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1 *RISK ASSESMENT*

1.1 *RISK ASSESSMENT FOR ONSHORE ACTIVITY*

This section on Quantitative Risk Assessment (QRA) aims to provide a systematic analysis of the major risks that may arise from **onshore** 10 exploratory and 23 development wells drilling and laying of oil and gas pipeline in Ravva Block. The QRA process outlines rational evaluations of the identified risks based on their significance and provides the outline for appropriate preventive and risk mitigation measures. Results of the QRA provides valuable inputs into the overall project planning and the decision making process for effectively addressing the identified risks. This will ensure that the project risks stay below As Low as Reasonably Practicable (ALARP) levels at all times during project implementation. In addition, the QRA will also help in assessing risks arising from potential emergency situations like a blow out and develop a structured Emergency Response Plan (ERP) to restrict damage to personnel, infrastructure and the environment.

The risk study for the onshore drilling and testing activities has considered all aspects of operation of the drilling rig and other associated activities during the exploratory/development phase. Loss of well control / blow-out and process/pipeline leaks constitute the major potential hazards that may be associated with the proposed onshore development and production of oil and natural gas at the identified well locations within the Ravva Block.

The following section describes objectives, methodology of the risk assessment study and then presents the assessment for each of the potential risk separately. This includes identification of major hazards, hazard screening and ranking, frequency and consequence analysis for major hazards. The hazards have subsequently been quantitatively evaluated through a criteria based risk evaluation matrix. Risk mitigation measures to reduce significant risks to acceptable levels have also been recommended as a part of the risk assessment study.

Objective of the QRA Study

The overall objective of this QRA with respect to the proposed project involves identification and evaluation of major risks, prioritizing risks identified based on their hazard consequences and formulating suitable risk reduction/mitigation measures in line with the ALARP principle. Hence in order to ensure effective management of any emergency situations (with potential individual and societal risks) that may arise during the development drilling activities, following specific objectives need to be achieved.

- Identify potential risk scenarios that may arise out of proposed development well drilling, operations of GCS, trunk and assorted oil and gas pipelines and associated equipment’s, mud chemicals storage and handling etc.

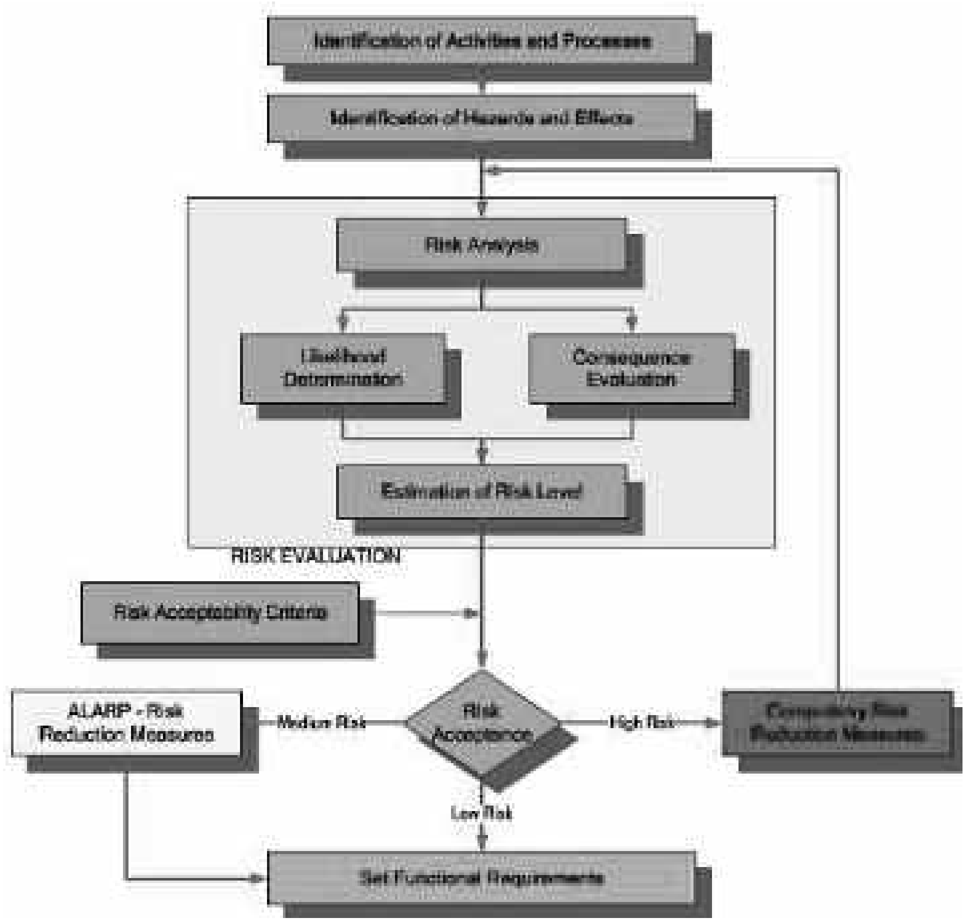
- Analyse the possible likelihood and frequency of such risk scenarios by reviewing historical accident related data for onshore oil and gas industries.
- Predict the consequences of such potential risk scenarios and if consequences are high, establish the same by through application of quantitative simulations.
- Recommend feasible preventive and risk mitigation measures as well as provide inputs for drawing up of Emergency Management Plan (EMP) for the Project.

Risk Assessment Methodology

The risk assessment process is primarily based on likelihood of occurrence of the risks identified and their possible hazard consequences particularly being evaluated through hypothetical accident scenarios. With respect to the proposed Project, major risks viz. blow outs, pipeline and process leaks, non-process fires etc. have been assessed and evaluated through a risk matrix generated to combine the risk severity and likelihood factor. Risk associated with the well exploration and development activities have been determined semi-quantitatively as the product of likelihood/probability and severity/consequence by using order of magnitude data (risk ranking = severity/consequence factor X likelihood/probability factor). Significance of such project related risks was then established through their classification as high, medium, low, very low depending upon risk ranking.

The risk matrix is a widely accepted as standardized method of quantitative risk assessment and is preferred over purely quantitative methods, given that its inherent limitations to define a risk event is certain. Application of this tool has resulted in the prioritization of the potential risks events for the drilling activity thus providing the basis for drawing up risk mitigation measures and leading to formulation of plans for risk and emergency management. The overall approach is summarized in the ***Figure 1.1***.

Figure 1.1 Risk Assessment Methodology



Hazard Identification

Hazard identification for the purposes of this QRA comprised of a review of the Project and associated activity related information provided by Cairn (Oil & Gas). In addition, guidance provided by knowledge platforms/portals of the upstream oil & gas industry including OGP, ITOPF, EGIG and DNV, Norwegian Petroleum Directorate etc. are used to identify potential hazards that can arise out of proposed Project activities. Taking into account the applicability of different risk aspects in context of the development drilling operations to be undertaken in the identified well locations, there are three major categories of hazards that can be associated with proposed Project which has been dealt with in detail. This includes:

- Blowouts leading to uncontrolled well flow, jet fires, pool fires;
- Non-process fires / explosions, the release of a dangerous substance or any other event resulting from a work activity which could result in death or serious injury to people within the site;
- Leaks from GCS, interconnecting pipeline network/trunk pipeline leading to jet fire; and
- Any event which may result in major damage to the structure of the rig

Well control incident covers a range of events which have the potential of leading to blow-outs but are generally controlled by necessary technological interventions. Hence, such incidents are considered of minor consequences and as a result not well documented. Other possible hazard scenarios like mud chemical spills, falls, etc. has also not been considered for detailed assessment as preliminary evaluation has indicated that the overall risk that may arise out of them would be low. In addition, it is understood that, causative factors and mitigation measures for such events can be adequately taken care of through exiting safety management procedures and practices of Cairn(Oil & Gas).

It must also be noted here that many hazards identified are sometimes interrelated with one hazard often having the ability to trigger off another hazard through a domino effect. For example, a large oil spill in most instances is caused by another hazardous incident like a blowout or process leak. This aspect has been considered while drawing up hazard mitigation measures and such linkages (between hazards) has also been given due importance for managing hazards and associated risks in a composite manner through Cairn(Oil & Gas)'s Health, Safety & Environmental Management System (HSEMS) and through the Emergency Management Plan, if a contingency situation so arises.

Frequency Analysis

Frequency analysis involves estimating the likelihood of each of the failure cases identified during the hazard identification stage. The analysis of frequencies of occurrences for the key hazards that has been listed out is important to assess the likelihood of such hazards to actually unfold during the lifecycle of the project. The frequency analysis approach for the proposed Project is based primarily on historical accident frequency data, event tree analysis and judgmental evaluation. Major oil and gas industry information sources viz. statistical data, historical records and global industry experience were considered during the frequency analysis of the major identified risks[1].

For QRA for the proposed Project, various accident statistics and published oil industry databases have been consulted for arriving at probable frequencies of identified hazards. However, taking into account the absence of representative historical data/statistics with respect to onshore operations[2], relevant offshore accident databases have been considered in the frequency analysis of identified hazards. The same has been recommended in the "*Risk Assessment Data Directory" published by the International Association of Oil & Gas Producers (OGP). Key databases/reports referred as part of the QRA study includes Worldwide Offshore Accident Databank (WOAD), Outer Continental Shelf (OCS) Reports,*

[1]It is to be noted that the frequency of occurrences are usually obtained by a combination of component probabilities derived on basis of reliability data and /or statistical analysis of historical data.

[2]Although Alberta Energy & Utilities Board (EUB) maintains a database for onshore incidents for the period 1975-1990 the same has not been considered in the context of the present study as the Alberta wells are believed to be sour with precaution being taken accordingly to minimize the likelihood of release

Norwegian Petroleum Directorate Directives, Offshore Reliability Data (OREDA) Handbook, HSE Offshore Incident Database, SINTEF Offshore Blowout Database etc.

Based on the range of probabilities arrived at for different potential hazards that may be encountered during the proposed well development activities, following criteria for likelihood rankings have been drawn up as presented in the ***Table 1.1***.

Table 1.1 Frequency Categories and Criteria

Likelihood Ranking	Criteria Ranking (cases/year)	Frequency Class
5	>1.0	Frequent
4	$>10^{-1}$ to <1.0	Probable
3	$>10^{-3}$ to $<10^{-1}$	Occasional/Rare
2	$>10^{-5}$ to $<10^{-3}$	Not Likely
1	$>10^{-6}$ to $<10^{-5}$	Improbable

Consequence Analysis

In parallel to frequency analysis, hazard prediction / consequence analysis exercise assesses resulting effects in instances when accidents occur and their likely impact on project personnel, infrastructure and environment. In relation to the proposed Project, estimation of consequences for each possible event has been based either on accident experience, consequence modelling or professional judgment, as appropriate.

Given the high risk perception associated with blow outs in context of onshore drilling operation, a detailed analysis of consequences has been undertaken for blow outs taking into account physical factors and technological interventions. Consequences of such accidental events on the physical, biological and socio-economic environment have been studied to evaluate the potential of the identified risks/hazards. In all, the consequence analysis takes into account the following aspects:

- Nature of impact on environment and community;
- Occupational health and safety;
- Asset and property damage;
- Corporate image
- Timeline for restoration of environmental and property damage
- Restoration cost for environmental and property damage

The following criterion for consequence rankings (***Table 1.2***) is drawn up in context of the possible consequences of risk events that may occur during proposed well development activities:

Table 1.2 Severity Categories and Criteria

Consequence	Ranking	Criteria Definition
Catastrophic	5	• Multiple fatalities/Permanent total disability to more than 50 persons • Severe violations of national limits for environmental emission • More than 5 years for natural recovery • Net negative financial impact of >10 crores • Long term impact on ecologically sensitive areas • International media coverage • National stakeholder concern and media coverage
Major	4	• Single fatality/permanent total disability to one or more persons • Major violations of national limits for environmental emissions • 2-5 years for natural recovery • Net negative financial impact of 5 -10 crores • Significant impact on endangered and threatened floral and faunal species • Loss of corporate image and reputation
Moderate	3	• Short term hospitalization & rehabilitation leading to recovery • Short term violations of national limits for environmental emissions • 1-2 years for natural recovery • Net negative financial impact of 1-5 crores • Short term impact on protected natural habitats • State wide media coverage
Minor	2	• Medical treatment injuries • 1 year for natural recovery • Net negative financial impact of 0.5 - 1 crore • Temporary environmental impacts which can be mitigated • Local stakeholder concern and public attention
Insignificant	1	• First Aid treatment with no Lost Time Incidents (LTIs) • Natural recovery < 1year • Net negative financial impact of <0.5 crores. • No significant impact on environmental components • No media coverage

Risk Evaluation

Based on ranking of likelihood and frequencies, each identified hazard has been evaluated based on the likelihood of occurrence and the magnitude of consequences. Significance of risks is expressed as the product of likelihood and consequence of the risk event, expressed as follows:

Significance = Likelihood X Consequence

The ***Table 1.3*** below illustrates all possible product results for five likelihood and consequence categories while the ***Table 1.4*** assigns risk significance criteria in four regions that identify the limit of risk acceptability. Depending on the position of intersection of a column with a row in the risk matrix, hazard prone activities have been classified as low, medium and high thereby qualifying a set of risk reduction / mitigation strategies.

Table 1.3 Risk Matrix

Consequence ↑			Likelihood →				
			Frequent	Probable	Remote	Not Likely	Improbable
			5	4	3	2	1
	Catastrophic	5	25	20	15	10	5
	Major	4	20	16	12	8	4
	Moderate	3	15	12	9	6	3
	Minor	2	10	8	6	4	2
	Insignificant	1	5	4	3	2	1

Table 1.4 Risk Criteria and Action Requirements

Risk Significance	Criteria Definition & Action Requirements
High (16 - 25)	**"Risk requires attention"** – Project HSE Management need to ensure that necessary mitigation are adopted to ensure that possible risk remains within acceptable limits
Medium (10 – 15)	**"Risk is tolerable"** – Project HSE Management needs to adopt necessary measures to prevent any change/modification of existing risk controls and ensure implementation of all practicable controls.
Low (5 – 9)	**"Risk is acceptable" –** Project related risks are managed by well-established controls and routine processes/procedures. Implementation of additional controls can be considered.
Very Low (1 – 4)	**"Risk is acceptable" –** All risks are managed by well-established controls and routine processes/procedures. Additional risk controls need not to be considered

Risk Assessment of Identified Project Hazards

As already discussed in the previous section, three major categories risk have identified in relation to proposed development drilling activities. A comprehensive risk assessment study has been undertaken to assess and evaluate significance of identified risks in terms of severity of consequences and likelihood of occurrence.

Risk assessment study details have been summarized in the subsequent sections below:

A) Blow Outs / Loss of Well Control

Blow out is an uncontrolled release of well fluid (primarily hydrocarbons viz. oil and/or gas and may also include drilling mud, completion fluid, water etc.) from an exploratory or development well. Blow outs are the result of failure to control a kick and regain pressure control and are typically caused by equipment failure or human error. The possible blow out cause events occurring in isolation or in combination have been listed below:

- Formation fluid entry into well bore;
- Loss of containment due to malfunction (viz. wire lining);
- Well head damage (e.g. by fires, storms, dropped object etc.); and
- Rig forced off station (e.g. by anchor failure) damaging Blow Out Preventer (BOP) or wellhead.

The most common cause of blow out can be associated with the sudden/unexpected entry/release of formation fluid into well bore that may arise as a result of the following events as discussed in the ***Box 1.1*** below:

Box 1.1 Primary Causes of Blow Outs

Shallow gas
In shallow formations there may be pockets of shallow gas. In these instances there is often insufficient mud density in the well and no BOP is in place. If the hole strikes shallow gas the gas may be released on the drilling rig very rapidly. Typical geological features which suggest the presence of shallow gas can then be detected. Historically, striking of shallow gas has been one of the most frequent causes of blowouts in drilling.

