ALARP limits for all workers.

Table 15: Individual Specific Risks – with hypothetical ESD & F&G mapping Credit

Group Name	Location	IRPA	ALARP, Y/N
CP1 – Security Guard	Jetty entrance	1.86E-05	Y
CP2 – Security Guard	Ethylene storage area	5.82E-06	Y
CP3 – Security Guard	VCM storage area	1.11E-05	Y
CP4 – Security Guard	MEG common user manifold	1.5E-06	Y
CP5 – Security Guard	LPG storage area	1.5E-07	Y
Jetty CP – Security Guard	water pump at jetty	1.59E-06	Y
Main gate CP – Security Guard	Main gate	9.7E-07	Y
Office Building Personnel	Office Building	2.97E-06	Y
Warehouse Personnel	Warehouse	1.23E-06	Y
BL01 - Operator	Acetic acid bowser loading	9.86E-06	Y
BL02 - Operator	Para Xylene bowser loading	6.72E-06	Y
BL03 - Operator	LPG Bowser loading	9.69E-06	Y
BL05 - Operator	MEG Area	6.72E-06	Y
Chemical Jetty - Operator	Chemical Jetty	1.55E-06	Y
RLNG Jetty - Operator	RLNG Jetty	1.93E-05	Y
BOG - Operator	BOG/Ethylene Area	1.11E-05	Y
VCM Operator - Operator	VCM Operator	1.17E-05	Y

Societal Risk curve shows significant risk reduction. Societal risk curve remains below The Netherlands risk criteria.

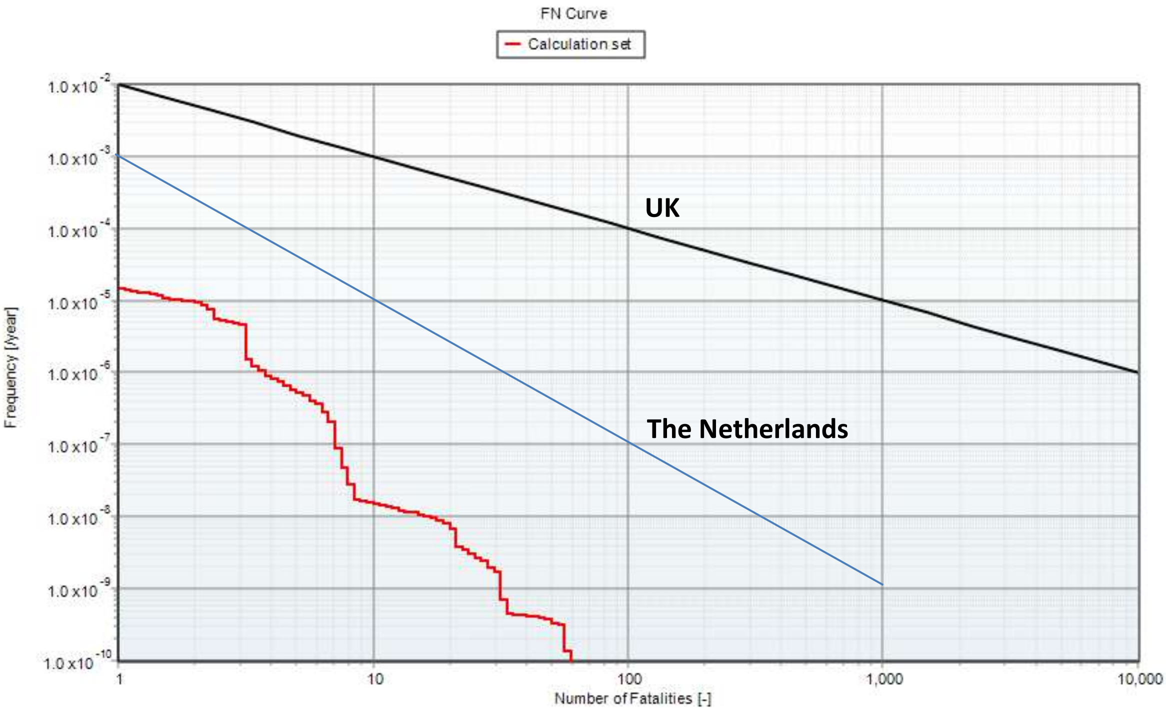

Figure 17: FN Curve with ESD Credit

4 Consequence Analysis

4.1 Fire Radiation

Based on Vopak QRA guidelines, contours of 3kw/m^2 and 10kw/m^2 have been plotted on plot plan (Fig. 17/18).

Following criteria is specified in Vopak guidelines:

Table 16: Fire Radiation Impact

Radiation level	Criteria	Criteria Met Y/N	Comments
3Kw/m^2	Should not exceed facility battery limits.	No	3Kw/m^2 exceeds facility battery limits
	Firefighting equipment shall not be located within 3K/m^2 contour	No	Most of the firefighting equipment (hydrants, monitors, valves) are located within 3 Kw/m^2 contour.
	Manned buildings (offices, control room shall be outside 3kw/m2 contour)	No	Office building/CR is within 3kw/m^2 contour. Distance between P-Xylene tank and Office/Control room building is

			less than 50m (from centre of tank) and less than 15m from dyke edge which is less than minimum spacing per most of industry spacing guidelines; Exxon (120m), Shell/GAPS (75m)
10Kw/m^2	Tanks within 10Kw/m2 contour shall be cooled by fixed system		All tanks require fixed cooling system as they fall within 10 kw/m2 contour from fires other than on equipment itself.

FW Water pump room located at Chemical Jetty entrance is impacted by flame from jet fires at ESV on RLNG line and Ethylene, LPG and VCM piping at the chemical jetty Refer Fig. 1.