Swabbing
As the drill pipe is pulled upwards during trips out of the hole or upward movement of the drill string, the pressure in the hole beneath the drill bit is reduced, creating a suction effect. Sufficient drilling mud must be pumped down-hole to compensate for this effect or well fluids may enter the bore. Swabbing is also a frequent cause of drilling blowouts.

High formation pressure
Drilling into an unexpected zone of high pressure may allow formation fluids to enter the well before mud weight can be increased to prevent it.

Insufficient mud weight
The primary method of well control is the use of drilling mud; in correct operation, the hydrostatic pressure exerted by the mud prevents well fluids from entering the well bore. A high mud weight provides safety against well fluids in-flows. However, a high mud weight reduces drilling speed, therefore, mud weight is calculated to establish weight most suitable to safely control anticipated formation pressures and allows optimum rates of penetration. If the required mud weight is incorrectly calculated then well fluid may be able to enter the bore.

Lost Circulation
Drilling mud circulation can be lost if mud enters a permeable formation instead of returning to the rig. This reduces the hydrostatic pressures exerted by the mud throughout the well bore, and may allow well fluids from another formation to enter the bore.

Gas cut mud
Drilling fluids are denser than well fluids; this density is required to provide the hydrostatic pressure which prevents well fluids from entering the bore. If well fluids mix with the mud then its density will be reduced. As mud is circulated back to surface, hydrostatic pressure exerted by the mud column is reduced. Once gas reaches surface it is released into the atmosphere.

Source: A Guide to Quantitative Risk Assessment for Offshore Installations; John Spouge – DNV Technical Publication 99/100a

For better understanding, causes of blow outs have been systematically defined in terms of loss of pressure control (failure of primary barrier), uncontrolled flow of fluid or failure of secondary barrier (BOP). The blow out incidents resulting from primary and secondary failures for proposed operations as obtained through comprehensive root cause analysis of the Gulf Coast (Texas, OCS and US Gulf of Mexico) Blow Outs[1] during 1960-1996 have been presented in the ***Table 1.5***.

Table 1.5 ***Blow Out Cause Distribution for Failures during Drilling Operations***

Sl. No.	Causal Factors	Blow Out Incidents (Nos.)
A.	**Primary Barrier**	
1	Swabbing	77
2	Drilling Break	52
3	Formation breakdown	38
4	Trapped/expanding gas	09
5	Gas cut mud	26
6	Low mud weight	17
7	Wellhead failure	05
8	Cement setting	05
B.	**Secondary Barrier**	
1	Failure to close BOP	07
2	Failure of BOP after closure	13
3	BOP not in place	10
4	Fracture at casing shoe	03
5	Failure to stab string valve	09
6	Casing leakage	06

Thus, underlying blowout causes as discussed in the above table can be primarily attributed to swabbing as the primary barrier failure which is indicative of insufficient attention given to trip margin and controlling pipe movement speed. Also, it is evident from the above table that lack of proper maintenance, operational failures and absence of BOPs as secondary barrier contributed to majority of blowout incidents (approx.. 30 nos.) is recorded.

Blowout Frequency Analysis

Blow out frequency estimates is obtained from a combination of incident experience and associated exposure in a given area over a given period. For the purpose of calculation of blow out frequency analysis in context of the present study involving developmental drilling, blow out frequencies per well drilled have been considered.

The blowout frequencies presented in this report are extracted from the latest revision of the Scandpower[2] report and are presented in ***Table 1.6***. The

[1] "Trends extracted from 1200 Gulf Coast blowouts during 1960-1996" – Pal Skalle and A.L Podio

[2] "Blowout and Well Release Frequencies" - Based on SINTEF Offshore Blowout Database 2010, Report, Scandpower Risk Management. Report no. 19.101.001-3009/2011/R3, 05.04.2011.

blowout probability is determined from blowouts in the North Sea. (i.e. British, Dutch and Norwegian sectors) given comparable data for onshore operations are not readily available.

Table 1.6 ***Blow Out Frequencies Recommended per Drilled Well***

Drilling Operation	Well Category	Frequency, gas well	Frequency, oil well
Exploration	Normal	1.12E-04	1.23E-04
Wild Cat	Normal	9.70E-05	1.17E-04
Appraisal	Normal	1.07E-04	1.30E-04
Development	Normal	2.16E-05	2.62E-05

Based on the aforesaid frequency and information provided by Cairn (Oil & Gas) the blow out frequency for the proposed project has been computed as follows:

No of onshore wells to be drilled per year = 5 exploratory & 5 developmental (A)

Blow out frequency for exploratory drilling (oil) = 1.12 x 10^{-4} per well drilled (B)

Blow out frequency for exploratory drilling (gas) = 1.23 x 10^{-4} per well drilled (C)

Blow out frequency for development drilling (oil) = 2.62 x 10^{-5} per well drilled (D)

Blow out frequency for development drilling (gas) = 2.16 x 10^{-5} per well drilled (E)

Frequency of blow out occurrence for exploration (oil) = (A x B) = 5 x 1.12 x 10^{-4}
= 5.60 X 10^{-4} per well drilled

Frequency of blow out occurrence for exploration (gas) = (A x C) = 5 x 1.23 x 10^{-4}
= 6.15 X 10^{-4} per well drilled

Frequency of blow out occurrence for development (oil) = (A X D) = 5 x 2.62 x 10^{-5}
= 1.31 X 10^{-4} per well drilled

Frequency of blow out occurrence for development (gas) = (A X E) = 5 x 2.16 x 10^{-5}
= 1.08 X 10^{-4} per well drilled

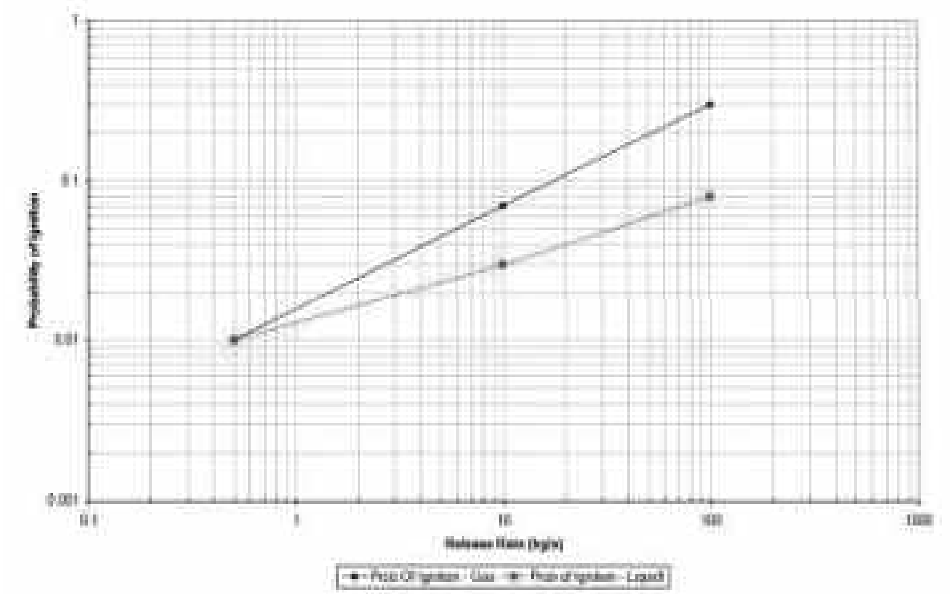
Thus, the blow out frequency for the proposed project for both exploratory and development oil and gas wells have been identified to be as **"Not Likely"**

Blowout Ignition Probability

Review of SINTEF database indicates that a rounded ignition probability of 0.3 has been widely used for the purpose of quantitative risk analysis arising from blow outs. As per this database generally ignition occurred within first 5 minutes in approximately 40% of the blowouts leading to either pool and/or jet fire. Blow out leading to flammable gas release has a greater probability of ignition compared to liquid releases[1] (***Figure 1.2***).

[1]Fire and Explosion – Fire Risk Analysis by Daejun Change, Division of Ocean System and Engineering

Figure 1.2 Ignition Probability Vs Release Rate



An alternative to the blowout ignition probabilities given by the UKOOA look-up correlations can be obtained from Scandpowers's interpretation of the blowout data provided by SINTEF 2. The most significant category is that for deep blowouts which indicates an early ignition probability of 0.09. For the purpose of the QRA study this can be taken as occurring immediately on release and calculation provided below:

No of onshore wells to be drilled per year = 5 (A) exploratory & 5 developmental
Blow out frequency for exploratory drilling (oil) = 1.12 X 10^{-4} per well drilled (B)

Blow out frequency for exploratory drilling (gas) = 1.23 X 10^{-4} per well drilled (C)

Blow out frequency for development drilling (oil) = 2.62 X 10^{-5} per well drilled (D)

Blow out frequency for development drilling (gas) = 2.16 X 10^{-5} per well drilled (E)

Blow out ignition probability = 0.09 (F)

Probability of Blow out ignition for exploration (oil) = (A x B x F) = 5 x 1.12 x 10^{-4} x 0.09 = 0.50 x 10^{-4}= ~ 0.005%

Probability of Blow out ignition for exploration (gas) = (A x C x F) = 5 x 1.23 x 10^{-4} X 0.09 = 0.55 X 10^{-4}= ~ 0.005%

Probability of Blow out ignition for development (oil) = (A x D x F) = 5 x 2.62 x 10^{-5} x 0.09 = 1.17x 10^{-5}= ~ 0.001%

Probability of Blow out ignition for development (gas) = (A x E x F) = 5 x 2.16 x 10^{-5} X 0.09 = 0.97 X 10^{-5}= ~ 0.0009%

Hence, based on the aforesaid calculation the probability of ignition of blow out releases of hydrocarbons for the proposed development project for both oil and gas is found to range within ~0.0009% and 0.005% and therefore can be considered to be as negligible.

Blowout Consequence Analysis

Blow out from a hydrocarbon development wells may lead to the following possible risk consequences:

a. Jet fires resulting from ignited gas blow outs; and
b. Oil slicks resulting from un-ignited oil pools.

Pool fire

A pool fire is a turbulent diffusion fire burning above a pool of vaporizing hydrocarbon fuel where the fuel vapor has negligible initial momentum. The probability of occurrence of pool fires for oil and gas exploration is high due to continuous handling of heavy hydrocarbons. The evaporation of hydrocarbons from a pool forms a cloud of vapor above the pool surface which, on ignition, leads to generation of pool fire.

For the purpose of consequence modeling for pool fires resulting from blow outs, following hypothetical scenarios in terms of hydrocarbon (particularly crude oil) release rates (***Table 1.7***) have been considered based on DNV Technica's FLARE program.

Table 1.7 ***Pool Fire Modelling Scenario***

Scenario	*Release Rate (kg/s)*	*Release Type*
Scenario - I	1	Small
Scenario - II	10	Medium
Scenario – III (Worst Case)	50	Large

The release rates as specified for the aforesaid scenarios have been utilized in the computing the pool fire diameter utilizing the following equation and input parameters:

$D = \sqrt{4Q/\pi b}$

Where D = pool diameter (m)
Q = release rate (kg/s)
b = burning rate (kg/m^2s)

The mass burning rate for crude oil has been considered to be 0.05 kg/m^2s
Based on above equation, the pool fire diameter and the steady study burning areas computed for various release types have been presented in the ***Table 1.8*** below.

Table 1.8 Pool Fire Diameter & Steady State Burning Scenario

Scenario	Release Rate (kg/s)	Release Type	Pool fire diameter (m)	Steady State Burning Area (m^2)
Scenario - I	1	Small	5.05	6.37
Scenario - II	10	Medium	15.96	63.69
Scenario - III	50	Large	35.69	318.47

The impact zone for long duration fires is conveniently described by thermal radiation contours and its effects on the people who are exposed to such radiation levels for one minute (60sec). The thermal radiation threshold values (measured in kilowatts per square meter) defined for crude oil pool fire consequence modeling is provided in ***Table 1.9*** below:

Table 1.9 Thermal Radiation Intensity Threshold Values Impact Criterion

Threshold Radiation Intensity	Threat Zone	Impact Criterion
5.0 kW/m²	**Green**	• Escape actions within one minute. • Cause second degree burns within 60 sec.
12.5 kW/m²	**Blue**	• Escape actions lasting for few seconds. • Cause second degree burns within 40 sec.
37.5 kW/m²	**Red**	• Results in immediate fatality. • Pain threshold is instantaneous leading to second degree burns within 8 sec.

For estimating the distance to a pool fire heat radiation level that could cause second degree burns and fatality for a maximum exposure of 60 sec the following EPA equation and input parameters are utilized.

$$X = H_c \sqrt{\frac{0.0001A}{5000\Pi\,(H_v + C_p\,(T_B - T_A))}}$$

Where:

X = distance to the heat radiation level (m)
HC = heat of combustion of the flammable liquid (joules/kg)
HV = heat of vaporization of the flammable liquid (joules/kg)
A = pool area (m^2)
CP = liquid heat capacity (joules/kg-ºK)
TB = boiling temperature of the liquid (ºK)
TA = ambient temperature (ºK)

For crude oil **HC = 42,600,000 joules/kg; HV = 957,144 joules/kg; CP = 1,892 joules/kg-°K; TB = 633 °K** and **TA = 300 °K.** The following input parameter along with pool area (m^2) computed for blow out risk scenarios provided the distance to the threshold heat radiation levels for the threat zones and have been presented in ***Table 1.10.***

Table 1.10 Distance to Thermal Radiation Threshold Levels

Release Type	*Pool fire diameter (m)*	*Pool fire area (m^2)*	*Distance to 5.0 kW/m^2 (m)*	*Distance to 12.5 kW/m^2 (m)*	*Distance to 37.5 kW/m^2 (m)*
Small	5.05	6.37	6.81	4.31	2.49
Medium	15.96	63.69	21.54	13.62	7.86
Large	35.69	318.47	48.16	30.46	17.59

The worst hazard for release and ignition of crude oil at a rate of **50kg/s** for a thermal radiation intensity of **37.5 kW/m^2** is likely to be experienced to a maximum distance of **17.59m** from the source with potential lethal effects experienced within 8 sec.

Risk Ranking – Blowout Pool Fire (Worst Case Scenario)

Likelihood ranking	**3**	**Consequence ranking**	**4**
Risk Ranking & Significance = 12 i.e. "Medium" i.e. Risk is Tolerable and can be managed through adoption of necessary controls.			

Ignition of Flammable Gas Release leading to Jet Fire

Jet fires are burning jet of gas or sprays of atomized liquids resulting from gas and condensate release from high pressure equipment and blow outs. Jet fires may also result in the release of high pressure liquid containing dissolved gas due to gas flashing off and turning the liquid into a spray of small droplets. In context of the present study, formation of jet fires can be attributed by the high pressure release and ignition of natural gas if encountered during exploration of block hydrocarbon reserves.