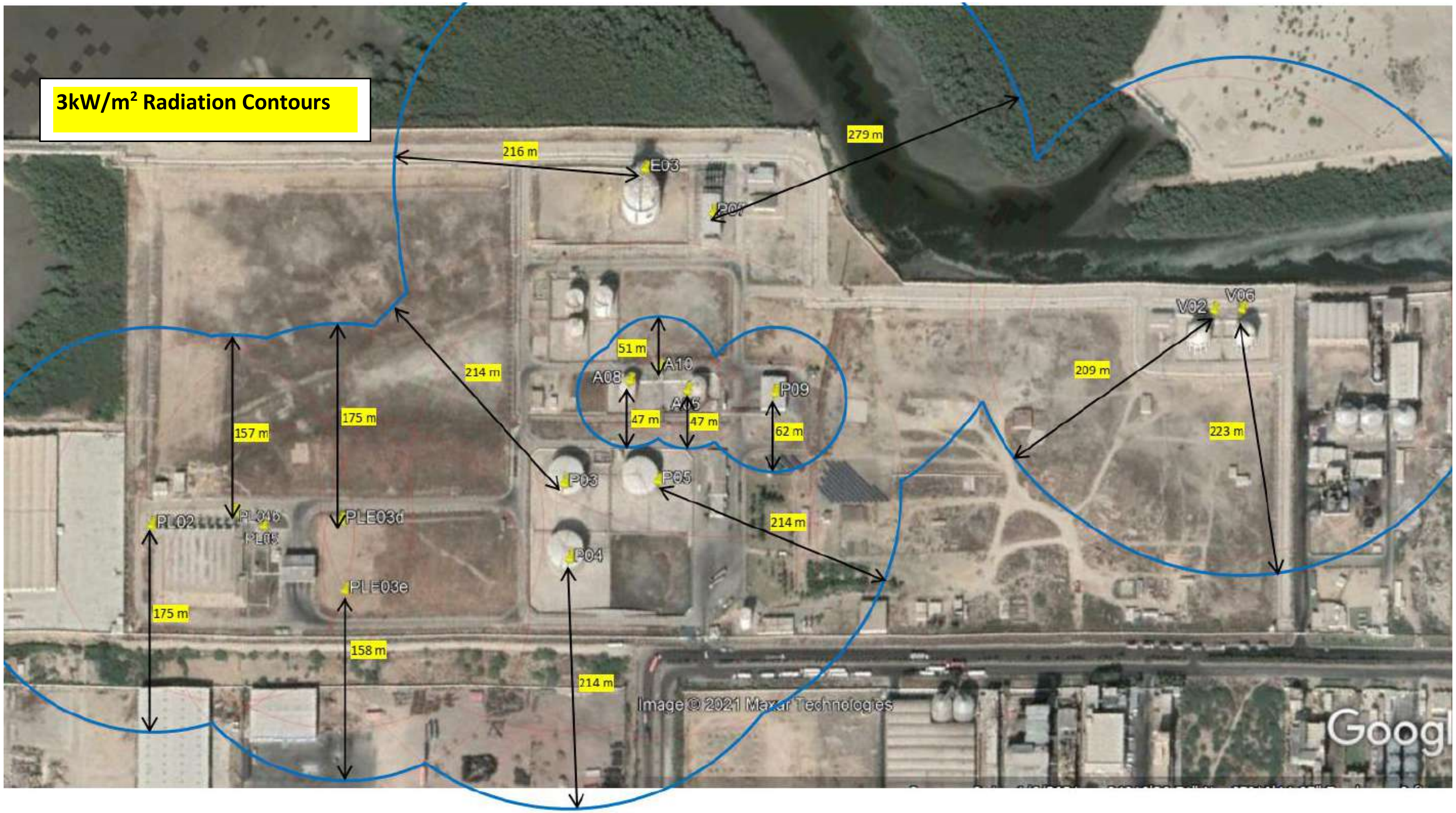

Figure 18: EVTL storage and handling area

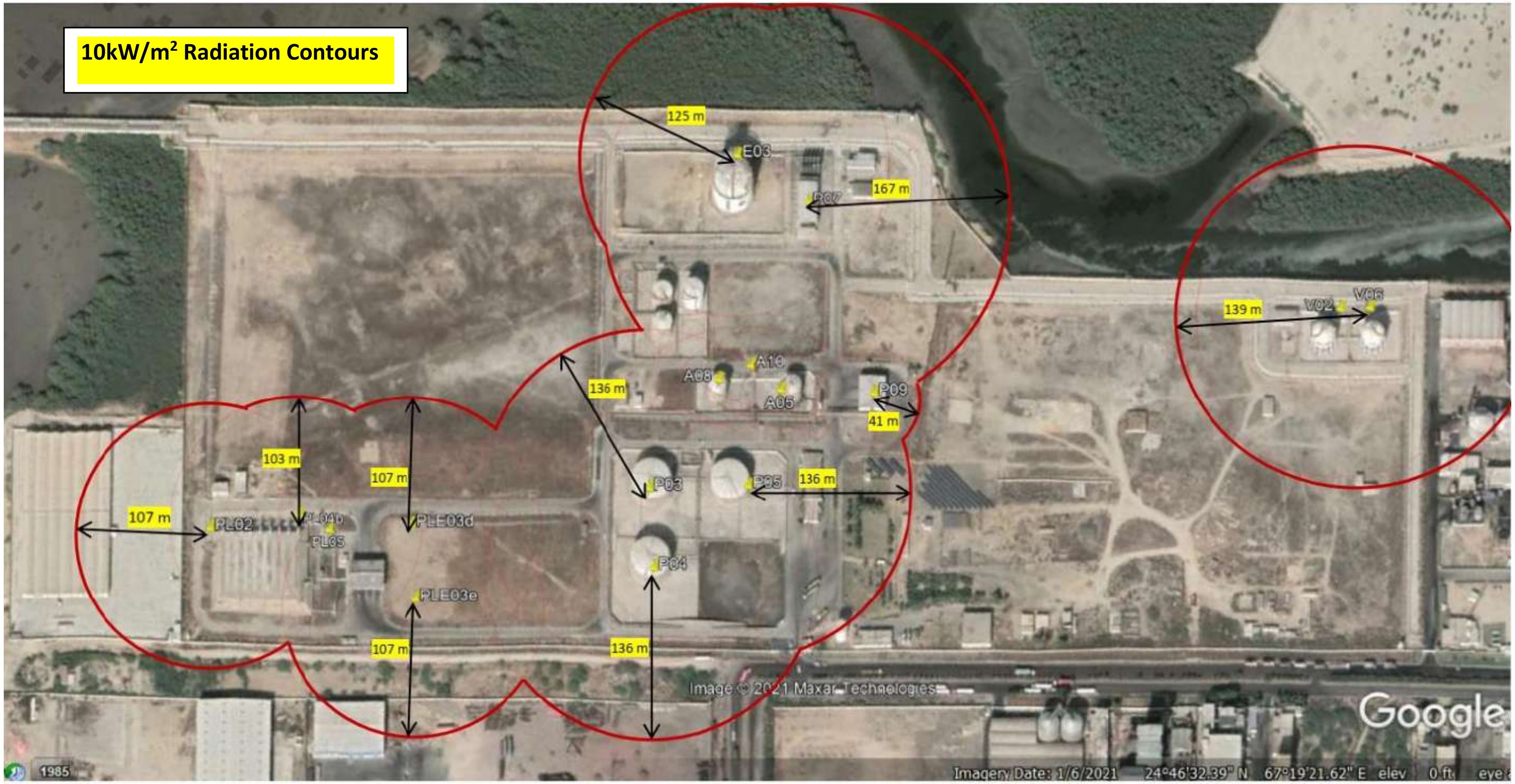

Figure 19: EVTL storage and handling area

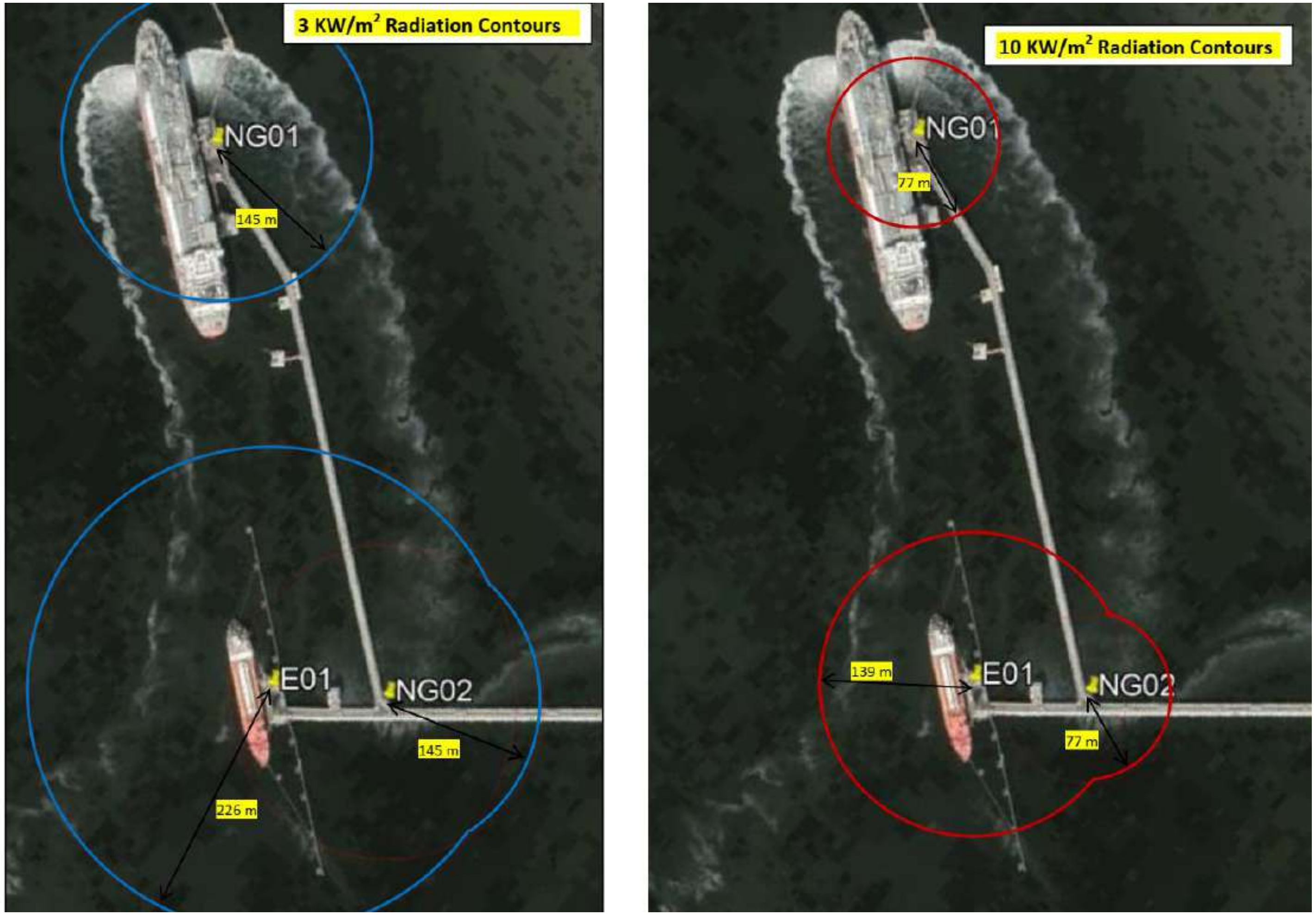

Figure 20: RLNG Jetty and Chemical Jetty areas

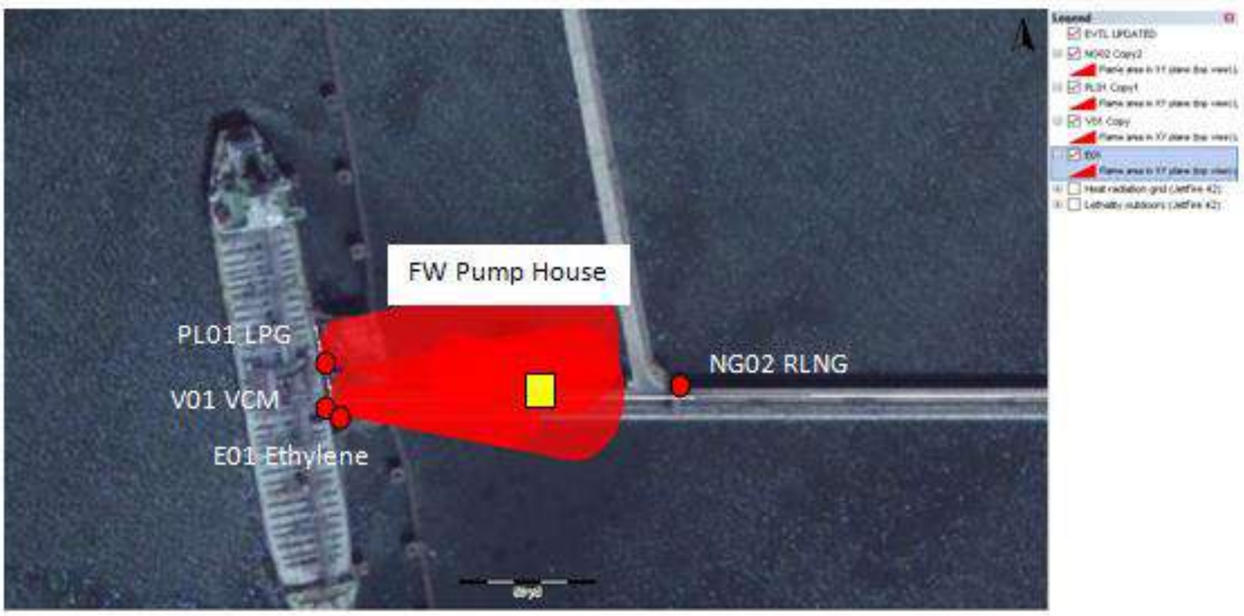

Figure 21: Jet Fire impact on FW Pump house

4.2 Vapor Cloud Explosion (VCE)

Blast over pressure modeling for VCE scenarios show no impact on Office building, warehouse, and security building at the main gate. Ethylene Operator Cabin is located in 1 – 5 Psi (70 – 350mbar) overpressure contour.

Figure 22: VCE Overpressure Contours

4.3 Office Building Escape & Evacuation Estimate

Office building is impacted by pool fire scenarios from loss of containment events at Para Xylene storage tanks. Consequence modeling shows that building will be impacted by 10kW/m^2 radiation contour; any person escaping out of the building shall reach to a distance out of 1.6kW/m^2 radiation levels, probability of safe escape is determined based on radiation dose received by the escaping person from starting point of 10kW/m^2 to the safe end point of 1.6kW/m^2. Based on probit calculations the likelihood of fatality for unprotected escape route is calculated to be 50%. Based on QRA, risk to Office building personnel is 1.08E-06 which is acceptable, hence on risk basis no action is required.

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Escape & Evacuation Calculation

Radiation level on the Building	10	kW/m2
Distance to 1.6 kw/m2 radiation	100	m
escape speed	2	m/s
Exposur time	50	sec
Calculated Probit	5.011758	

Table 3.1 Relationship between the percentage and the value of the probit function.

%	0	1	2	3	4	5	6	7	8	9
0	-	2.67	2.95	3.12	3.25	3.36	3.45	3.52	3.59	3.66
10	3.72	3.77	3.82	3.87	3.92	3.96	4.01	4.05	4.08	4.12
20	4.16	4.19	4.23	4.26	4.29	4.33	4.36	4.39	4.42	4.45
30	4.48	4.50	4.53	4.56	4.59	4.61	4.64	4.67	4.69	4.72
40	4.75	4.77	4.80	4.82	4.85	4.87	4.90	4.92	4.95	4.97
50	5.00	5.03	5.05	5.08	5.10	5.13	5.15	5.18	5.20	5.23
60	5.25	5.28	5.31	5.33	5.36	5.39	5.41	5.44	5.47	5.50
70	5.52	5.55	5.58	5.61	5.64	5.67	5.71	5.74	5.77	5.81
80	5.84	5.88	5.92	5.95	5.99	6.04	6.08	6.13	6.18	6.23
90	6.28	6.34	6.41	6.48	6.55	6.64	6.75	6.88	7.05	7.33
-	0.0	0.1	0.2	0.3	0.4	0.5	0.6	0.7	0.8	0.9
99	7.33	7.37	7.41	7.46	7.51	7.58	7.65	7.75	7.88	8.09

Distance, m	t, sec	Radaition impact, W/m2	dose	Probit value
1	1	10000	208929.6	-5.020633101
2	1	9915	415500.6	-3.260667322
3	1	9830	619719.6	-2.237222617
4	1	9745	821593.4	-1.515357802
5	1	9660	1021129	-0.958767276
6	1	9575	1218332	-0.506737084
7	1	9490	1413211	-0.126880723
8	1	9405	1605771	0.200133516
9	1	9320	1796020	0.486774854
10	1	9235	1983966	0.741557068
11	1	9150	2169614	0.970552585
12	1	9065	2352971	1.178244961