Natural gas as recovered from underground deposits primarily contains methane (CH_4) as a flammable component, but it also contains heavier gaseous hydrocarbons such as ethane (C_2H_6), propane (C_3H_8) and butane (C_4H_{10}). Other gases such as CO_2, nitrogen and hydrogen sulfide (H_2S) are also often present. Methane is typically 90 percent, ethane 5-15 percent, propane and butane, up to 5 percent. Thus, considering higher percentage of methane in natural gas, the thermo-chemical properties of the same has been utilized in the jet fire blow out consequence modelling. The following risk scenarios (***Table 1.11***) have been considered for nature gas release consequence modelling:

Table 1.11 Natural Gas Release Modelling Scenario

Scenario	**Release Rate (kg/s)**	**Release Type**
Scenario - I	1	Small
Scenario - II	5	Medium
Scenario – III (Worst Case)	10	Large

The modelling of nature gas releases has been carried out using ALOHA. A Flammable Level of Concern approach has been utilized for assessing safety risk associated with the release of flammable gases (here methane) from well blow outs. In ALOHA, a flammable Level of Concern (LOC) is a threshold concentration of fuel in the air above which a flammability hazard may exist. While modelling the release of a flammable gas that may catch fire—but which is not currently burning—ALOHA can predict the flammable area of the vapour cloud so that flammability hazard can be established.

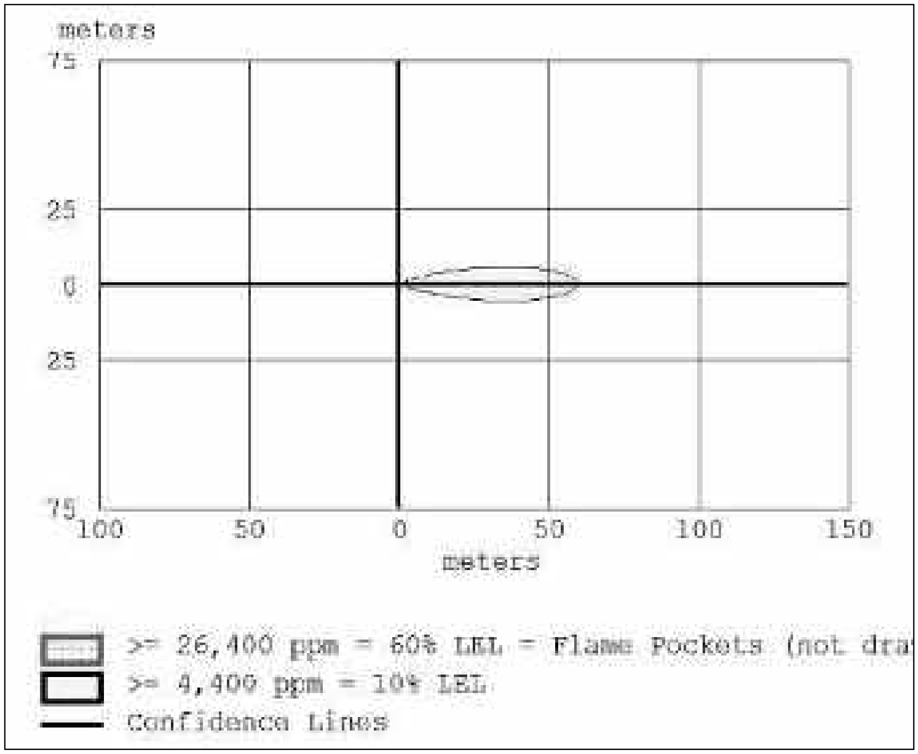
The flammable area is the part of a flammable vapor cloud where the concentration is in the flammable range, between the Lower and Upper Explosive Limits (LEL and UEL). These limits are percentages that represent the concentration of the fuel (that is, the chemical vapor) in the air. If the chemical vapor comes into contact with an ignition source (such as a spark), it will burn only if its fuel-air concentration is between the LEL and the UEL—because that portion of the cloud is already pre-mixed to the right mixture of fuel and air for burning to occur. If the fuel-air concentration is below the LEL, there is not enough fuel in the air to sustain a fire or an explosion—it is too lean. If the fuel-air concentration is above the UEL, there is not enough oxygen to sustain a fire or an explosion because there is too much fuel—it is too rich.

When a flammable vapor cloud is dispersing, the concentration of fuel in the air is not uniform; there will be areas where the concentration is higher than the average and areas where the concentration is lower than the average. This is called concentration patchiness. Because of concentration patchiness, there will be areas (called pockets) where the chemical is in the flammable range even though the average concentration has fallen below the LEL. Because of this, ALOHA's default flammable LOCs are each a fraction of the LEL, rather than the LEL itself. ALOHA uses 60% of the LEL as the default LOC for the red threat zone, because some experiments have shown that flame pockets can occur in places where the average concentration is above that level. Another common threat level used by responders is 10% of the LEL, which is ALOHA's default LOC for the yellow threat zone. The flammable LOC threat zones for methane release are as follows:

Red : 26,400 ppm = 60% LEL = Flame Pockets
Yellow: 4,400 ppm = 10% LEL

Well site risk contour maps for worst case scenario prepared based on ALOHA modeling of natural gas releases for flammable vapour cloud has been presented in **Figure 1.3 - Figure 1.5** below.

Figure 1.3 Scenario I: Risk Contour Map



THREAT ZONE:

Threat Modelled: Flammable Area of Vapor Cloud

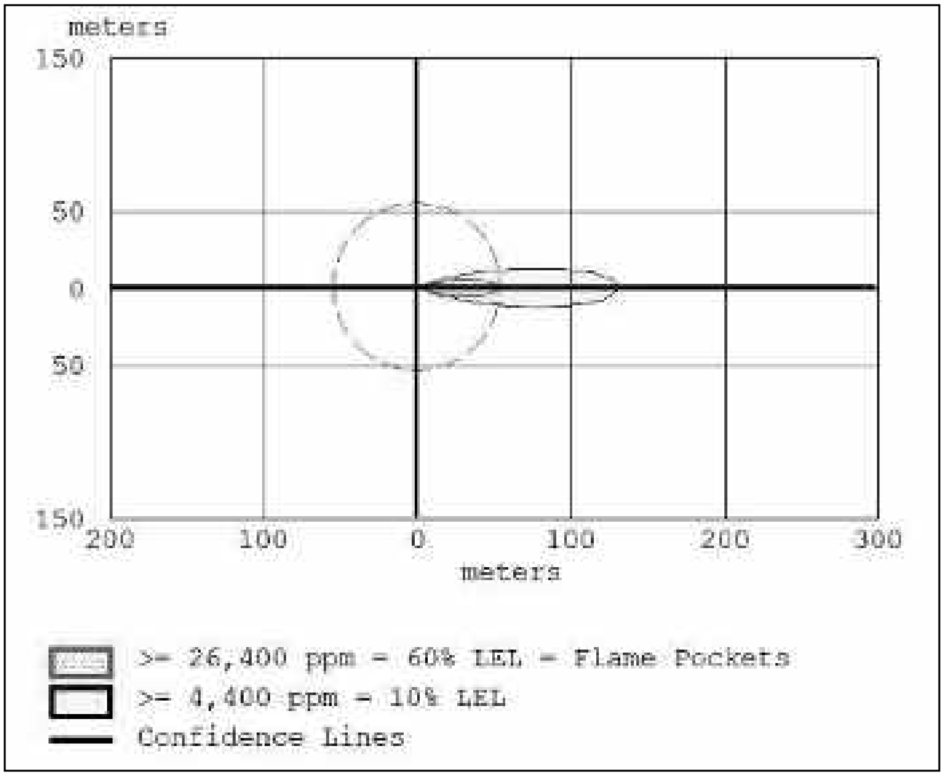
Model Run: Gaussian

Red : 25 meters --- (26,400 ppm = 60% LEL = Flame Pockets)

Note: Threat zone was not drawn because effects of near-field patchiness make dispersion predictions less reliable for short distances.

Yellow: 60 meters --- (4,400 ppm = 10% LEL)

Figure 1.4 Scenario II: Risk Contour Map



THREAT ZONE:

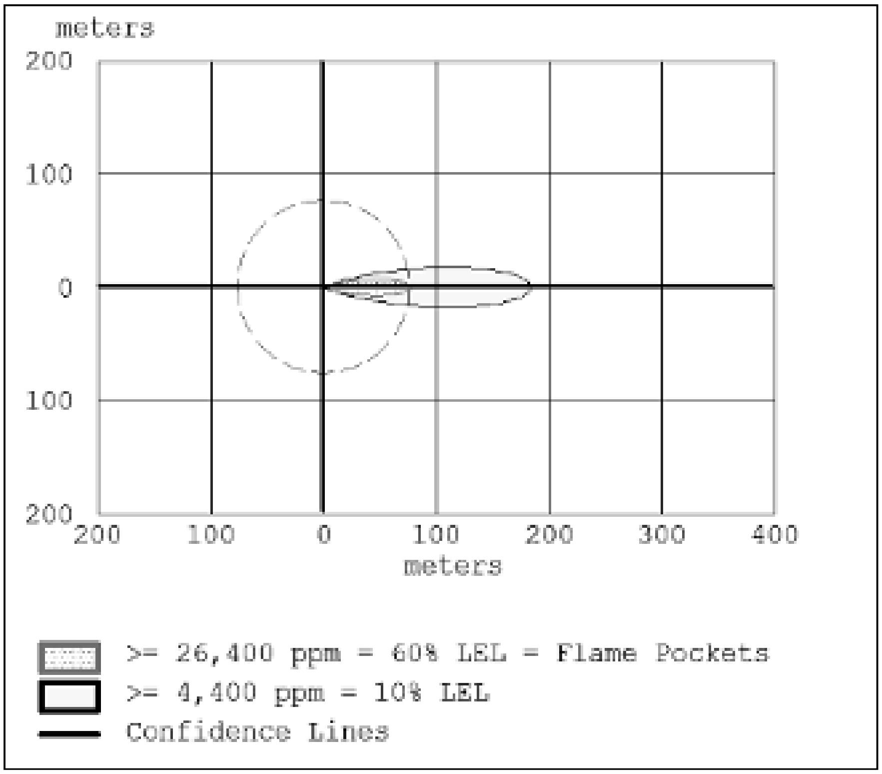
Threat Modeled: Flammable Area of Vapor Cloud

Model Run: Gaussian

Red : 55 meters --- (26,400 ppm = 60% LEL = Flame Pockets)

Yellow: 131 meters --- (4,400 ppm = 10% LEL)

Figure 1.5 Scenario III: Risk Contour Map



THREAT ZONE:

Threat Modeled: Flammable Area of Vapor Cloud

Model Run: Gaussian

Red : 77 meters --- (26,400 ppm = 60% LEL = Flame Pockets)

Yellow: 183 meters --- (4,400 ppm = 10% LEL)

The zone of flammable vapour cloud calculated for hypothetical natural gas release under risk scenarios discussed in the earlier sections have been presented in the ***Table 1.12*** below.

Table 1.12 Zone of Flammable Vapour Cloud-Natural Gas Release Scenarion

Release Type	Release Rate (kg/s)	Red -60% LEL (m)	Yellow -10% LEL (m)
Small	1	25	65
Medium	5	55	131
Large	10	77	183

Hence for a worst case scenario (10kg/s) the flammable vapor cloud zone/flame pockets' resulting from accidental release of natural gas will be covering a radial zone of 77m from source with the flammable gas concentration within this zone being 26,400 ppm.

Based on the flammable vapour cloud concentration modelled for the worst case scenario (10 kg/s) an effort was made to establish the overpressure (blast force zone) that may result from delayed ignition of vapour cloud generated from any such accidental release. For overpressure risk modelling using ALOHA a delayed ignition time of 5 minutes was considered of the vapour cloud mass. However the threat modelled revealed that Level of Concern (LOC) was never exceeded that may possibly lead to damage to property or life within the blast radius. The results have been provided in ***Figure 1.6*** below.

Figure 1.6 ***Scenario III (Worst Case) – Overpressure Risk Modeling***

```
Threat Modeled: Overpressure (blast force) from vapor cloud explosion
Time of Ignition: 5 minutes after release begins
Type of Ignition: ignited by spark or flame
Level of Congestion: uncongested
Model Run: Gaussian
Explosive mass at time of ignition: 188 kilograms
Red   : LOC was never exceeded --- (8.0 psi = destruction of buildings)
Orange: LOC was never exceeded --- (3.5 psi = serious injury likely)
Yellow: LOC was never exceeded --- (1.0 psi = shatters glass)
```

The risk significance for the potential blow out scenario resulting from exploratory and development drilling has been presented below. For calculating the risk significance, the likelihood ranking is considered to be "2" as the frequency analysis for blow outs incidents is computed at "~ 10^{-4}" whereas the consequence ranking has been identified to be as "4" given the worst case scenario modelling (blast overpressure) indicates that the LOC was never exceeded leading to multiple fatalities (For criteria ranking please refer to ***Table 1.1*** and ***Table 1.2***).

Risk Ranking – Blowout Natural Gas Release (Worst Case Scenario)

Likelihood ranking	**2**	**Consequence ranking**	**4**
Risk Ranking & Significance = 8 i.e. "Low" i.e. Risk is Acceptable and can be managed through use of existing controls and evaluation of additional controls.			

B) <u>Hydrocarbons Leaks Due to Loss of Containment While Drilling & Testing</u>

The releases of hydrocarbons that may be isolated from reservoir fluids include gas releases in the mud return area during drilling. The consequences of gas releases are described in this section. ALOHA model has been used to model the releases from failure of the test separator.

Frequency Analysis

Review of the hydrocarbon release database (HCRD) of 2003 for **One North Sea Platform** indicates the process gas leak frequencies for large releases (>10 kg/s) to be about **6.0 x 10^{-3} per year**. The same frequency has been considered for potential release from leaks due to loss of containment while drilling.

Gas Releases during Drilling

a) Flash Fire

If gas is entrained in the mud then it could be released from the mud pits or shakers. The amount of gas returned is unlikely to be so great that a jet fire could occur, but the gas could build up into a flammable vapour cloud in the mud pit area. If the cloud then ignites it will result in a flash fire or vapour cloud explosion. Again, there is also the potential for a toxic cloud to be present if the release is during a period when sour crude is a possibility. The mud return typically contains around 50% water this means it cannot be ignited in liquid form so there is no danger of pool fires. Liquid mud fires are therefore not considered further.

The mud - gas separator can be other source that contains both flammable liquid and gas.

A well test separator rupture could result in release of gas when a gas cloud will form, initially located around the release point. If the release is ignited immediately then a fireball will be formed. If this cloud is not immediately ignited, then a vapour cloud will form, which will disperse with the wind and diluted as a result of air entrainment. The principal hazard arising from a cloud of dispersing flammable material is its subsequent (delayed) ignition, resulting in a flash fire. Large-scale experiments on the dispersion and ignition of flammable gas clouds show that ignition is unlikely when the average concentration is below the lower flammability limit (LFL).

As in the case for blow outs,) an effort was made to establish the overpressure (blast force zone) that may result from delayed ignition of vapour cloud generated from any such accidental release. For overpressure risk modelling using ALOHA a delayed ignition time of 5 minutes was considered of the vapour cloud mass. However the threat modelled revealed that Level of Concern (LOC) was never exceeded that may possibly lead to damage to property or life within the blast radius. The results have been provided in ***Figure 1.7*** below.

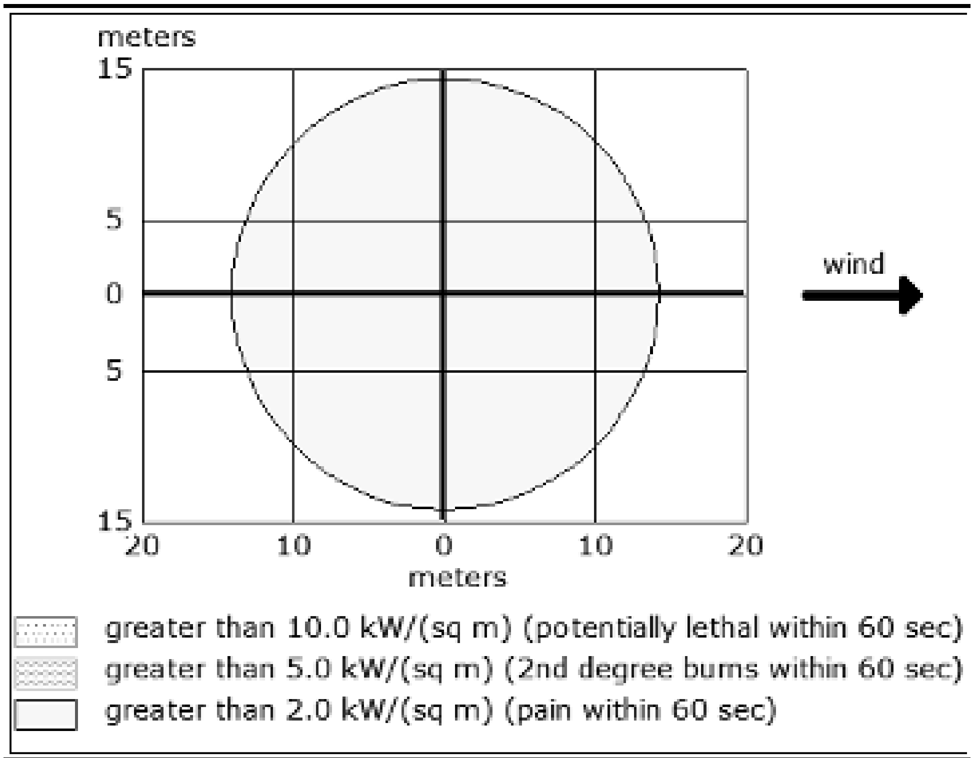
Figure 1.7 ***Overpressure Risk Modeling – Well Releases during drilling***

Threat Modeled: Overpressure (blast force) from vapor cloud explosion
Type of Ignition: ignited by spark or flame
Level of Congestion: uncongested
Model Run: Gaussian
Red : LOC was never exceeded --- (8.0 psi = destruction of buildings)
Orange: LOC was never exceeded --- (3.5 psi = serious injury likely)
Yellow: LOC was never exceeded --- (1.0 psi = shatters glass)

b) Jet Fire

The term jet fire is used to describe the flame produced due to the ignition of a continuous pressurised leakage from the pipe work. Combustion in a jet fire occurs in the form of a strong turbulent diffusion flame that is strongly influenced by the initial momentum of the release. Flame temperatures for typical jet flames vary from 1600°C for laminar diffusion flames to 2000°C for turbulent diffusion flames. The principal hazards from a jet fire are thermal radiation and the potential for significant knock-on effects, such as equipment failure due to impingement of the jet fire. The thermal radiations distances due to Jet Flame are shown in ***Figure 1.8*** and ***Figure 1.9*** below.

Figure 1.8 Thermal Radiation Distances of Jet Flame due to Leak of 25 mm size



THREAT ZONE:

Threat Modeled: Thermal radiation from jet fire

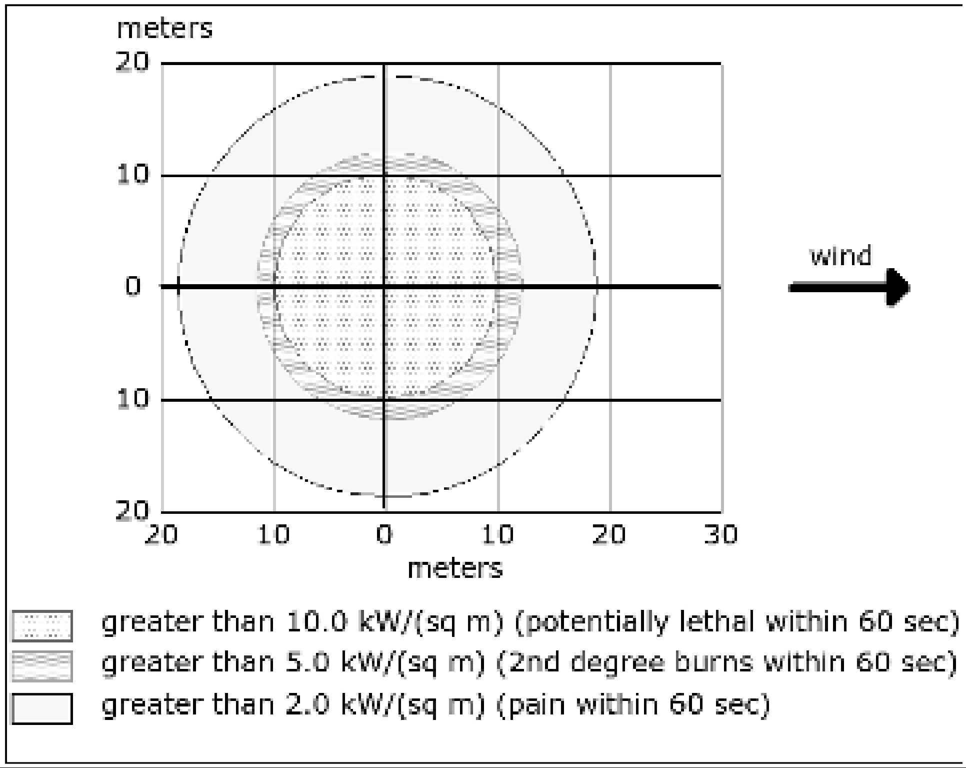
Model Run: Gaussian

Red: < 10 meters --- (10.0 kW/(sq m) = potentially lethal within 60 sec)

Orange: < 10 meters --- (5.0 kW/(sq m) = 2nd degree burns within 60 sec)

Yellow: 14 meters --- (2.0 kW/(sq m) = pain within 60 sec)

Figure 1.9 Thermal Radiation Distances of Jet Flame due to Leak of 50 mm size



THREAT ZONE:

Threat Modeled: Thermal radiation from jet fire

Model Run: Gaussian

Red : 10 meters --- (10.0 kW/(sq m) = potentially lethal within 60 sec)

Orange: 12 meters --- (5.0 kW/(sq m) = 2nd degree burns within 60 sec)

Yellow: 19 meters --- (2.0 kW/(sq m) = pain within 60 sec)

The zone of thermal radiation calculated for hypothetical release and ignition of natural gas during well testing have been presented in the ***Table 1.13*** below.

Table 1.13 Thermal Radiation Zone (in meters) of Natural Gas Release Scenario during Well Testing

Release Type	Red (kW/sqm)	Orange (kW/sqm)	Yellow (kW/sqm)
Leak of 25 mm size	<10	<10	14
Leak of 50 mm size	10	12	19

Hence for a worst case scenario (50 mm leak) the ignition of natural gas release will be resulting in generation of thermal radiation which will be lethal within a maximum radius of 10m within 1 minute of its occurrence.

The risk significance for the potential well release scenario resulting from exploratory drilling has been presented below. For calculating the risk significance, the likelihood ranking is considered to be "2" as the frequency analysis for blow outs incidents is computed at "~ 10^{-4}" whereas the consequence ranking has been identified to be as "4" given the worst case scenario modelling (blast overpressure)/jet fire indicates that the LOC was never exceeded leading to multiple fatalities (For criteria ranking please refer to ***Table 1.1*** and ***Table 1.2***).

Risk Ranking – Jet Fire/Blast Overpressure from Well Releases (Worst Case Scenario)

Likelihood ranking	**2**	**Consequence ranking**	**4**
Risk Ranking & Significance = 8 i.e. "Low" i.e. Risk is Acceptable and can be managed through use of existing controls and evaluation of additional controls.			

C) Interconnecting Hydrocarbon Pipeline Network

As discussed in the project description section, the following hydrocarbon pipelines is likely to be laid as part of the proposed project viz.

- 8" sub surface crude oil (well fluid) pipelines from onshore well pads to Ravva Terminal; and
- 6" sub surface gas lift pipeline of from onshore well pads to Ravva Terminal.

Some of the key hazard likely to be associated with same has been presented below

- Jet fires associated with pipework failures;
- Vapour cloud explosions; and
- Flash fires.

Each of these hazards has been described below.

Jet Fire

Jet fires result from ignited releases of pressurized flammable gas or superheated/pressurized liquid. The momentum of the release carries the material forward in a long plume entraining air to give a flammable mixture. Jet fires only occur where the natural gas is being handled under pressure or when handled in gas phase and the releases are unobstructed.

Flash Fire

Vapour clouds can be formed from the release of vapour of pressurized flammable material as well as from non-flashing liquid releases where vapour clouds can be formed from the evaporation of liquid pools or leakage/rupture of pressurized pipelines transporting flammable gas.

Where ignition of a release does not occur immediately, a vapour cloud is formed and moves away from the point of origin under the action of the wind.

This drifting cloud may undergo delayed ignition if an ignition source is reached, resulting in a flash fire if the cloud ignites in an unconfined area or vapour cloud explosion (VCE) if within confined area.

Vapour Cloud Explosion

If the generation of heat in a fire involving a vapour-air mixture is accompanied by the generation of pressure then the resulting effect is a vapour cloud explosion (VCE). The amount of overpressure produced in a VCE is determined by the reactivity of the gas, the strength of the ignition source, the degree of confinement of the vapour cloud, the number of obstacles in and around the cloud and the location of the point of ignition with respect to the escape path of the expanding gases.

However, in the case of the interconnecting gas pipeline network *jet fire* has been identified as the most probable hazard.

Pipeline Frequency Analysis – Gas Pipelines

An effort has also been made to understand the primary failure frequencies of pressurised gas/oil to be transported through the interconnecting pipeline network. Based on the European Gas Pipeline Incident Data Group (EGIG) database the evolution of the primary failure frequencies over the entire period and for the last five years has been provided in ***Table 1.14*** below.

Table 1.14 Primary Gas Pipeline Failure Frequency

Period	No. of Incidents	Total System Exposure (km.yr)	Primary Failure Frequency (1000 km.yr)
1970-2007	1173	$3.15.10^6$	0.372
1970-2010	1249	$3.55.10^6$	0.351
1970-2013	1309	$3.98.10^6$	0.329
1974-2013	1179	$3.84.10^6$	0.307
1984-2013	805	$3.24.10^6$	0.249
1994-2013	426	$2.40.10^6$	0.177
2004-2013	209	$1.33.10^6$	0.157
2009-2013	110	$0.70.10^6$	0.158

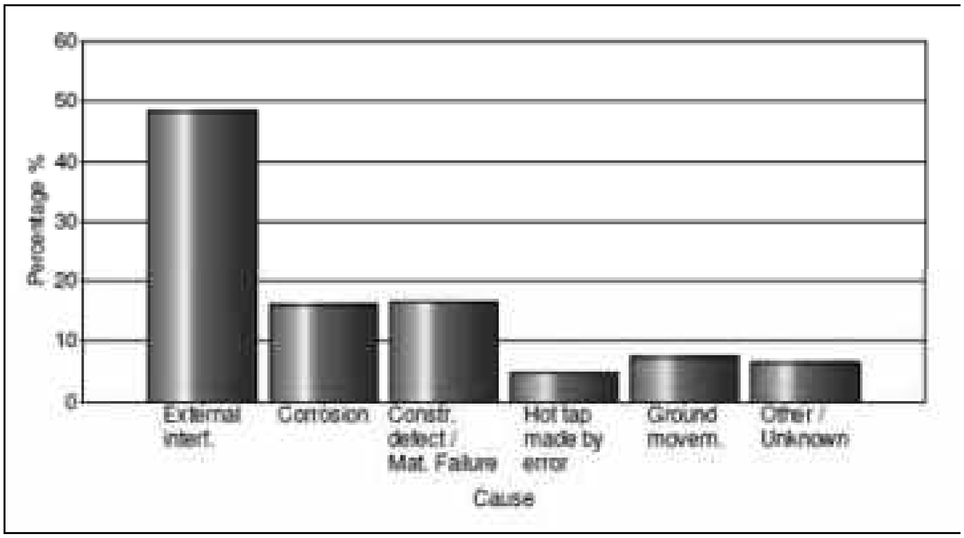
Source: 9th EGIG Report

As referred in the above table the overall failure frequency (0.33) of the entire period (1970-2013) is slightly lower than the failure frequency of 0.35 reported in the 8th EGIG report (1970-2010). The failure frequency of the last 5 years was found to be 0.16 per 1000km.year, depicting an improved performance over the recent years.

Incident Causes

Gas pipeline failure incidents can be attributed to the following major causes viz. external interference, construction defects, corrosion (internal & external), ground movement and hot tap. The distribution of incidents with cause has been presented in the ***Figure 1.10*** below.

Figure 1.10 Gas Pipeline Failure – Distribution of Incident & Causes



Source: 8th EGIG Report

The interpretation of the aforesaid figure indicated external interference as the major cause of pipeline failure contributing to about 48.4% of the total failure incidents followed by construction defects (16.7%) and corrosion related problems (16.1%). Ground movement resulting from seismic disturbance, landslides, flood etc. contributed to only 7.4% of pipeline failure incident causes.

Review of the 9th EGIG report indicates that primary failure frequency varies with pipeline diameter, and the same has been presented in ***Table 1.15*** below.

Table 1.15 Primary Failure Frequency based on Diameter Class (1970-2013)

Nominal Diameter (inch)	Primary Failure Frequency (per km.yr)		
	Pinhole/Crack	Hole	Rupture
diameter < 5"	4.45×10^{-4}	2.68×10^{-4}	1.33×10^{-4}
5" ≤ diameter < 11"	2.80×10^{-4}	1.97×10^{-4}	6.40×10^{-5}
11" ≤ diameter < 17"	1.27×10^{-4}	0.98×10^{-4}	4.10×10^{-5}
17" ≤ diameter < 23"	1.02×10^{-4}	5.00×10^{-5}	3.40×10^{-5}
23" ≤ diameter < 29"	8.50×10^{-5}	2.70×10^{-5}	1.20×10^{-5}
29" ≤ diameter < 35"	2.30×10^{-5}	5.00×10^{-6}	1.40×10^{-5}
35" ≤ diameter < 41"	2.30×10^{-5}	8.00×10^{-6}	3.00×10^{-6}
41" ≤ diameter < 47"	7.00×10^{-6}	-	-
diameter ≥ 47"	6.00×10^{-6}	6.00×10^{-6}	6.00×10^{-6}

Source: 9th EGIG Report

The pipeline failure frequency viz. leaks or rupture for the natural gas pipeline has been computed based on the aforesaid table. Considering the gas pipeline to be laid is likely to have a diameter of 6 inches, the probability of pinhole is estimated to be **2.80 x 10^{-4} per km year,** while full bore rupture is considered to be **6.40 x 10^{-5} per km year. (Refer** *Table 1.16* below).

Table 1.16 *Interconnecting Gas Pipeline - Failure Frequency*

S N	Pipeline Failure Case	EGIG Failure Frequency (per km. year)	Pipeline Dia. (inch)	Avg. Pipeline Length (km)	Project Pipeline Failure Frequency (per year)	Frequency
1	Pipeline Rupture	6.40 x 10^{-5}	6	15	9.60 x 10^{-4}	Not Likely
2	Pipeline Leak	2.80 x 10^{-4}	6	15	4.20 x 10^{-3}	Occasional /Rare

Thus the probability of pipeline leak and rupture with respect to the interconnecting hydrocarbon pipeline network is identified to be both "*Not Likely*" and "*Occasional/Rare*".