13	1	8980	2534046	1.368038968
14	1	8895	2712844	1.542581106
15	1	8810	2889374	1.703969265
16	1	8725	3063642	1.853894593
17	1	8640	3235656	1.993740265
18	1	8555	3405423	2.124651994
19	1	8470	3572950	2.247589438
20	1	8385	3738245	2.363364416
21	1	8300	3901315	2.472669784
22	1	8215	4062167	2.576101589
23	1	8130	4220810	2.674176299
24	1	8045	4377251	2.767344354
25	1	7960	4531497	2.856000958
26	1	7875	4683556	2.940494748
27	1	7790	4833437	3.021134827
28	1	7705	4981146	3.098196519
29	1	7620	5126692	3.171926111
30	1	7535	5270082	3.242544795
31	1	7450	5411326	3.310251956
32	1	7365	5550430	3.375227949
33	1	7280	5687403	3.437636436
34	1	7195	5822253	3.497626382
35	1	7110	5954988	3.555333763
36	1	7025	6085617	3.610883027
37	1	6940	6214148	3.664388357
38	1	6855	6340590	3.71595477
39	1	6770	6464950	3.765679066
40	1	6685	6587239	3.813650665
41	1	6600	6707463	3.859952333
42	1	6515	6825633	3.904660823
43	1	6430	6941757	3.947847447
44	1	6345	7055843	3.989578571
45	1	6260	7167901	4.029916061
46	1	6175	7277940	4.068917683
47	1	6090	7385970	4.106637452
48	1	6005	7491998	4.143125953
49	1	5920	7596035	4.178430617
50	1	5835	7698090	4.212595986
51	1	5750	7798173	4.245663936
52	1	5665	7896292	4.277673886
53	1	5580	7992459	4.308662988
54	1	5495	8086682	4.338666296
55	1	5410	8178971	4.367716922
56	1	5325	8269337	4.395846173
57	1	5240	8357790	4.423083687
58	1	5155	8444339	4.449457542
59	1	5070	8528996	4.474994371
60	1	4985	8611770	4.499719456
61	1	4900	8692672	4.523656819
62	1	4815	8771713	4.546829309
63	1	4730	8848904	4.569258672
64	1	4645	8924255	4.590965628
65	1	4560	8997778	4.611969934
66	1	4475	9069484	4.632290446
67	1	4390	9139384	4.651945169
68	1	4305	9207490	4.67095132
69	1	4220	9273813	4.689325365
70	1	4135	9338366	4.707083073
71	1	4050	9401159	4.724239553
72	1	3965	9462206	4.740809295
73	1	3880	9521519	4.756806206
74	1	3795	9579109	4.772243647
75	1	3710	9634991	4.787134461
76	1	3625	9689176	4.801491007
77	1	3540	9741678	4.815325189
78	1	3455	9792509	4.82864848
79	1	3370	9841685	4.84147195
80	1	3285	9889218	4.853806289
81	1	3200	9935121	4.865661833
82	1	3115	9979411	4.877048583
83	1	3030	10022100	4.887976227
84	1	2945	10063204	4.898454159
85	1	2860	10102738	4.908491504
86	1	2775	10140716	4.918097129
87	1	2690	10177156	4.927279667
88	1	2605	10212072	4.936047533
89	1	2520	10245481	4.944408941
90	1	2435	10277399	4.952371921
91	1	2350	10307844	4.959944338
92	1	2265	10336834	4.967133907
93	1	2180	10364386	4.97394821
94	1	2095	10390518	4.980394713
95	1	2010	10415249	4.986480787
96	1	1925	10438600	4.992213719
97	1	1840	10460589	4.997600737
98	1	1755	10481237	5.002649025
99	1	1670	10500566	5.007365746
100	1	1585	10518598	5.011758061

5 Recommendations

Following recommendations should be implemented to minimize the risk to personnel and business.

1. Develop 3D mapping for installation of F&G detectors at locations not covered in previous mapping studies.
2. Review and update ESD philosophy, consideration shall be given to automatic ESD upon gas or fire detection to achieve the objective of isolation and blow-down within 120 seconds.
3. Develop and implement plan for SIL studies with HAZOP revalidation cycle. Implement IEC-61511 Safety Instrumented System lifecycle requirements to ensure all safety instrumented functions including F&G detection system achieve minimum SIL 1 for all safety functions throughout project life.
4. All ESD valves shall be fire proofed. Develop and implement plan for replacement of MOVs with ESD valves as per maintenance/obsolesce need; all new and existing ESD valves shall be fire proofed.
5. Security check post near Ethylene storage and VCM storage shall be relocated to a safer location outside $1x10^{-4}$/yr risk contour, refer to Figure 12 (if recommendation 1 - 4 are implemented, then this recommendation can be dropped as in case of ESD credit, risk at subject security post is acceptable) or limit the occupancy of the security guards to the maximum of 12 hr per day.
6. Operator cabin at Ethylene area shall be designated unoccupied and preferably demolished as it is no more functional as operator cabin.
7. All fixed Fire monitors shall have remotely operated valves (from control room).
   If this recommendation can be implemented with total spending not exceeding values given in Cost-benefits-Analysis sheet in Annex-4 than implement the recommendation else additional spending on risk mitigation is not justified. If the cost of implementation of this recommendation exceeds values given in Annex-4 then;
   Provide NFPA/ASTM rated fire fighters suits to fire responders suitable for fire radiations up to 12.5Kw/m2 for 60 seconds.
8. FW pump house shall be protected from fire impact either by relocating to outside $3kW/m^2$ radiation contour or providing fire rated walls. It is better to relocate to a safer location so that room is approachable by operator in case of fire, refer to Figure 22.
   Refer to Annex-4, Risk of consequential damages is extremely low and acceptable per EVTL risk acceptance criteria hence on risk basis this recommendation can be dropped.
9. Relocate Assembly point to a safe location, out of $1.6Kw/m^2$ contours.
10. Designate the Office Building/Control Room as Shelter-in-Place for the duration of event. This would require assurance on fire radiation (10 KW/m2) resistance of building structure for the duration of event; further study is required to upgrade the building as Shelter-in-Place. Based on QRA, risk to Office building personnel is 1.08E-06 which is acceptable, hence on risk basis no action is required, for detail see section 4.3.
11. Review and update ERP in light of QRA report; develop scenario based pre plans.

6 References

1- Vopak Major Hazard Risk Assessment – Annex 4 QRA Standard
2- CCPS Guidelines for Quantitative Risk Assessments
3- TNO CPE 18E – Guidelines for QRA
4- Failure Rate and Event Data for use within Risk – UK HSE
5- DNV QRA Failure Frequency Guidance
6- OREDA Handbook
7- API RP 581 Risk Based Inspection Technology
8- UK Onshore Pipelines Operators Association Report Number: UKOPA/11/0076
9- European Gas Pipeline Incidents Group
10- TNO CPE 16E – TNO Green Book
11- OGP Risk Assessment Data Directory – Report 434

Annexure 1
Failure Frequency Data

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VOPAK QRA Leak Frequencies Data

Pipeline (above ground)						
Hole diameter		Leak frequency (per m/year)				
Range	Nominal	2" Dia (50 mm)	6" Dia (150 mm)	12" Dia (300 mm)	18" Dia (450 mm)	24" Dia (600 mm)
Small	10 mm	9.80E-05	4.30E-05	3.40E-05	3.30E-05	3.30E-05
Medium	35 mm	3.80E-05	8.90E-06	7.20E-06	6.70E-06	6.60E-06
Large	100 mm		1.00E-05	9.40E-06	9.10E-06	9.00E-06
	Total	**1.36E-04**	**6.19E-05**	**5.06E-05**	**4.88E-05**	**4.86E-05**

Pipeline (underground)						
Hole diameter		Leak frequency (per m/year)				
Range	Nominal	12" Dia (300 mm)	18" Dia (450 mm)	24" Dia (600 mm)	30" Dia (750 mm)	36" Dia (900 mm)
Small	10 mm	3.60E-04	2.40E-04	1.90E-04	1.60E-04	1.50E-04
Medium	35 mm	1.10E-04	7.50E-05	5.80E-05	5.10E-05	4.70E-05
Large	100 mm	1.20E-04	8.20E-05	6.40E-05	6.60E-05	5.30E-05
	Total	**5.90E-04**	**3.97E-04**	**3.12E-04**	**2.77E-04**	**2.50E-04**

Valves: summary of valve external leak frequencies				
Hole diameter		Leak frequency (per valve year)		
Range	Nominal	Manual valve 12" Dia	Actuated non-pipeline valves	Actuated pipeline valve
Small	10 mm	2.70E-04	6.10E-04	1.40E-03
Medium	35 mm	4.90E-05	1.10E-04	2.50E-04
Large	100 mm	2.50E-05	5.40E-05	1.30E-04
	Total	**3.44E-04**	**7.74E-04**	**1.78E-03**

Valves: summary of valve failure rates				
Valve type	Failure mode	Failure rate (per hour)	Example test interval	Example failure rate (per demand)
Control valve	Failure to close (inc. control system failures)	0.000003	1 year	1.30E-02
Emergency shutdown valve	Failure to close (inc. control system failures)	0.000003	3 year	3.30E-03
Non return valve	Failure to close	0.000001	10 year	4.40E-03
Non return valve	Internal leak while closed	0.000007	10 year	3.10E-02
Excess flow valve	Failure to close	0.000003	10 year	1.30E-01
Pressure relief valve	Failure to lift within 2x set pressure (hydrocarbon gas)	0.000004	1 year	0.018

Pumps			
Hole diameter		Leak frequency (per pump year in service)	
Range	Nominal	Centrifugal	Reciprocating
Small	10 mm	5.40E-03	3.80E-03
Medium	35 mm	6.50E-04	1.20E-03
Large	100 mm	2.30E-04	1.30E-03
	Total	**6.28E-03**	**6.30E-03**

Storage Tank			
Type of fire	Atmospheric storage tank fire frequencies		
	Floating roof tank,(per tank per year)	Fixed roof tank, (per tank per year)	Fixed plus internal floating roof tank, (per tank per year)
Rim seal fire	1.60E-03		
Full surface fire on roof	1.20E-04		
Internal explosion and full surface fire		9.00E-05	9.00E-05
Internal explosion without fire		2.50E-05	2.50E-05
Vent fire		9.00E-05	
Small bund fire	9.00E-05	9.00E-05	9.00E-05
Large bund fire (full bund area)	6.00E-05	9.00E-05	6.00E-05

Storage Tank		
Type of Tank	Atmospheric storage tank release frequencies	
	Type of release	Release Leak frequency (per tank per year) frequency
Floating roof	Liquid spill on roof	0.0016
	Sunken roof	0.0011
Fixed/floating roof	Liquid spill outside tank	0.0028
	Tank Rupture	0.000003

Pressure vessel leak frequency				
Hole diameter		**Leak frequency (per vessel year)**		
Range	**Nominal**	**process vessel**	**Storage Vessel**	**Small container**
Small	10 mm	3.50E-03	3.50E-05	9.00E-07
Medium	35 mm	7.10E-04	7.10E-06	
Large	100 mm	4.80E-04	4.80E-06	1.00E-07
Total		**4.69E-03**	**4.69E-05**	**1.00E-06**