Oil Pipeline Failure Frequency

Concawe (2015) has developed estimates for leak frequencies from onshore crude oil pipelines. Over the past 20 years the typical leak frequency from larger oil pipelines (>16") has been of the order 0.2 per 1000 km pipeline and year, among these 19% are defined as rupture, giving the largest spill rate, often of the order the transport rate of the pipeline after an initially higher transient leak rate. 17% of the holes were defined as "split", with an opening of 75-1000mm x 10% of diameter, which could also give release rates similar to the pipeline flow rate. This would correspond to a total release frequency of $2x10^{-4}/y$ and rupture plus split frequency of $7x10^{-5}/y$ per km pipeline. Almost half of the releases were categorized as caused by 3rd party, a small, but a strongly increasing fraction last couple of years was found to be intentional, primarily due to theft.

Review of the CONCAWE[1] accident database for the period 1970-2010, reveals the liquid pipeline failure frequency in Europe to be around 1.01 $X10^{-6}$; hence for the 8" inch sub surface crude oil (well fluid) pipelines (~15km length) from onshore well pads to Ravva Terminal the frequency is computed to be around 1.51 $X10^{-5}$ i.e. "*Not Likely*".

Gas Pipeline Failure – Ignition Probability

The ignition probability of natural gas pipeline failure (rupture & leaks) with respect to the proposed expansion project is derived based on the following equations as provided in the IGEM/TD/2 standard

$P_{ign} = 0.0555 + 0.0137pd2$; for $0 \leq pd^2 \leq 57$
(For pipeline ruptures)

[1] Davis, P. M., Dubois, J., Gambardella, F., Sanchez-Garcia, E., Uhlig F., (2011). "Performance of European cross-country oil pipelines - Statistical summary of reported pillages in 2010 and since 1971". Report no. 8/11, CONCAWE,

$P_{ign} = 0.81$; for $pd^2 > 57$

$P_{ign} = 0.0555 + 0.0137(0.5pd2)$; for $0 \leq 0.5pd^2 \leq 57$
(For pipeline leaks)
$P_{ign} = 0.81$; for $0.5pd^2 > 57$

Where:

P_{ign} = Probability of ignition
p = Pipeline operating pressure (bar)
d = Pipeline diameter (m)

The ignition and jet fire probability of natural gas release from a leak/rupture of interconnected pipeline network is calculated based on the above equations and presented in **Table 1.17** below.

Table 1.17 Interconnecting Pipeline – Ignition & Jet Fire Probability

S. N	Pipeline Failure Case	Pipeline Dia (inch)	Project Pipeline Failure Frequency (per year)	Ignition Probability	Jet Fire Probability
7	Pipeline Rupture	6	9.60×10^{-4}	0.06	5.76×10^{-5}
8	Pipeline Leak	6	4.20×10^{-3}	0.058	2.43×10^{-4}

Hence from the above table it can be concluded that ignition probability of natural gas that may be released from the interconnecting pipeline due to any accidental event is considered to be "***Not likely***".

Oil Pipeline Failure – Ignition Probability

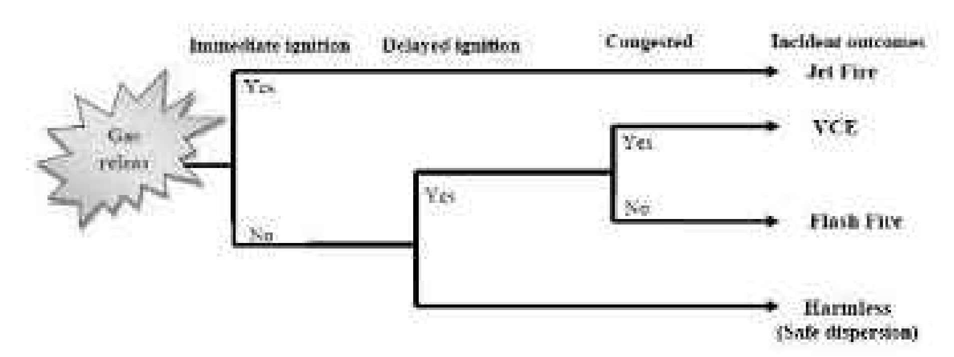
OGP (2010) gives an estimated ignition probability for large crude oil releases of 0.70% in rural areas; hence considering the same the ignition probability of oil spills/leakages from 8" sub surface pipeline (~15km length) is computed to be around **1.05×10^{-5}.**

Consequence Analysis – Pipelines

Pipelines generally contains large inventories of oil or gas under high pressure; although accidental releases from them are remote they have the potential of catastrophic or major consequences if related risks are not adequately analysed or controlled. The consequences of possible pipeline failure is generally predicted based on the hypothetical failure scenario considered and defining parameters such as meteorological conditions (stability class), leak hole & rupture size and orientation, pipeline pressure & temperature, physicochemical properties of chemicals released etc.

In case of pipe rupture containing highly flammable natural gas, an immediate ignition will cause a jet fire. Flash fires can result from the release of natural gas through the formation of a vapour cloud with delayed ignition and a fire burning through the cloud. A fire can then flash back to the source of the leak and result in a jet fire. Flash fires have the potential for offsite impact as the vapour clouds can travel considerable distances downwind of the source. Explosions can occur when a flammable gas cloud in a confined area is ignited; however where vapour cloud concentration of released material is lower than Lower Flammability Limit (LFL), consequently the occurrence of a VCE is highly unlikely. VCE, if occurs may result in overpressure effects that become more significant as the degree of confinement increases (Refer ***Figure 1.11***).Therefore, in the present study, only the risks of jet fires for the below scenarios have been modelled and calculated.

Figure 1.11 ***Natural Gas Release – Potential Consequences***



[Source: "Safety risk modelling and major accidents analysisof hydrogen and natural gas releases: A comprehensive risk analysis framework" - Iraj Mohammadfam, Esmaeil Zarei]

Based on the above discussion and frequency analysis as discussed in the earlier section, the following hypothetical risk scenarios (Refer ***Table 1.18***) have been considered for consequence analysis of the interconnecting pipelines.

Table 1.18 ***Interconnecting Pipeline Risk Modelling Scenarios***

Scenario	Source	Pipeline dia (inch)	Accident Scenario	Design Pressure (bar)	Temperature	Potential Risk
1	Pipeline	6	Leak of 25mm dia	17.23	24°C	Jet Fire
2	Pipeline	6	Leak of 50mm dia	17.23	24°C	Jet Fire
3	Pipeline	6	Complete rupture	17.23	24°C	Jet Fire
4	Pipeline	8	Leak of 25mm dia	17.23	24°C	Pool Fire
5	Pipeline	8	Leak of 50mm dia	17.23	24°C	Pool Fire
6	Pipeline	8	Complete rupture	17.23	24°C	Pool Fire

The pipeline failure risk scenarios have been modeled using ALOHA and interpreted in terms of Thermal Radiation Level of Concern (LOC) encompassing the following threshold values (measured in kilowatts per square meter) for natural gas (comprising of ~95% methane[1]) and crude oil (represented by n-decane) to create the default threat zones:

Red: 10 kW/(sq. m) -- potentially lethal within 60 sec;

Orange: 5 kW/(sq. m) -- second-degree burns within 60 sec; and

Yellow: 2 kW/(sq. m) -- pain within 60 sec.

For vapour cloud explosion, the following threshold level of concern has been interpreted in terms of blast overpressure as specified below:

Red: 8.0 psi – destruction of buildings;

Orange: 3.5 psi – serious injury likely; and

Yellow: 1.0 psi – shatters glass

The risk scenarios modelled for pipeline failure has been presented below:

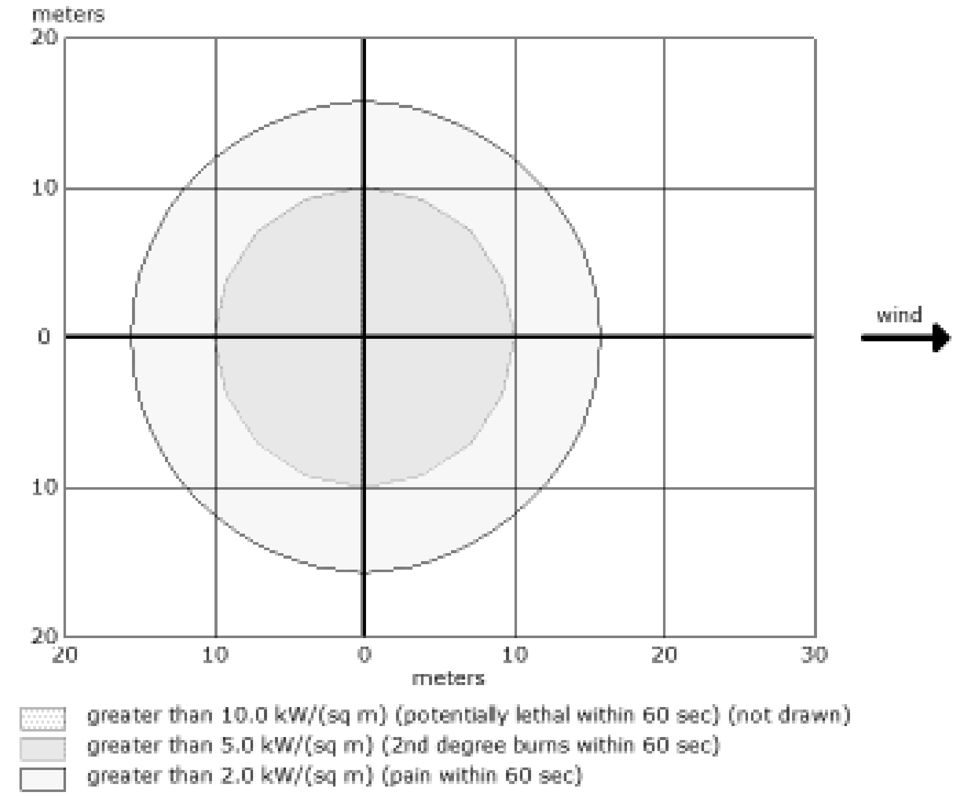
Scenario 1: Gas Pipeline Leak (25mm dia)

The jet fire threat zone plot for release and ignition of natural gas from pipeline leak (25mm) is represented in ***Figure 1.12*** below.

[1] https://www.naesb.org//pdf2/wgq_bps100605w2.pdf

http://www.google.co.in/url?sa=t&rct=j&q=&esrc=s&source=web&cd=18&ved=0ahUKEwjF7MiDttPRAhVCMI8KHd7aD6cQFghrMBE&url=http%3A%2F%2Fwww.springer.com%2Fcda%2Fcontent%2Fdocument%2Fcda_downloaddocument%2F9781848828711-c1.pdf%3FSGWID%3D0-0-45-862344-p173918930&usg=AFQjCNEaJklfYKl3fRUdi6xiRYeW-FJb2A

Figure 1.12 Threat Zone Plot – Gas Pipeline Leak (25mm dia)



Source: ALOHA

THREAT ZONE:

Threat Modeled: Thermal radiation from jet fire

Red : <10 meters --- (10.0 kW/ (sq. m) = potentially lethal within 60 sec)

Orange: 10 meters --- (5.0 kW/ (sq. m) = 2nd degree burns within 60 sec)

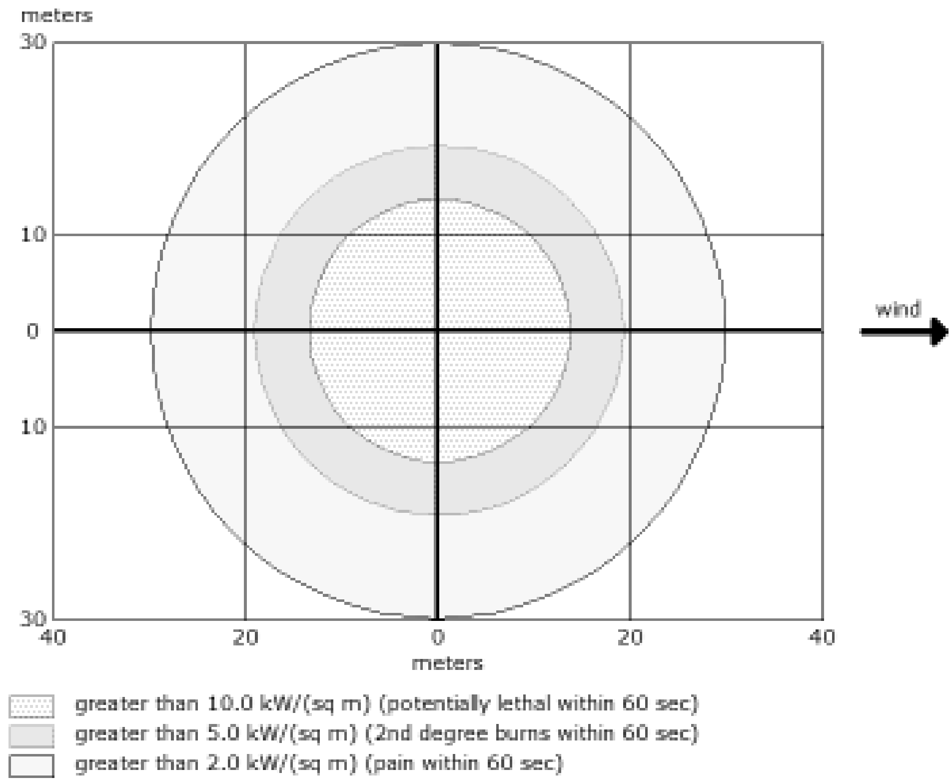
Yellow: 16 meters --- (2.0 kW/ (sq. m) = pain within 60 sec)

The worst hazard for release and ignition of natural gas from the gas pipeline leak (25mm dia) will be experienced to a maximum radial distance of <10m from the source with potential lethal effects within 1 minute.

Scenario 2: Gas Pipeline Leak (50mm dia)

The jet fire threat zone plot for release and ignition of natural gas from pipeline leak (50mm) is represented in ***Figure 1.13*** below.

Figure 1.13 Threat Zone Plot – Gas Pipeline Leak (50mm dia)



Source: ALOHA

THREAT ZONE:

Threat Modeled: Thermal radiation from jet fire

Red : 14 meters --- (10.0 kW/ (sq. m) = potentially lethal within 60 sec)

Orange: 19 meters --- (5.0 kW/ (sq. m) = 2nd degree burns within 60 sec)

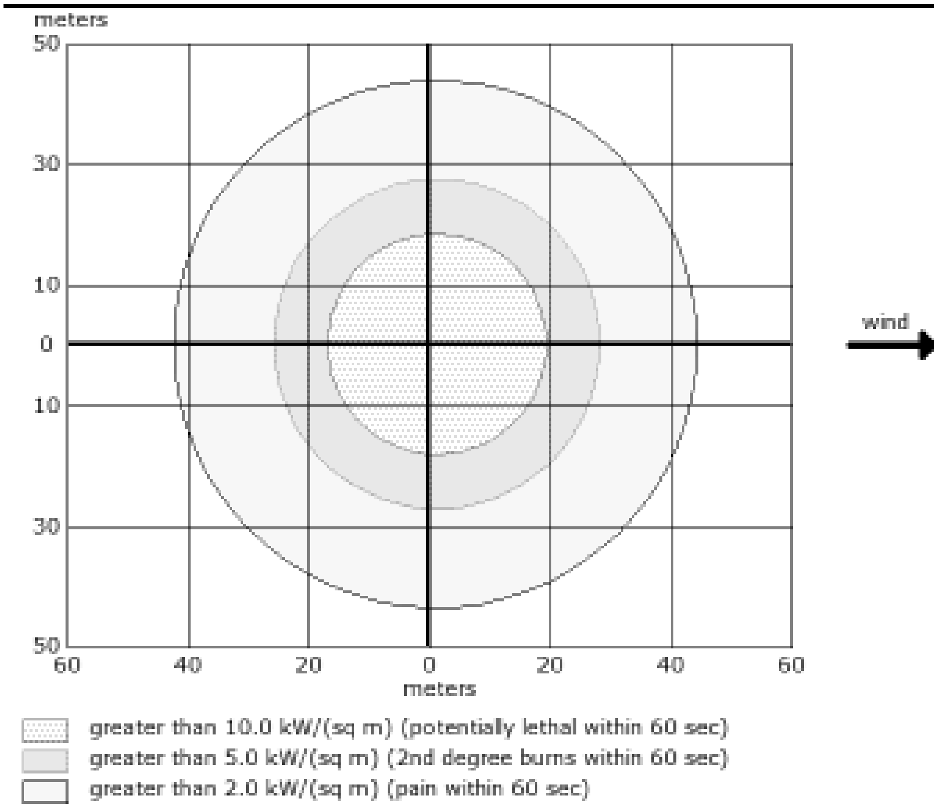
Yellow: 30 meters --- (2.0 kW/ (sq. m) = pain within 60 sec)

The worst hazard for release and ignition of natural gas from the gas pipeline leak (50mm dia) will be experienced to a maximum radial distance of 14m from the source with potential lethal effects within 1 minute.