Pipe Work

		DNV			OGP			
Equipment Size	**Category**	**Total**	**Full Pressure**	**Zero Pressure**		**Full Flange Release**	**Limited Flange Release**	**Zero Pressure Flange Release**
0.5 in	1- 3 mm	9.17E-04	9.41E-04	7.56E-06				
	3- 10mm	3.44E-04	3.29E-04	5.30E-06				
	10- 50mm	1.68E-04	1.44E-04	1.08E-05				
	50- 150mm	0.00E+00	0.00E+00	0.00E+00				
	>150mm	0.00E+00	0.00E+00	0.00E+00				
	Total	1.43E-03	1.41E-03	2.37E-05				
1 in	1- 3 mm	2.73E-04	2.85E-04	4.77E-06				
	3- 10mm	1.02E-04	9.98E-05	3.34E-06				
	10- 50mm	5.31E-05	4.58E-05	7.58E-06				
	50- 150mm	0.00E+00	0.00E+00	0.00E+00				
	>150mm	0.00E+00	0.00E+00	0.00E+00				
	Total	4.28E-04	4.31E-04	1.57E-05				
2 in	1- 3 mm	9.99E-05	1.03E-04	3.55E-06		1.80E-05	1.50E-05	2.70E-06
	3- 10mm	3.74E-05	3.61E-05	2.49E-06		7.00E-06	1.30E-05	6.00E-06
	10- 50mm	1.39E-05	1.24E-05	1.94E-06		0.00E+00	0.00E+00	0.00E+00
	50- 150mm	8.42E-06	6.10E-06	4.22E-06		0.00E+00	0.00E+00	0.00E+00
	>150mm	0.00E+00	0.00E+00	0.00E+00	Total	2.5E-05	2.8E-05	8.7E-06
	Total	1.60E-04	1.58E-04	1.22E-05				
4 in	1- 3 mm	5.36E-05	5.27E-05	3.02E-06				
	3- 10mm	2.01E-05	1.85E-05	2.12E-06				
	10- 50mm	7.46E-06	6.33E-06	1.65E-06				
	50- 150mm	6.61E-06	4.58E-06	3.89E-06				
	>150mm	0.00E+00	0.00E+00	0.00E+00				
	Total	8.78E-05	8.21E-05	1.07E-05				
6 in	1- 3 mm	4.45E-05	4.25E-05	2.86E-06		2.60E-05	9.90E-06	3.20E-06
	3- 10mm	1.67E-05	1.49E-05	2.01E-06		8.50E-06	4.90E-06	2.30E-06
	10- 50mm	6.19E-06	5.10E-06	1.56E-06		6.00E-07	2.50E-06	1.90E-06
	50- 150mm	1.13E-06	8.50E-07	6.23E-07		2.40E-06	3.20E-06	3.40E-06
	>150mm	5.12E-06	3.43E-06	3.17E-06		0.00E+00	0.00E+00	0.00E+00
	Total	7.37E-05	6.67E-05	1.02E-05	Total	3.75E-05	2.05E-05	1.08E-05
10 in	1- 3 mm	3.97E-05	3.69E-05	2.75E-06				
	3- 10mm	1.49E-05	1.29E-05	1.93E-06				
	10- 50mm	5.52E-06	4.43E-06	1.50E-06				
	50- 150mm	1.00E-06	7.38E-07	5.98E-07				
	>150mm	5.06E-06	3.37E-06	3.12E-06				
	Total	6.61E-05	5.83E-05	9.89E-06				
12 in	1- 3 mm					2.30E-05	8.10E-06	3.10E-06
	3- 10mm					7.60E-06	4.00E-06	2.30E-06
	10- 50mm					2.40E-06	2.00E-06	1.80E-06
	50- 150mm					3.70E-07	5.20E-07	7.70E-07
	>150mm					1.70E-07	2.40E-06	2.60E-06
	Total				Total	3.35E-05	1.70E-05	1.06E-05

14 in	1- 3 mm	3.88E-05	3.59E-05	2.72E-06				
	3- 10mm	1.45E-05	1.26E-05	1.91E-06				
	10- 50mm	5.40E-06	4.31E-06	1.48E-06				
	50- 150mm	9.81E-07	7.17E-07	5.92E-07				
	>150mm	5.04E-06	3.36E-06	3.11E-06				
	Total	6.48E-05	5.68E-05	9.81E-06				
18 in	1- 3 mm					2.30E-05	7.80E-06	3.10E-06
	3- 10mm					7.50E-06	3.80E-06	2.30E-06
	10- 50mm					2.40E-06	1.90E-06	1.80E-06
	50- 150mm					3.60E-07	5.00E-07	7.70E-07
	>150mm					1.70E-07	2.40E-06	2.60E-06
	Total				Total	3.3E-05	1.64E-05	1.06E-05
20 in	1- 3 mm	3.79E-05	3.48E-05	2.69E-06				
	3- 10mm	1.42E-05	1.22E-05	1.89E-06				
	10- 50mm	5.27E-06	4.18E-06	1.47E-06				
	50- 150mm	9.59E-07	6.97E-07	5.85E-07				
	>150mm	5.03E-06	3.35E-06	3.09E-06				
	Total	6.34E-05	5.52E-05	9.72E-06				
24 in	1- 3 mm					2.30E-05	7.80E-06	3.10E-06
	3- 10mm					7.50E-06	3.80E-06	2.30E-06
	10- 50mm					2.40E-06	1.90E-06	1.80E-06
	50- 150mm					3.60E-07	5.00E-07	7.70E-07
	>150mm					1.70E-07	2.40E-06	2.60E-06
	Total				**Total**	3.34E-05	1.64E-05	1.1E-05
36 in	1- 3 mm					2.30E-05	7.80E-06	3.10E-06
	3- 10mm					7.50E-06	3.80E-06	2.30E-06
	10- 50mm					2.40E-06	1.90E-06	1.80E-06
	50- 150mm					3.60E-07	5.00E-07	7.70E-07
	>150mm					1.70E-07	2.40E-06	2.60E-06
	Total				**Total**	3.34E-05	1.64E-05	1.06E-05

Pig Trap

DNV

Equipment Size	Category	Total	Full Pressure	Zero Pressure
0.5	1- 3 mm	3.25E-03	3.27E-03	4.82E-05
	3- 10 mm	1.81E-03	1.59E-03	4.94E-05
	10- 50 mm	1.75E-03	1.18E-03	6.83E-04
	50- 150 mm	0.00E+00	0.00E+00	0.00E+00
	> 150 mm	0.00E+00	0.00E+00	0.00E+00
	Total	6.82E-03	6.04E-03	7.80E-04
1	1- 3 mm	3.25E-03	3.27E-03	4.82E-05
	3- 10 mm	1.81E-03	1.59E-03	4.94E-05
	10- 50 mm	1.75E-03	1.18E-03	6.83E-04
	50- 150 mm	0.00E+00	0.00E+00	0.00E+00
	> 150 mm	0.00E+00	0.00E+00	0.00E+00
	Total	6.82E-03	6.04E-03	7.80E-04
2	1- 3 mm	3.25E-03	3.27E-03	4.82E-05
	3- 10 mm	1.81E-03	1.59E-03	4.94E-05
	10- 50 mm	1.08E-03	8.02E-04	6.08E-05
	50- 150 mm	6.78E-04	3.76E-04	6.22E-04
	> 150 mm	0.00E+00	0.00E+00	0.00E+00
	Total	6.82E-03	6.04E-03	7.80E-04
4	1- 3 mm	3.25E-03	3.27E-03	4.82E-05
	3- 10 mm	1.81E-03	1.59E-03	4.94E-05
	10- 50 mm	1.08E-03	8.02E-04	6.08E-05
	50- 150 mm	6.78E-04	3.76E-04	6.22E-04
	> 150 mm	0.00E+00	0.00E+00	0.00E+00
	Total	6.82E-03	6.04E-03	7.80E-04
6	1- 3 mm	3.25E-03	3.27E-03	4.82E-05
	3- 10 mm	1.81E-03	1.59E-03	4.94E-05
	10- 50 mm	1.08E-03	8.02E-04	6.08E-05
	50- 150 mm	3.24E-04	2.03E-04	3.84E-05
	> 150 mm	3.55E-04	1.72E-04	5.83E-04
	Total	6.82E-03	6.04E-03	7.80E-04

OGP

Equipment Size	Category	Total	Full Pressure	Limited Flange Release	Zero Pressure
Inlet 50 to 150 mm	1 to 3	0.0032	0.0023	0.00074	0.00027
	3 to 10	0.0019	0.00072	0.00056	0.00023
	10 to 50	0.0012	0.00022	0.00048	0.00023
	>50	0.00083	0.000047	0.00071	0.00052
	TOTAL	0.007	0.0033	0.0025	0.0013
Inlet >150 mm	1 to 3	0.0032	0.0023	0.00074	0.00027
	3 to 10	0.0019	0.00072	0.00056	0.00023
	10 to 50	0.0012	0.00022	0.00048	0.00023
	50 to 150	0.00037	0.000033	0.00021	0.00011
	>150	0.00046	0.000014	0.0005	0.00041
	TOTAL	0.007	0.0033	0.0025	0.0013

Flanges								
	DNV				OGP			
Equipment Size	Category	Total	Full Pressure	Zero Pressure		Full Flange Release	Limited Flange Release	Zero Pressure Flange Release
0.5in	1- 3 mm	3.73E-05	3.54E-05	1.16E-06				
	3- 10mm	1.36E-05	1.24E-05	8.77E-07				
	10- 50mm	1.23E-05	1.03E-05	2.37E-06				
	50- 150mm	0.00E+00	0.00E+00	0.00E+00				
	>150mm	0.00E+00	0.00E+00	0.00E+00				
	Total	6.32E-05	5.81E-05	4.40E-06				
1 in	1- 3 mm	4.04E-05	3.77E-05	1.16E-06				
	3- 10mm	1.48E-05	1.32E-05	8.77E-07				
	10- 50mm	1.28E-05	1.07E-05	2.37E-06				
	50- 150mm	0.00E+00	0.00E+00	0.00E+00				
	>150mm	0.00E+00	0.00E+00	0.00E+00				
	Total	6.80E-05	6.16E-05	4.40E-06				
2 in	1- 3 mm	4.63E-05	4.23E-05	1.16E-06		2.60E-05	1.50E-05	1.50E-06
	3- 10mm	1.70E-05	1.48E-05	8.78E-07		7.60E-06	7.90E-06	1.10E-06
	10- 50mm	6.13E-06	5.08E-06	7.52E-07		4.00E-06	8.60E-06	2.00E-06
	50- 150mm	7.66E-06	6.27E-06	1.62E-06		0.00E+00	0.00E+00	0.00E+00
	>150mm	0.00E+00	0.00E+00	0.00E+00		0.00E+00	0.00E+00	0.00E+00
	Total	7.70E-05	6.84E-05	4.40E-06	Total	3.8E-05	3.2E-05	4.6E-06
4 in	1- 3 mm	5.75E-05	5.13E-05	1.17E-06				
	3- 10mm	2.10E-05	1.80E-05	8.89E-07				
	10- 50mm	7.61E-06	6.16E-06	7.61E-07				
	50- 150mm	8.06E-06	6.54E-06	1.63E-06				
	>150mm	0.00E+00	0.00E+00	0.00E+00				
	Total	9.42E-05	8.20E-05	4.45E-06				
6 in	1- 3 mm	6.82E-05	6.03E-05	1.24E-06		3.70E-05	2.30E-05	1.70E-06
	3- 10mm	2.50E-05	2.11E-05	9.42E-07		1.10E-05	1.20E-05	1.20E-06
	10- 50mm	9.02E-06	7.24E-06	8.07E-07		3.00E-06	6.40E-06	1.00E-06
	50- 150mm	1.59E-06	1.21E-06	3.55E-07		2.00E-06	5.40E-06	1.30E-06
	>150mm	6.85E-06	5.60E-06	1.34E-06		0.00E+00	0.00E+00	0.00E+00
	Total	1.11E-04	9.54E-05	4.69E-06	Total	5.30E-05	4.68E-05	5.20E-06
10 in	1- 3 mm	8.88E-05	7.80E-05	1.88E-06				
	3- 10mm	3.25E-05	2.73E-05	1.43E-06				
	10- 50mm	1.18E-05	9.36E-06	1.23E-06				
	50- 150mm	2.08E-06	1.56E-06	5.39E-07				
	>150mm	7.11E-06	5.78E-06	1.78E-06				
	Total	1.42E-04	1.22E-04	6.86E-06				
12 in	1- 3 mm					5.90E-05	3.10E-05	2.60E-06
	3- 10mm					1.70E-05	1.60E-05	1.90E-06
	10- 50mm					4.70E-06	8.70E-06	1.50E-06
	50- 150mm					6.10E-07	2.40E-06	6.40E-07
	>150mm					1.70E-06	4.30E-06	1.40E-06
	Total				Total	8.30E-05	6.24E-05	8.04E-06
14 in	1- 3 mm	1.09E-04	9.56E-05	4.15E-06				
	3- 10mm	3.98E-05	3.35E-05	3.15E-06				
	10- 50mm	1.44E-05	1.15E-05	2.70E-06				
	50- 150mm	2.54E-06	1.91E-06	1.19E-06				
	>150mm	7.36E-06	5.96E-06	3.32E-06				
	Total	1.73E-04	1.48E-04	1.45E-05				

	Total	[illegible]	[illegible]	[illegible]				
18 in	1- 3 mm					8.30E-05	3.80E-05	4.20E-06
	3- 10mm					2.40E-05	2.00E-05	3.10E-06
	10- 50mm					6.60E-06	1.10E-05	2.50E-06
	50- 150mm					8.70E-07	2.90E-06	1.10E-06
	>150mm					1.80E-06	4.80E-06	2.20E-06
	Total				Total	1.2E-04	7.67E-05	1.31E-05
20 in	1- 3 mm	1.38E-04	1.22E-04	1.45E-05				
	3- 10mm	5.05E-05	4.26E-05	1.10E-05				
	10- 50mm	1.83E-05	1.46E-05	9.45E-06				
	50- 150mm	3.23E-06	2.44E-06	4.16E-06				
	>150mm	7.72E-06	6.22E-06	1.04E-05				
	Total	2.18E-04	1.88E-04	4.96E-05				
24 in	1- 3 mm					1.10E-04	4.40E-05	6.70E-06
	3- 10mm					3.20E-05	2.30E-05	4.90E-06
	10- 50mm					8.80E-06	1.20E-05	4.00E-06
	50- 150mm					1.10E-06	3.40E-06	1.70E-06
	>150mm					1.90E-06	5.20E-06	3.50E-06
	Total				Total	1.54E-04	8.76E-05	2.1E-05
36 in	1- 3 mm					1.70E-04	5.40E-05	1.40E-05
	3- 10mm					4.90E-05	2.80E-05	1.10E-05
	10- 50mm					1.40E-05	1.50E-05	8.60E-06
	50- 150mm					1.80E-06	4.10E-06	3.60E-06
	>150mm					2.20E-06	5.90E-06	7.60E-06
	Total				Total	2.37E-04	1.07E-04	4.48E-05

Actuated Valves

		DNV			OGP			
Equipment Size	**Category**	**Total**	**Full Pressure**	**Zero Pressure**		**Full Flange Release**	**Limited Flange Release**	**Zero Pressure Flange Release**
0.5in	1- 3 mm	5.59E-04	5.42E-04	6.08E-06				
	3- 10mm	1.77E-04	1.68E-04	4.21E-06				
	10- 50mm	7.51E-05	7.02E-05	7.80E-06				
	50- 150mm	0.00E+00	0.00E+00	0.00E+00				
	>150mm	0.00E+00	0.00E+00	0.00E+00				
	Total	8.11E-04	7.80E-04	1.81E-05				
1 in	1- 3 mm	5.59E-04	5.43E-04	7.71E-06				
	3- 10mm	1.77E-04	1.68E-04	5.34E-06				
	10- 50mm	7.52E-05	7.03E-05	9.63E-06				
	50- 150mm	0.00E+00	0.00E+00	0.00E+00				
	>150mm	0.00E+00	0.00E+00	0.00E+00				
	Total	8.11E-04	7.81E-04	2.27E-05				
2 in	1- 3 mm	5.61E-04	5.44E-04	9.93E-06		2.40E-04	1.70E-04	1.10E-05
	3- 10mm	1.77E-04	1.69E-04	6.88E-06		7.30E-05	8.80E-05	7.80E-06
	10- 50mm	5.40E-05	5.03E-05	5.28E-06		3.00E-05	7.80E-05	1.30E-05
	50- 150mm	2.13E-05	2.02E-05	6.84E-06		0.00E+00	0.00E+00	0.00E+00
	>150mm	0.00E+00	0.00E+00	0.00E+00		0.00E+00	0.00E+00	0.00E+00
	Total	8.14E-04	7.84E-04	2.89E-05	Total	3.4E-04	3.4E-04	3.2E-05
4 in	1- 3 mm	5.66E-04	5.49E-04	1.29E-05				
	3- 10mm	1.79E-04	1.70E-04	8.96E-06				
	10- 50mm	5.45E-05	5.07E-05	6.87E-06				
	50- 150mm	2.14E-05	2.03E-05	8.61E-06				
	>150mm	0.00E+00	0.00E+00	0.00E+00				
	Total	8.20E-04	7.90E-04	3.74E-05				
6 in	1- 3 mm	5.71E-04	5.54E-04	1.52E-05		2.20E-04	1.30E-04	1.80E-05
	3- 10mm	1.81E-04	1.72E-04	1.05E-05		6.60E-05	6.90E-05	1.30E-05
	10- 50mm	5.50E-05	5.12E-05	8.06E-06		1.90E-05	3.80E-05	9.60E-06
	50- 150mm	8.03E-06	7.29E-06	3.17E-06		8.60E-06	2.30E-05	1.10E-05
	>150mm	1.35E-05	1.31E-05	6.75E-06		0.00E+00	0.00E+00	0.00E+00
	Total	8.28E-04	7.97E-04	4.37E-05	Total	3.14E-04	2.60E-04	5.16E-05
10 in	1- 3 mm	5.84E-04	5.67E-04	1.86E-05				
	3- 10mm	1.85E-04	1.76E-04	1.29E-05				
	10- 50mm	5.63E-05	5.24E-05	9.89E-06				
	50- 150mm	8.22E-06	7.46E-06	3.89E-06				
	>150mm	1.36E-05	1.31E-05	8.05E-06				
	Total	8.47E-04	8.16E-04	5.33E-05				