Scenario 3: Gas Pipeline Rupture

The jet fire threat zone plot for release and ignition of natural gas from gas pipeline rupture is represented in ***Figure 1.14*** below.

Figure 1.14 Threat Zone Plot – Gas pipeline rupture



Source: ALOHA

THREAT ZONE:

Threat Modeled: Thermal radiation from jet fire

Red : 20 meters --- (10.0 kW/ (sq. m) = potentially lethal within 60 sec)

Orange: 28 meters --- (5.0 kW/ (sq. m) = 2nd degree burns within 60 sec)

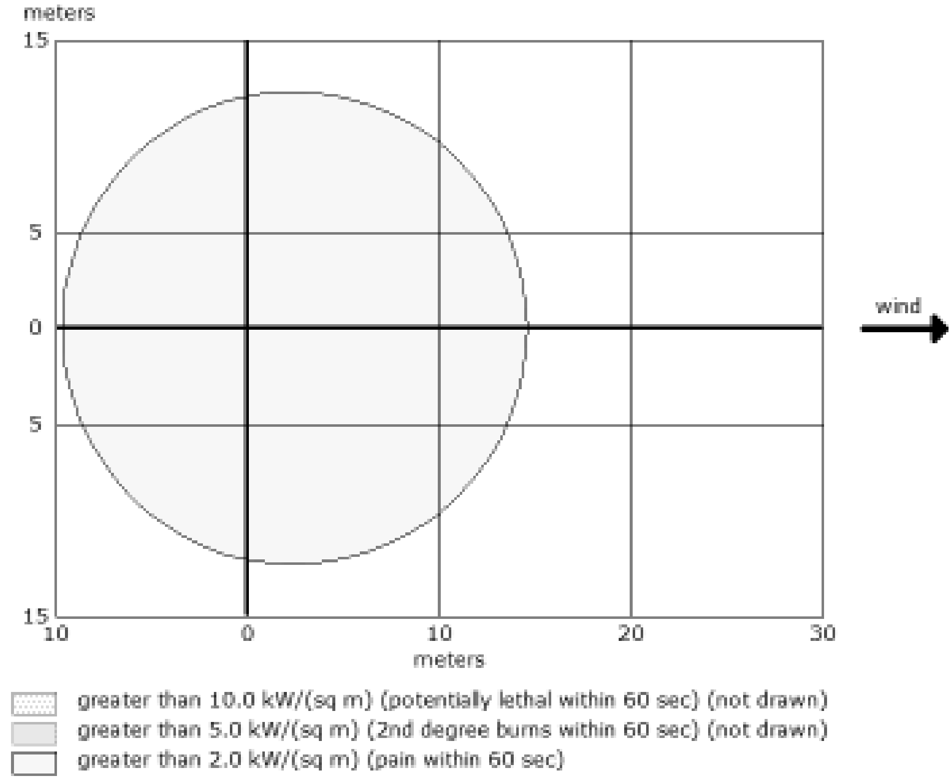
Yellow: 45 meters --- (2.0 kW/ (sq. m) = pain within 60 sec)

The worst hazard for release and ignition of natural gas from pipeline rupture will be experienced to a maximum radial distance of 20m from the source with potential lethal effects within 1 minute.

Scenario 4: Oil Pipeline Leak (25mm dia)

The pool fire threat zone plot for release and ignition of oil from pipeline leak (25mm dia) is represented in **Figure 1.15** *below.*

Figure 1.15 Threat Zone Plot –Oil Pipeline Leak (25mm dia)



Source: ALOHA

THREAT ZONE:

Threat Modeled: Thermal radiation from pool fire

Red : <10 meters --- (10.0 kW/ (sq. m) = potentially lethal within 60 sec)

Orange: <10 meters --- (5.0 kW/ (sq. m) = 2nd degree burns within 60 sec)

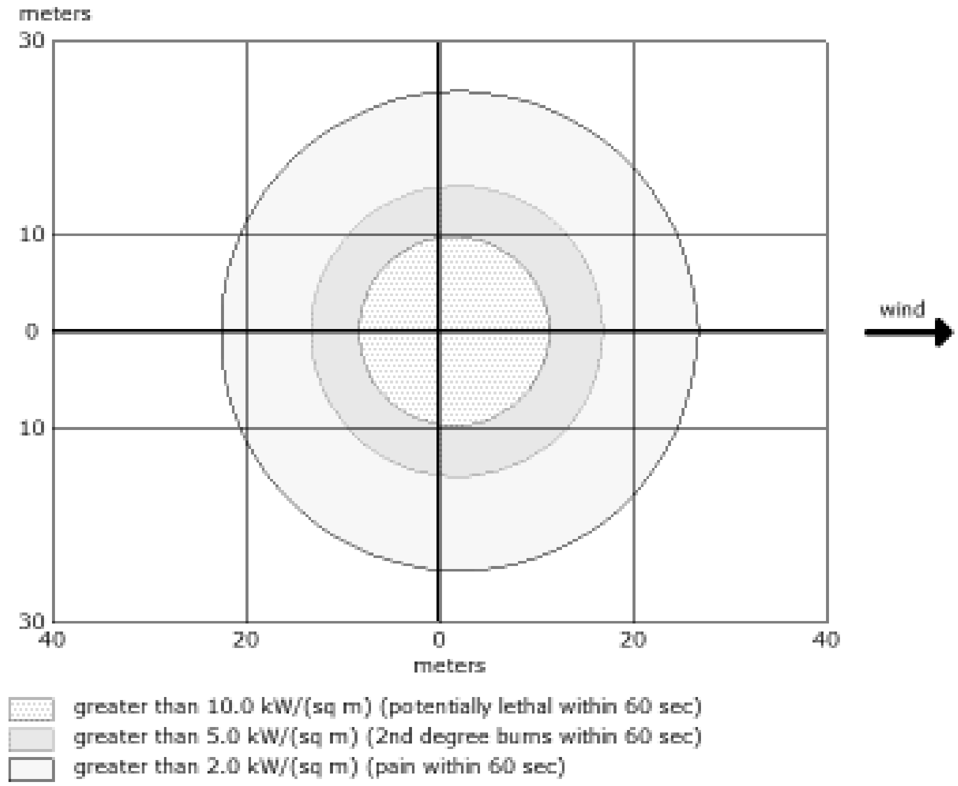
Yellow: 15 meters --- (2.0 kW/ (sq. m) = pain within 60 sec)

The worst hazard for release and ignition of oil from pipeline leak (25mm dia) will be experienced to a maximum radial distance of <10m from the source with potential lethal effects within 1 minute.

Scenario 5: Oil Pipeline Leak (50mm dia)

The pool fire threat zone plot for release and ignition of oil from pipeline leak (50mm dia) is represented in ***Figure 1.16*** below.

Figure 1.16 Threat Zone Plot – Oil Pipeline Leak (50mm dia)



Source: ALOHA

THREAT ZONE:

Threat Modeled: Thermal radiation from pool fire

Red : 12 meters --- (10.0 kW/ (sq. m) = potentially lethal within 60 sec)

Orange: 17 meters --- (5.0 kW/ (sq. m) = 2nd degree burns within 60 sec)

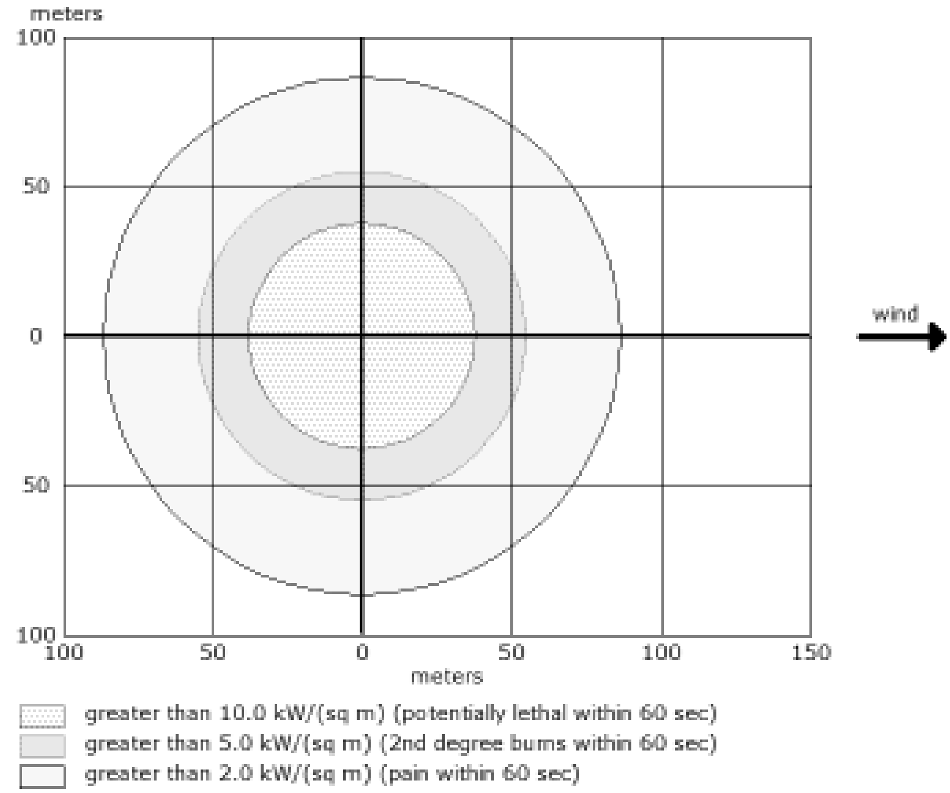
Yellow: 27 meters --- (2.0 kW/ (sq. m) = pain within 60 sec)

The worst hazard for release and ignition of oil from pipeline leak (50mm dia) will be experienced to a maximum radial distance of 12m from the source with potential lethal effects within 1 minute.

Scenario 6: Oil Pipeline Rupture

The pool fire threat zone plot for release and ignition of oil from pipeline rupture is represented in ***Figure 1.17*** below.

Figure 1.17 Threat Zone Plot –Oil Pipeline Rupture



Source: ALOHA

THREAT ZONE:

Threat Modeled: Thermal radiation from pool fire

Red : 38 meters --- (10.0 kW/ (sq. m) = potentially lethal within 60 sec)

Orange: 55 meters --- (5.0 kW/ (sq. m) = 2nd degree burns within 60 sec)

Yellow: 86 meters --- (2.0 kW/ (sq. m) = pain within 60 sec)

The worst hazard for release and ignition of oil from pipeline rupture will be experienced to a maximum radial distance of 38m from the source with potential lethal effects within 1 minute.

For VCE modelled for catastrophic failure of interconnecting pipeline the LOC level was never exceeded

THREAT ZONE:

Threat Modeled: Overpressure (blast force) from vapor cloud explosion

Type of Ignition: ignited by spark or flame

Level of Congestion: uncongested

Model Run: Heavy Gas

Red : LOC was never exceeded --- (8.0 psi = destruction of buildings)

Orange: LOC was never exceeded --- (3.5 psi = serious injury likely)

Yellow: LOC was never exceeded --- (1.0 psi = shatters glass)

For calculating the risk significance of oil and gas pipeline, the likelihood ranking is considered to be "3" as the probability of pipeline rupture is computed to be ~10^{-4} per year; whereas the consequence ranking has been identified to be as "3" as given for a worst case scenario (rupture) lethal effects is likely to be limited within a radial zone of ~38m.

Further as discussed in the earlier section, adequate number of leak and fire detection system of appropriate design will be provided for the interconnecting pipeline network including GCS to prevent for any major risk at an early stage of the incident.

Risk Ranking – Pipeline Rupture (Worst Case Scenario)

Likelihood ranking	**3**	**Consequence ranking**	**3**
Risk Ranking & Significance = 9 i.e. "Low" i.e. Risk is Acceptable and can be managed through use of existing controls and evaluation of additional controls.			

D) Transportation of Crude by Road Tankers

As discussed in the project description section, the proposed project involves generation of 1500 barrels of oil per day from each well which will be transported to Ravva onshore terminal by approximately 12 Oil Tankers (considering tanker size of 20 KL and 1 barrel = 0.1589873 KL). Hence considering simultaneous operations of both wells, a movement of 24 crude oil bearing tankers is anticipated in a day to the Ravva Terminal.

The crude is pumped from the well site storage area through aboveground pipework to the site road tanker loading gantry. Road tanker loading occurs during the day and at night. The details of the road tanker loading facilities has been provided in the ***Table 1.19*** below.

Table 1.19 Road Tanker Loading Facility Details

S. N.	Characteristics	Values
1	Tanker Sizes	20 m^3
2	Compartment Size	5 m^3
3	Connections per Tanker	2
4	Hose Size	100mm
6	Average flowrate in pipeline to Gantry	0.1 m^3/s

Road Tanker Failure Hazards

As compared to other modes of transport, tanker trucks operate in close proximity to the general public and share the same infrastructure (i.e., highways, roads, neighbourhoods). Trucks can also operate in densely populated areas. This increases the risk of accidents, including collisions and accidents at crossings. Collisions may involve multiple vehicles and can occur at high speeds, which may increase the risk of fire and explosion.

The potential hazards associated with the failure of road tanker loading and transport has been presented in the ***Table 1.20*** below with the pool fire identified to be the most common hazard.

Table 1.20 Road Tanker Failure - Potential Hazards

S. N.	Failure Scenario	Potential Hazards
1	Road tanker loading hose leak/rupture	Flash Fire; Pool Fire
2	Road tanker collision/toppling	Flash Fire; Pool Fire

Road Tanker Failure Frequency

To determine the probability of a pool fire occurring, the failure rate needs to be modified by the probability of the material finding an ignition source. The probability of a pool fire occurring in the event of a release is therefore equal to the product of the failure rate and the probability of ignition. The frequency of the release scenarios identified in the above section is represented in ***Table 1.21*** & ***Table 1.22.***

Table 1.21 Failure Frequencies for Road Tanker Loading Hoses

Sl. No.	Failure Type	Failure Frequency
1	Full Bore Rupture	4.0×10^{-6} per operation
2	15mm Hole	0.4×10^{-6} per operation
3	5mm Hole	6.0×10^{-6} per operation

Table 1.22 Frequencies for Road Tanker Incidents

S.N	Failure Type	Failure Frequency (per km)	Max. Distance to terminal (km)	Calculated Frequency
1	Catastrophic failure	1.0×10^{-5}	15	1.5×10^{-4}
2	Large connection failure	5.0×10^{-7}	15	7.5×10^{-6}

Thus the probability of road tanker failures with respect to the proposed project is identified to be "*Improbable*" with respect to road tanker loading hose failure and "*Not Likely*" for road tanker collision/toppling.