12 in	1- 3 mm					2.10E-04	1.10E-04	2.50E-05
	3- 10mm					6.30E-05	5.70E-05	1.70E-05
	10- 50mm					1.80E-05	3.20E-05	1.30E-05
	50- 150mm					2.40E-06	9.00E-06	5.20E-06
	>150mm					6.00E-06	1.10E-05	9.30E-06
	Total				Total	2.99E-04	2.19E-04	6.95E-05
14 in	1- 3 mm	6.00E-04	5.82E-04	2.13E-05				
	3- 10mm	1.90E-04	1.81E-04	1.48E-05				
	10- 50mm	5.78E-05	5.38E-05	1.13E-05				
	50- 150mm	8.44E-06	7.66E-06	4.46E-06				
	>150mm	1.37E-05	1.32E-05	9.09E-06				
	Total	8.70E-04	8.37E-04	6.10E-05				
18 in	1- 3 mm					2.00E-04	9.70E-05	3.00E-05
	3- 10mm					6.00E-05	5.10E-05	2.10E-05
	10- 50mm					1.70E-05	2.80E-05	1.60E-05
	50- 150mm					2.30E-06	8.00E-06	6.20E-06
	>150mm					5.90E-06	9.80E-06	1.10E-05
	Total				Total	2.9E-04	1.94E-04	8.42E-05
20 in	1- 3 mm	6.27E-04	6.08E-04	2.47E-05				
	3- 10mm	1.98E-04	1.89E-04	1.71E-05				
	10- 50mm	6.04E-05	5.62E-05	1.31E-05				
	50- 150mm	8.82E-06	8.01E-06	5.17E-06				
	>150mm	1.38E-05	1.34E-05	1.04E-05				
	Total	9.08E-04	8.75E-04	7.05E-05				
24 in	1- 3 mm					2.00E-04	8.90E-05	3.40E-05
	3- 10mm					5.90E-05	4.70E-05	2.30E-05
	10- 50mm					1.70E-05	2.60E-05	1.80E-05
	50- 150mm					2.20E-06	7.30E-06	7.10E-06
	>150mm					5.90E-06	9.20E-06	1.30E-05
	Total				Total	2.84E-04	1.79E-04	9.5E-05
36 in	1- 3 mm					1.90E-04	7.70E-05	4.10E-05
	3- 10mm					5.60E-05	4.10E-05	2.80E-05
	10- 50mm					1.60E-05	2.30E-05	2.20E-05
	50- 150mm					2.20E-06	6.40E-06	8.50E-06
	>150mm					5.90E-06	8.30E-06	1.50E-05
	Total				Total	2.70E-04	1.56E-04	1.15E-04

Manual Valves								
	DNV				OGP			
Equipment Size	Category	Total	Full Pressure	Zero Pressure		Full Flange Release	Limited Flange Release	Zero Pressure Flange Release
0.5in	1- 3 mm	5.17E-05	5.25E-05	3.03E-07				
	3- 10mm	2.40E-05	2.28E-05	2.22E-07				
	10- 50mm	1.84E-05	1.48E-05	4.24E-07				
	50- 150mm	0.00E+00	0.00E+00	0.00E+00				
	>150mm	0.00E+00	0.00E+00	0.00E+00				
	Total	9.40E-05	9.00E-05	9.49E-07				
1 in	1- 3 mm	5.18E-05	5.26E-05	5.84E-07				
	3- 10mm	2.41E-05	2.28E-05	4.28E-07				
	10- 50mm	1.84E-05	1.48E-05	8.17E-07				
	50- 150mm	0.00E+00	0.00E+00	0.00E+00				
	>150mm	0.00E+00	0.00E+00	0.00E+00				
	Total	9.43E-05	9.03E-05	1.83E-06				
2 in	1- 3 mm	5.26E-05	5.34E-05	1.15E-06		2.00E-05	2.40E-05	3.60E-07
	3- 10mm	2.45E-05	2.32E-05	8.40E-07		7.70E-06	1.40E-05	3.50E-07
	10- 50mm	1.17E-05	1.02E-05	6.91E-07		4.90E-06	1.40E-05	2.40E-06
	50- 150mm	6.99E-06	4.81E-06	9.13E-07		0.00E+00	0.00E+00	0.00E+00
	>150mm	0.00E+00	0.00E+00	0.00E+00		0.00E+00	0.00E+00	0.00E+00
	Total	9.58E-05	9.17E-05	3.59E-06	Total	3.3E-05	5.2E-05	3.1E-06
4 in	1- 3 mm	5.76E-05	5.85E-05	2.27E-06				
	3- 10mm	2.68E-05	2.54E-05	1.66E-06				
	10- 50mm	1.28E-05	1.12E-05	1.37E-06				
	50- 150mm	7.46E-06	5.18E-06	1.81E-06				
	>150mm	0.00E+00	0.00E+00	0.00E+00				
	Total	1.05E-04	1.00E-04	7.11E-06				
6 in	1- 3 mm	6.88E-05	6.98E-05	3.39E-06		3.10E-05	2.70E-05	7.10E-07
	3- 10mm	3.20E-05	3.03E-05	2.49E-06		1.20E-05	1.50E-05	6.90E-07
	10- 50mm	1.53E-05	1.34E-05	2.05E-06		4.70E-06	9.50E-06	7.80E-07
	50- 150mm	3.66E-06	2.94E-06	8.63E-07		2.40E-06	6.40E-06	4.00E-06
	>150mm	4.86E-06	3.05E-06	1.84E-06		0.00E+00	0.00E+00	0.00E+00
	Total	1.25E-04	1.20E-04	1.06E-05	Total	5.01E-05	5.79E-05	6.18E-06
10 in	1- 3 mm	1.16E-04	1.18E-04	5.64E-06				
	3- 10mm	5.41E-05	5.13E-05	4.14E-06				
	10- 50mm	2.58E-05	2.26E-05	3.40E-06				
	50- 150mm	6.19E-06	4.97E-06	1.44E-06				
	>150mm	6.83E-06	4.46E-06	3.06E-06				
	Total	2.09E-04	2.01E-04	1.77E-05				

12 in	1- 3 mm					4.30E-05	3.20E-05	1.10E-06
	3- 10mm					1.70E-05	1.80E-05	1.10E-06
	10- 50mm					6.50E-06	1.10E-05	1.20E-06
	50- 150mm					1.20E-06	3.50E-06	7.10E-07
	>150mm					1.70E-06	4.10E-06	5.40E-06
	Total				Total	6.94E-05	6.86E-05	9.51E-06
14 in	1- 3 mm	2.07E-04	2.10E-04	7.89E-06				
	3- 10mm	9.61E-05	9.11E-05	5.79E-06				
	10- 50mm	4.59E-05	4.02E-05	4.75E-06				
	50- 150mm	1.10E-05	8.83E-06	2.01E-06				
	>150mm	1.06E-05	7.15E-06	4.28E-06				
	Total	3.70E-04	3.57E-04	2.47E-05				
18 in	1- 3 mm					5.30E-05	3.70E-05	1.40E-06
	3- 10mm					2.10E-05	2.10E-05	1.40E-06
	10- 50mm					8.00E-06	1.30E-05	1.60E-06
	50- 150mm					1.50E-06	4.10E-06	9.20E-07
	>150mm					1.90E-06	4.80E-06	7.00E-06
	Total				Total	8.5E-05	7.99E-05	1.23E-05
20 in	1- 3 mm	4.44E-04	4.51E-04	1.13E-05				
	3- 10mm	2.06E-04	1.96E-04	8.26E-06				
	10- 50mm	9.85E-05	8.63E-05	6.79E-06				
	50- 150mm	2.36E-05	1.90E-05	2.86E-06				
	>150mm	2.04E-05	1.42E-05	6.11E-06				
	Total	7.92E-04	7.66E-04	3.53E-05				
24 in	1- 3 mm					6.20E-05	4.30E-05	1.70E-06
	3- 10mm					2.40E-05	2.50E-05	1.70E-06
	10- 50mm					9.40E-06	1.50E-05	1.90E-06
	50- 150mm					1.80E-06	4.70E-06	1.10E-06
	>150mm					2.10E-06	5.50E-06	8.50E-06
	Total				Total	9.93E-05	9.32E-05	1.5E-05
36 in	1- 3 mm					7.80E-05	5.40E-05	2.20E-06
	3- 10mm					3.00E-05	3.10E-05	2.10E-06
	10- 50mm					1.20E-05	1.90E-05	2.40E-06
	50- 150mm					2.20E-06	6.00E-06	1.40E-06
	>150mm					2.30E-06	7.00E-06	1.10E-05
	Total				Total	1.25E-04	1.17E-04	1.91E-05