Road Tanker Failure Consequence Analysis

For offloading scenarios, generally release rates for this assessment have been taken equal to the initial release rates. Where the flow through a hose is driven by a pump, the maximum flow rate arising from a leak was set to 150% of the normal flow rate to allow for pump over-speed. The following representative scenarios (Refer ***Table 1.23***) for the tankers loading and transport have been considered:

Table 1.23 Road Tanker Failure Scenarios

S. N.	Failure Type	Characteristics	
A	**Hose Failure[1]**	**Hose Dia (mm)**	**Hose Length (m)**
1	5mm Hole	100	50
2	15mm Hole	100	50
3	Full Bore Rupture	100	50
B	**Road Tanker Failure[2]**	**Tank Capacity (KL)**	**Tank Dia (m)**
1	Catastrophic failure	20	1.5
2	50mm dia tank leak	20	1.5
3	100mm dia tank leak	20	1.5

The aforesaid failure risk scenarios have been modeled using ALOHA and interpreted in terms of Thermal Radiation Level of Concern (LOC) encompassing the following threshold values (measured in kilowatts per square meter) for natural gas (comprising of ~95% methane[3]) and crude oil (represented by n-decane) to create the default threat zones:

Red: 10 kW/(sq. m) -- potentially lethal within 60 sec;

Orange: 5 kW/(sq. m) -- second-degree burns within 60 sec; and

Yellow: 2 kW/(sq. m) -- pain within 60 sec.

For vapour cloud explosion, the following threshold level of concern has been interpreted in terms of blast overpressure as specified below:

Red: 8.0 psi – destruction of buildings;

Orange: 3.5 psi – serious injury likely; and

Yellow: 1.0 psi – shatters glass

The risk scenarios modelled for tanker failure as outlined in the ***Table 7.23*** has been presented below.

Scenario A.1: Road Tanker Loading Hose Leak (5mm dia)

THREAT ZONE:
Threat Modeled: Thermal radiation from pool fire

[1] Failure Rate and Event Data for use within Land Use Planning Risk Assessments – FR 1.2.3 – Hoses and Couplings

[2] Publication Series on Dangerous Substances - Guidelines for quantitative risk assessment, 'Purple Book', CPR18E, Chapter 3.2.9 Transport units in an establishment, Page 3.12

[3] https://www.naesb.org//pdf2/wgq_bps100605w2.pdf

http://www.google.co.in/url?sa=t&rct=j&q=&esrc=s&source=web&cd=18&ved=0ahUKEwjF7MiDttPRAhVCMI8KHd7aD6cQFghrMBE&url=http%3A%2F%2Fwww.springer.com%2Fcda%2Fcontent%2Fdocument%2Fcda_downloaddocument%2F9781848828711-c1.pdf%3FSGWID%3D0-0-45-862344-p173918930&usg=AFQjCNEaJklfYKl3fRUdi6xiRYeW-FJb2A

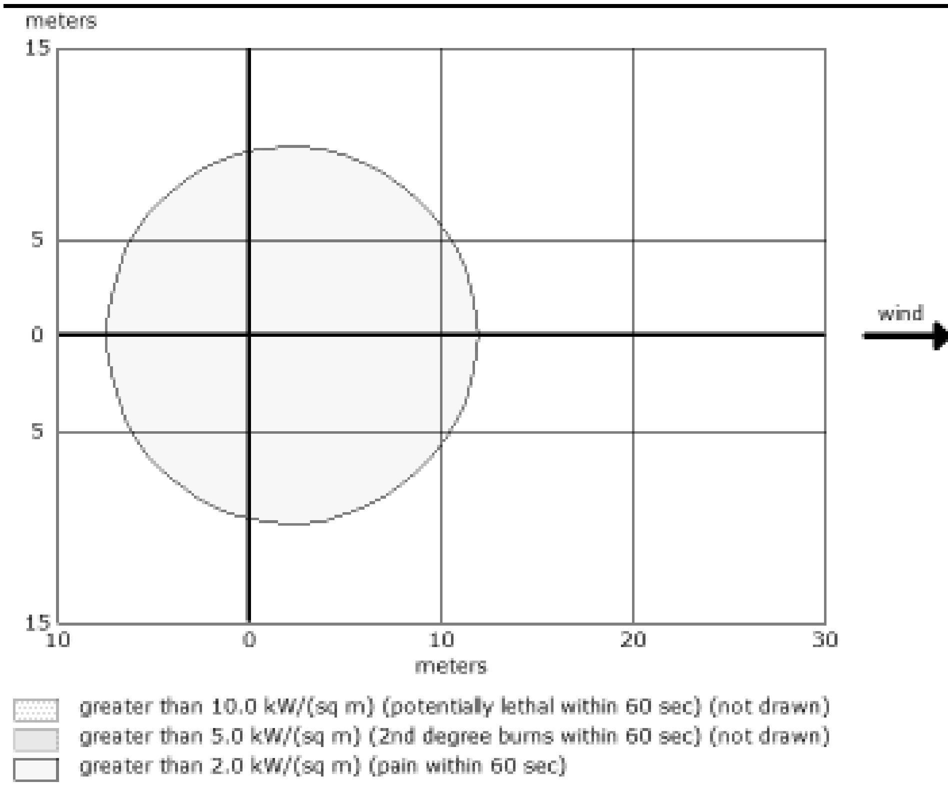
Red : less than 10 meters - (10.0 kW/(sq m) = potentially lethal within 60 sec)
Orange: less than 10 meters -- (5.0 kW/(sq m) = 2nd degree burns within 60 sec)
Yellow: less than 10 meters - (2.0 kW/(sq m) = pain within 60 sec)

The worst hazard for release and ignition of crude oil from tanker loading hose leak (5mm dia) will be experienced to a maximum radial distance of <10m from the source with potential lethal effects within 1 minute.

Scenario A.2: Road Tanker Loading Hose Leak (15mm dia)

The pool fire threat zone plot for release and ignition of crude oil from tanker loading hose leak (20mm) is represented in ***Figure 1.18*** below.

Figure 1.18 Threat Zone Plot – Road Tanker Loading Hose Leak (20mm dia)



Source: ALOHA

THREAT ZONE:

Threat Modeled: Thermal radiation from pool fire

Red : <10 meters --- (10.0 kW/ (sq. m) = potentially lethal within 60 sec)

Orange: <10 meters --- (5.0 kW/ (sq. m) = 2nd degree burns within 60 sec)

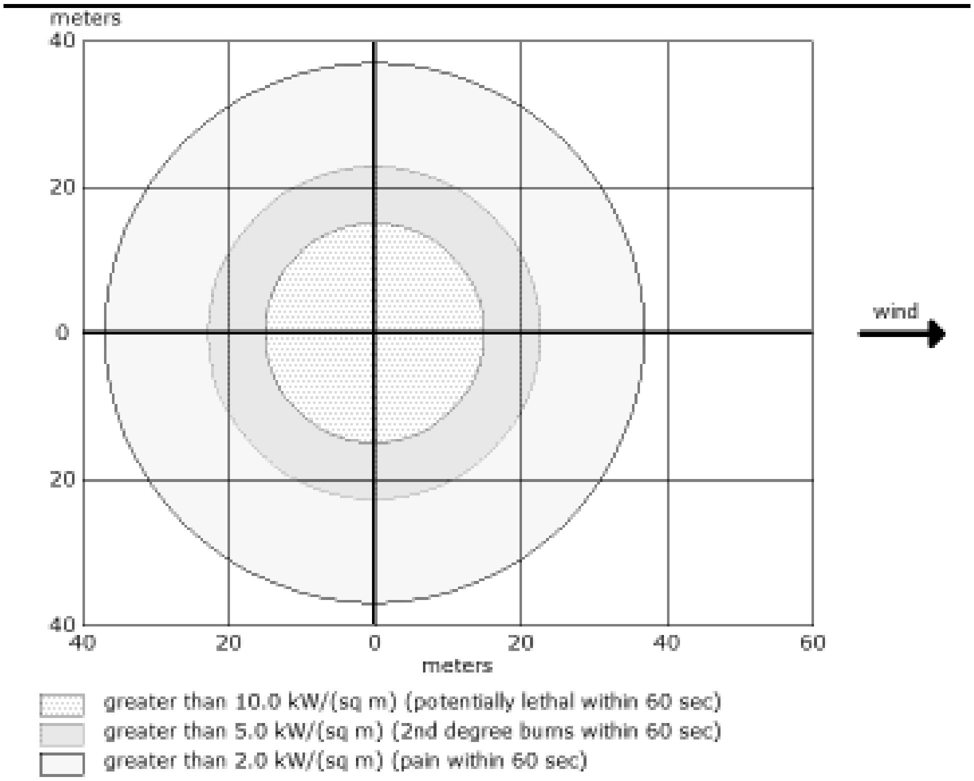
Yellow: 12 meters --- (2.0 kW/ (sq. m) = pain within 60 sec)

The worst hazard for release and ignition of crude oil from tanker loading hose leak (5mm dia) will be experienced to a maximum radial distance of <10m from the source with potential lethal effects within 1 minute.

Scenario A.3: Road Tanker Loading Hose Rupture

The pool fire threat zone plot for release and ignition of crude oil from tanker loading hose rupture is represented in ***Figure 1.19*** below.

Figure 1.19 Threat Zone Plot – Road Tanker Loading Hose Rupture



Source: ALOHA

THREAT ZONE:

Threat Modeled: Thermal radiation from pool fire

Red : 15 meters --- (10.0 kW/ (sq. m) = potentially lethal within 60 sec)

Orange: 23 meters --- (5.0 kW/ (sq. m) = 2nd degree burns within 60 sec)

Yellow: 37 meters --- (2.0 kW/ (sq. m) = pain within 60 sec)

The worst hazard for release and ignition of crude oil from tanker loading hose rupture will be experienced to a maximum radial distance of 15m from the source with potential lethal effects within 1 minute.

The risk significance for the potential worst case scenario resulting from road tanker loading hose rupture has been presented below. For calculating the risk significance, the likelihood ranking is considered to be "1" as the frequency analysis for rupture is computed at "*4 X 10^{-6}*" whereas the consequence ranking has been identified to be as "3" as the potential lethal zone is likely to be limited within a distance of 15m. (For criteria ranking please refer to ***Table 1.1*** and ***Table 1.2***).

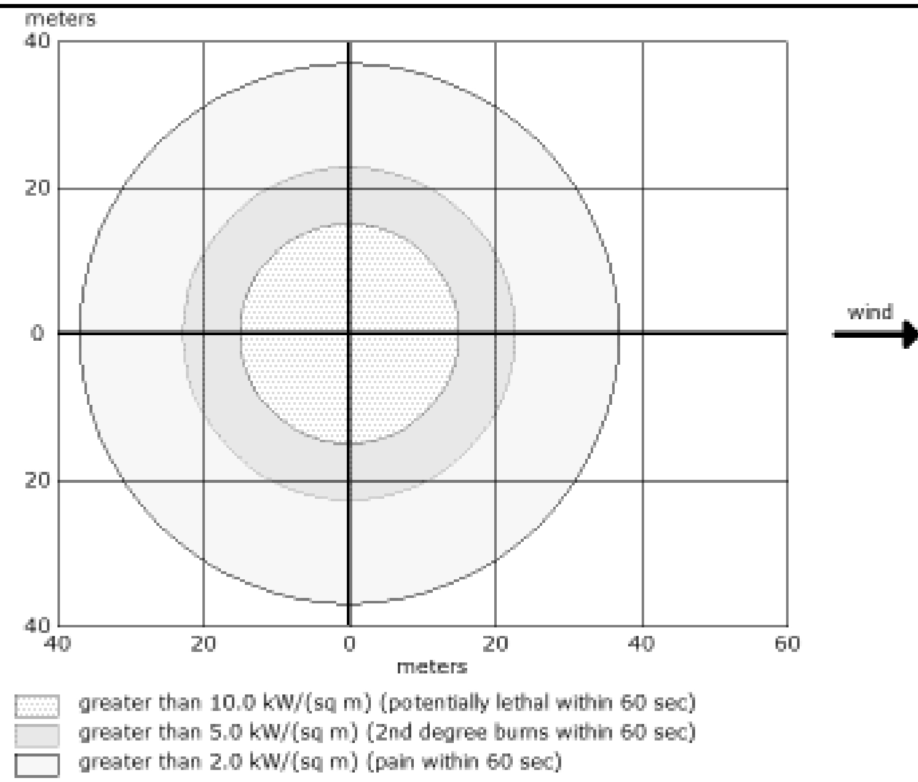
Risk Ranking – Road Tanker Hose Rupture (Worst Case Scenario)

Likelihood ranking	**1**	**Consequence ranking**	**3**
Risk Ranking & Significance = 3 i.e. "Very Low" i.e. Risk is Acceptable and can be managed through use of existing controls.			

Scenario B.1: Road Tanker Leak (50mm dia)

The pool fire threat zone plot for release and ignition of crude oil from road tanker leak (50mm dia) is represented in ***Figure 1.20*** below.

Figure 1.20 Threat Zone Plot – Road Tanker Leak (50mm dia)



Source: ALOHA

THREAT ZONE:

Threat Modeled: Thermal radiation from pool fire

Red : 12 meters --- (10.0 kW/ (sq. m) = potentially lethal within 60 sec)

Orange: 17 meters --- (5.0 kW/ (sq. m) = 2nd degree burns within 60 sec)

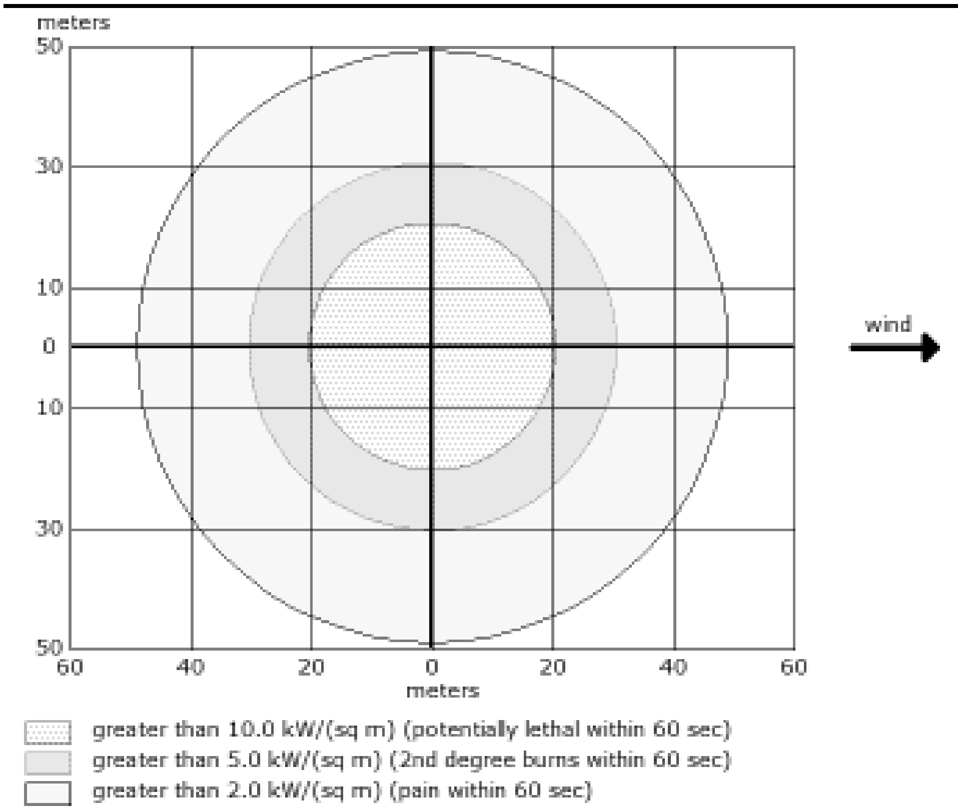
Yellow: 27 meters --- (2.0 kW/ (sq. m) = pain within 60 sec)

The worst hazard for release and ignition of crude oil from road tanker leak (50mm dia) will be experienced to a maximum radial distance of 12m from the source with potential lethal effects within 1 minute.