Small Bore Fittings

DNV

Equipment Size	Category	Total	Full Pressure	Zero Pressure
0.5in	1- 3 mm	3.09E-04	3.00E-04	1.09E-05
	3- 10mm	1.37E-04	1.29E-04	7.14E-06
	10- 50mm	8.64E-05	7.64E-05	9.94E-06
	50- 150mm	0.00E+00	0.00E+00	0.00E+00
	>150mm	0.00E+00	0.00E+00	0.00E+00
	Total	5.33E-04	5.05E-04	2.80E-05
1 in	1- 3 mm	3.09E-04	3.00E-04	1.09E-05
	3- 10mm	1.37E-04	1.29E-04	7.14E-06
	10- 50mm	8.64E-05	7.64E-05	9.94E-06
	50- 150mm	0.00E+00	0.00E+00	0.00E+00
	>150mm	0.00E+00	0.00E+00	0.00E+00
	Total	5.33E-04	5.05E-04	2.80E-05
2 in	1- 3 mm	3.09E-04	3.00E-04	1.09E-05
	3- 10mm	1.37E-04	1.29E-04	7.14E-06
	10- 50mm	6.22E-05	5.60E-05	5.12E-06
	50- 150mm	2.42E-05	2.04E-05	4.82E-06
	>150mm	0.00E+00	0.00E+00	0.00E+00
	Total	5.33E-04	5.05E-04	2.80E-05

OGP

HOLE DIA Range (mm)	All releases	Full releases	Limited Releases	Zero Pressure Releases
Instrument connection release frequencies (per instrument year; sizes 10 to 50 mm diameter)				
1 to 3	3.50E-04	1.80E-04	1.60E-04	8.80E-06
3 to 10	1.50E-04	6.80E-05	7.40E-05	5.50E-06
10 to 50	6.50E-05	2.50E-05	3.60E-05	3.80E-06
Total	5.70E-04	2.80E-04	2.70E-04	1.80E-05

Pipeline

British Petroleum GP 48-50

The following information represents average data and should be used for general guidance only:

1	6 in to 9 in D pipeline FBR	7,2 x 10^{-5}/km yr.
2	10 in to 14 in D pipeline FBR	6,1 x 10^{-5}/km yr.
3	15 in to 20 in D pipeline FBR	5,0 x 10^{-5}/km yr.
4	21 in to 32 in D pipeline FBR	3,8 x 10^{-5}/km yr.
5	33 in to 48 in D pipeline FBR	2,6 x 10^{-5}/km yr.
6	6 in to 9 in D pipeline 50 mm (2 in) hole	1,1 x 10^{-4}/km yr.
7	10 in to 14 in D pipeline 50 mm (2 in) hole	9,2 x 10^{-5}/km yr.
8	15 in to 20 in D pipeline 50 mm (2 in) hole	5,7 x 10^{-5}/km yr.
9	33 in to 48 in D pipeline 50 mm (2 in) hole	3,9 x 10^{-5}/km yr.
10	FBR equivalent event during pig receiver/launcher operations	
	a) Without interlocks	2,4 x 10^{-5}/operation
	b) With interlocks	2,4 x 10^{-7}/operation

UK HSE

Failure Category	Failure Rate (per m per year)
Rupture (>110mm	6.5 x 10-9
Large Hole (>75 – □110mm	3.3 x 10-8
Small Hole (>25 mm – □75 mm diameter)	6.7 x 10-8
Pin Hole (□25 mm diameter)	1.6 x 10-7

PDO			Total	Frequency per release hole Size				
Equipment	Unit	Description		2 mm	7 mm	22 mm	70 mm	150 mm
PIPELINE / ONSHORE / STEEL / ALL	Per m length	Transmission pipeline only. Components (valves, etc.) should be recorded separately as should	1.70E-07	2.13E-08	2.13E-08	7.00E-08	3.12E-08	2.63E-08

Spherical Vessels

UK HSE		
Type of release	**Failure rate (per vessel year)**	**Notes**
Catastrophic	6×10^{-6}	Upper failures
Catastrophic	4×10^{-6}	Median
Catastrophic	2×10^{-6}	Lower
50 mm diameter hole	5×10^{-6}	
25 mm diameter hole	5×10^{-6}	
13 mm diameter hole	1×10^{-5}	
6 mm diameter hole	4 x 10	

Annexure 2
Shipping Data

2012 – 2017

Ship								
Chemical name	Number of Ship unloading per year	Ship Flow Rate MT/Hr	Ship Unloading Time, hr	Mass containing one Ship, metric ton	Inside Ship		Total Ship unloading duration in one year, Hrs.	Service Factor
					T, degC	P, bar		
Acetic Acid	9.2	368	8.169057833	3006.213283	30	4	75.15533207	0.00869853
Ethylene	13.8	300	17.36671227	5210.013681	-102	6	239.6606293	0.0277385
PARAXYLENE	51.8	938	6.561193454	6154.399459	30	5	339.8698209	0.03933678
Liquefied petroleum Gas (LPG)	36	297	11.90081412	3534.541794	30	12	428.4293084	0.04958673
Vinyl Chloride monomer (VCM)	2.2			953.4501818	30	9		
EDC (Ethylene dichloride)	8.8	307	14.61391916	4486.473182	30	4	128.6024886	0.01488455
Mono Ethylene Glycol (MEG)	23	371	4.903168968	1819.075687	35		112.7728863	0.01305242
Liquefied Natural Gas (LNG)								1

Bowser								
Chemical name	Number of Bowser loading per year	Bowser loading Flow Rate MT/Hr	Bowser loading Time, min	Mass containing one Bowser, metric ton	Inside Bowser		Total bowser loading duration in one year, Hrs.	Service Factor
					T, degC	P, bar		
Acetic Acid	1059.4		30	24.92028544	30	4	529.7	0.061
Ethylene								1.000
PARAXYLENE	11652		30	27.20449328	30	6	5826	0.674
Liquefied petroleum Gas (LPG)	11520		45	28.47324684	30	11	8640	1.000
Vinyl Chloride monomer (VCM)								1.000
EDC (Ethylene dichloride)	801.6		30	48.25833333	30	4	400.8	0.046
Mono Ethylene Glycol (MEG)	852.8		40	47.99805788			568.5333333	0.066
Liquefied Natural Gas (LNG)								1.000

Annexure 3

Event Tree Models (Not attached)

Annexure 5

ALARP Scenarios for recommendation

1- Recommendation#7: All fixed Fire monitors shall have remotely operated valves (from control room).

Scenario: Radiation level on a tank exceeding $10kw/m^2$ require cooling with fire water application, however, sprinkler system actuation valve and monitors fall within $3kw/m^2$ radiation contour hence manual action cannot be initiated.

ALARP Case: If the initial risk is in Acceptable (red) or ALARP region (region) on EVTL risk matrix, Risk shall be brought to acceptable region (green) or else an ALARP justification shall be made.

Assumption: Worst case consequential damage (equipment + business loss) for all fire cases assumed to be ≤ €2,000,000 (severity 3 on EVTL Risk matrix).

Target frequency for Severity 3 is 0.5E-06

Event frequencies from QRA results:

Acetic Acid Tank Fire	6.98E-05/yr
Ethylene Tank Fire	2.90E-04/yr
Para Xylene Tank Fire	3.43E-04/yr
EDC Tank Fire	1.2685E-05/yr

Justified spending over a period of 10 years on recommendation #7:

Scenario	Unmittigated Frequency, per year	Cost of Unmittigated risk, €	Target Mittigated Event Frequency, per year	Cost of mittigated risk, €	incremental cost	Justified spending over 10 years with Disproportionate factor[1] of 10 ,€
Acetic Acid Tank Fire	6.98E-05	139.6	5.00E-06	10	129.6	12,960
Ethylene Tank Fire	2.90E-04	580	5.00E-06	10	570	57,000
Para Xylene Tank Fire	3.43E-04	686	5.00E-06	10	676	67,600
EDC Tank Fire	1.27E-05	25.37	5.00E-06	10	15.37	1,537

Note1: For disproportionate factor refer to UK HSE ALARP Guide, R2P2

If the recommendation #7 can be implemented with total spending not exceeding above values than implement the recommendation else additional spending on risk mitigation is not justified in that case implement either of the following:

- Provide NFPA/ASTM rated fire fighters suits to fire responders suitable for fire radiations up to 12.5Kw/m2 for 60 seconds

Or

- Update fire response plan that no manual action will be taken to activate the fire monitors for cooling adjacent tanks in case of fire, accept consequential damages.

2- FW pump house shall be protected from fire impact either by relocating to outside 3kW/m2 radiation contour or providing fire rated walls.

Scenario: Jet fire from RLNG line or from Jetty (Ethylene, VCM or LPG) impacting Fire Water pump house, causing total damage to pump house, re-building and replacement may take 6 months, during this period if any fire occurs at site, FW will not be available hence there will be total burnout scenario.

ALARP Case: If the initial risk is in Acceptable (red) or ALARP region (region) on EVTL risk matrix, Risk shall be brought to acceptable region (green) or else an ALARP justification shall be made.

Assumption: Worst case consequential damage (equipment + business loss) for all fire cases assumed to be ≤ €2,000,000 (severity 3 on EVTL Risk matrix).

Target frequency for Severity 3 is **0.5E-06**

Event Frequency (Fire at any tank during FW pump unavailability) from QRA: 2.51E-09/yr (total likely hood of fires impacting on FW Pump house x total likelihood of fires requiring FW application on tanks (ALARP Case for recommendation# 7)).

Risk is acceptable as per EVTL Risk matrix.