Scenario B.2: Road Tanker Leak (100mm dia)

The pool fire threat zone plot for release and ignition of crude oil from road tanker leak (100mm dia) is represented in ***Figure 1.21*** below.

Figure 1.21 Threat Zone Plot – Road Tanker Leak (100mm dia)



Source: ALOHA

THREAT ZONE:

Threat Modeled: Thermal radiation from pool fire

Red : 20 meters --- (10.0 kW/ (sq. m) = potentially lethal within 60 sec)

Orange: 30 meters --- (5.0 kW/ (sq. m) = 2nd degree burns within 60 sec)

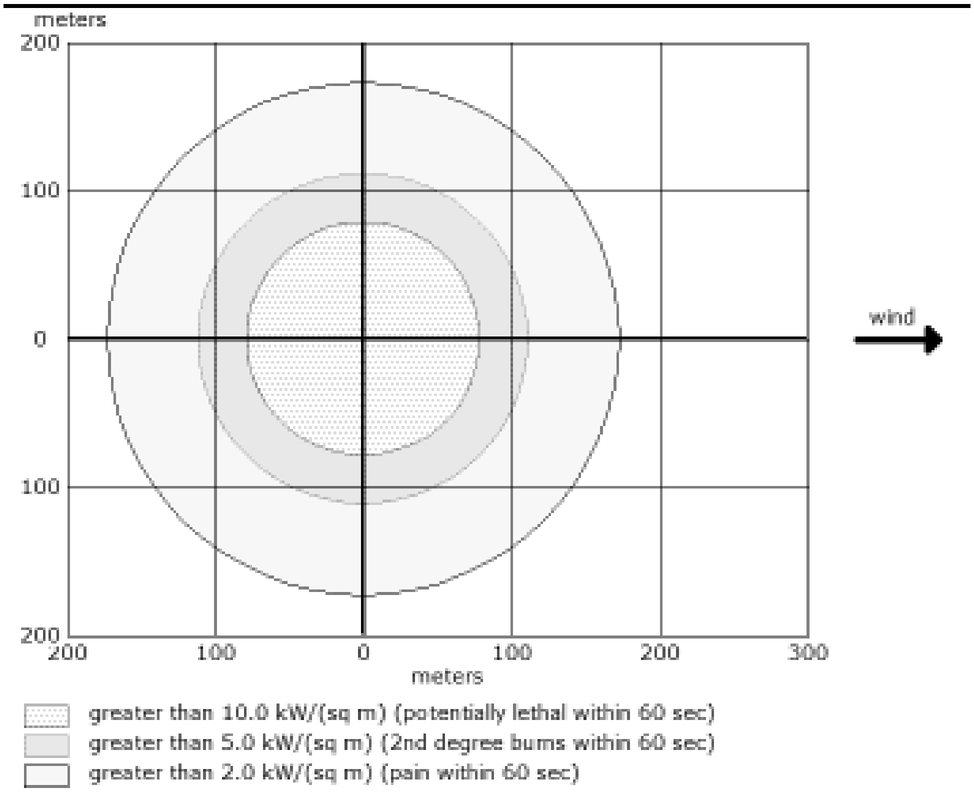
Yellow: 49 meters --- (2.0 kW/ (sq. m) = pain within 60 sec)

The worst hazard for release and ignition of crude oil from road tanker leak (100mm dia) will be experienced to a maximum radial distance of 20m from the source with potential lethal effects within 1 minute.

Scenario B.3: Road Tanker Catastrophic Failure

The pool fire threat zone plot for release and ignition of crude oil from catastrophic failure of road tanker is represented in ***Figure 1.22*** below.

Figure 1.22 Threat Zone Plot – Road Tanker Catastrophic Failure



Source: ALOHA

THREAT ZONE:

Threat Modeled: Thermal radiation from pool fire

Red : 79 meters --- (10.0 kW/ (sq. m) = potentially lethal within 60 sec)

Orange: 112 meters --- (5.0 kW/ (sq. m) = 2nd degree burns within 60 sec)

Yellow: 173 meters --- (2.0 kW/ (sq. m) = pain within 60 sec)

The worst hazard for release and ignition of crude oil from road tanker catastrophic failure will be experienced to a maximum radial distance of 79m from the source with potential lethal effects within 1 minute.

The risk significance for the potential worst case scenario resulting from road tanker accident/incident has been presented below. For calculating the risk significance, the likelihood ranking is considered to be "2" as the frequency analysis for rupture is computed at "*$1.5 X 10^{-5}$*" whereas the consequence ranking has been identified to be as "*5*" as the potential fatal zone is likely to span over a radial distance of 78m. (For criteria ranking please refer to ***Table 1.1*** and ***Table 1.2***).

Risk Ranking – Road Tanker Catastrophic Failure (Worst Case Scenario)

Likelihood ranking	**2**	**Consequence ranking**	**5**
Risk Ranking & Significance = 10 i.e. "Medium" i.e. Risk is Tolerable and can be managed through adoption of necessary controls.			

E) <u>Hazardous Material Releases or Mishaps</u>

Release of following materials are not considered as major accidents and therefore are not quantified in terms of frequency, consequence and the resulting risk.

- Diesel fuel;
- Lubricants;
- Mud Chemicals;
- Explosives.

Exposure to such hazards would be **occupational** rather than **major** hazards.

F) <u>External Hazards</u>

External hazards which may impair the safety of the rig include the following:
- Severe weather conditions;
- Earthquake or ground movement; and
- Security breaches.

Extreme weather conditions are primarily lightening, cyclones and high winds and heavy rains. They may result in injury (through slips trips of personnel) or equipment damage. Cyclones and high winds may damage the rig structure. There are potential hazards to workers from direct impact of the structure i.e. falling equipment and any subsequent hydrocarbon releases caused by equipment damage. However, no fatalities are expected from such conditions i.e. the risk to workers is low, providing:

- Reliable weather forecasts are available;
- Work or rig move is suspended if conditions become too severe;
- Design and operational limits of the rig structure are known and not exceeded.

The risk of external hazards causing blowouts has been considered in the frequency estimation of oil and gas blowouts in the earlier sections.

Individual Risk

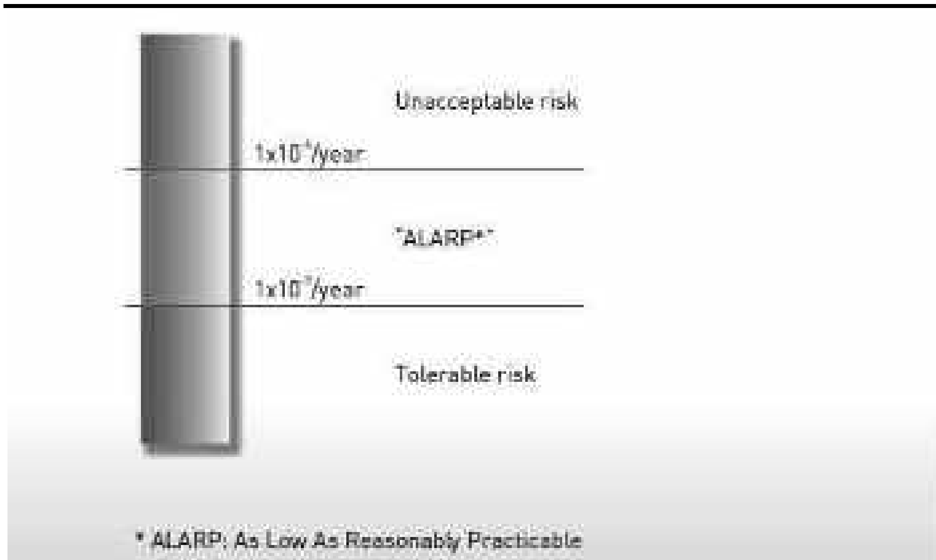
Individual risk is the probability at which an individual may be expected to sustain a given level of harm from the realization of specified hazards. In simple terms it is a measure to assess the overall risk of the area concerned thus to protect each individual against hazards involving hazardous chemicals, irrespective of the size of the accident that may occur. Graphically it represents as iso-risk contour which connects all of the geographical locations around a hazardous activity with the same probability of fatality. In order to generate different level of iso-risk curves for the area concerned, it is required to estimate the respective contribution of each reference scenario. Accordingly, individual risk of each scenario was estimated by combining the frequency of the initiating event, the conditional probability of that scenario sequence and the Probit value of the effect footprints. In particular following expression was used to estimate the Individual Risk (IR) at a given geographical location for each reference scenario:

$$IR(x, y, i) = fi.PFi \ldots\ldots\ldots \text{(Eq. iv)}$$

where:
- fi is the frequency of the accident scenario i (year-1); calculated as multiplicative factor of the frequency of the initiating event and the probability that the sequence of events leading to the accident scenario i will occur: fi = fincident i . Psequence i
- PFi is the probability of fatality that the accident scenario i will result at location (i.e. Probit).

The individual risk so obtained is then compared with the Tolerance Criteria of Individual Risk as provided in the ***Figure 1.23*** below.

Figure 1.23 Tolerance Criteria for Individual Risks



Hence for the proposed project the individual risk has been considered for both blow outs and gas releases and ignition during well drilling and from oil & gas pipeline failure. Based on the above equation the individual risk as calculated including the tolerance criteria has been presented in the ***Table 1.24*** below.

Table 1.24 Individual Risk – Blow Out & Loss of Containment

Accident Scenarion-Frequency	Fatality Probability	Individual Risk	Individual Risk Criterion
A. Blow Outs			
0.50×10^{-4}	0.01	5.00×10^{-5}	Tolerable
0.55×10^{-4}	0.01	5.50×10^{-5}	Tolerable
1.17×10^{-5}	0.01	1.17×10^{-7}	Tolerable
0.97×10^{-5}	0.01	9.70×10^{-6}	Tolerable
B. Oil/Gas Pipeline Failure			
2.43×10^{-4}	0.01	2.43×10^{-6}	Tolerable
1.05×10^{-5}	0.01	1.05×10^{-7}	Tolerable

The individual risk criterion for blow outs and well releases leading to 1% fatality probability has been identified to be within ALARP limits. However still necessary control measures in the form of design interventions, use of well control equipment's etc. will be adopted by Cairn (Oil & Gas) to minimise the risk further.

1.2 RISK ASSESSMENT FOR OFFSHORE ACTIVITY

Objectives and Scope

This study is conducted as a representative case for one RF Platform, which is an offshore platform located almost in the central area of the PKGM-1 Block. Other existing platforms are assumed to be similar to the RF Platform and hence the risk associated with them is expected to be similar in line with the risks associated with the RF Platform.

The scope of the risk assessment Study included evaluation of the risks to personnel working on the RF Platform during normal operations. As stated earlier other existing platforms are assumed to be similar to the RF Platform and hence the risk associated with them is expected to be similar lines.The analysis carried out was limited to estimation of personnel risks associated with travel to/from and their presence on the Platform.

Assumptions

The risk analysis has been based on combination of data. Some of the data are derived from the operational data of the already existing RF & other existing Platforms. In some cases where specific data has not been available or is not practicable to obtain, industry-wide data has been used; primarily from the North Sea (examples of this include transport, system leak / fire frequencies, etc.) in the absence of data for the Indian continental shelf. Where this has been the case, the data has been assessed for its applicability and, if necessary, modification factors were applied using engineering judgement and ERM's experience of the offshore risk analysis. The remainder of this section has been structured as follows:

- Facilities Description
- Methodology of the QRA Study

- Hazards identified in this study
- The study inputs
- Consequence analysis
- Results of the QRA Study
- Conclusions
- *Annex 2* presents Ship Collisions Risk Assessment
- *Annex 3* presents Transport & Occupational Risks
- *Annex 4* presents Dropped Object Hazards and Risk Assessment

Facility Description

a) Topside Process Facilities

A wellhead platform typically consist of the following process facilities as a minimum:

- Well flow arm;
- Production header & Test header (Gas & Oil);
- Multi-Phase Flow Meter (Gas & Oil);
- Instrument/Utility gas system;
- Pneumatic based well shutdown panel inclusive of safety shutdown system;
- Safety & relief system;
- Fire & gas detection system;
- Chemical injection system;
- Crude/ condensate transfer system;
- Vent and drain system;
- Lift gas system;
- Launchers / Receivers; and
- Fresh Water System.

b) Oil/Gas Production Manifold, Test Header, Lift Gas Manifold

The production manifold (Oil) is designed for hook-up of wells (both existing and proposed). The production manifold has a production header for gathering of well fluid and a test header for testing individual wells. The production and test header are inter-connected for processing of well fluid and testing of individual wells, respectively.

The production manifold (Gas) is designed for hook-up of wells (both existing and proposed). The production manifold has a production header for gathering of well fluid and a test header for testing individual wells. The production and test header is inter-connected for processing of well fluid and testing of individual wells, respectively. The lift gas manifold is designed for hook-up of wells (both existing and proposed). The individual lift gas flow arms can also be hooked-up with vent header for manual depressurizing whenever required.

c) Well Testing Facilities

Well testing facility consist of – Multi Phase Flow Meter (MPFM) along with associated instrumentation, for measurement of oil, water and gas flow rate, for the flow arm string capacity additionally 25% surge factor on well fluid flow and 15% swell factor on oil flow. MPFM functions for wells testing purposes.

d) Instrument/Utility Gas System

The instrument/utility gas system is designed for 180 Nm^3/hour of instrument/utility gas requirement as minimum. The instrument/utility gas is generated by following three various sources:

1. Lift gas;
2. Non-associated gas from gas manifold; and
3. Associated gas from Oil manifold.

Among the above, lift gas source is the primary source for instrument/ utility gas system. Instrument/utility gas system consists of lift gas heater (will be in line when lift gas is a primary source for instrument/utility gas system), pressure reduction, instrument gas drum along with associated piping, instrumentation and safety items.

d1) Inlet Gas Condition

Lift Gas

- Pressure, psig : 1737
- Temperature, ºC : 19

Associated Gas (Oil manifold)

- Pressure, psig : 217-287
- Temperature °C : 90

Associated Gas (Gas manifold)

- Pressure, psig : 624-839
- Temperature °C : 90

The instrument/utility gas system consists of the following equipment:

e) Lift Gas Heater

Lift gas heater is designed to preheat the lift gas from 19 ºC to 60 ºC by well fluid as heating source. Lift gas heater will be in line when lift gas is a primary source for instrument/utility gas system.

Shell side

- Fluid : Well fluid from Oil Manifold
- Operative pressure : 217 psig (min), 287 psig (max)
- Operative temperature : 90 °C (inlet)

Tube side

- Fluid : Lift gas
- Operative pressure : 1737 psig
- Operative temperature : 19 °C (inlet), 60 °C (outlet)

f) Instrument Gas Drum

Platform instrument/utility gas requirement is supplied by instrument gas drum at the platform. Typical details are as follows:

- Number : One
- Capacity : 0.44 m^3 (508 mm ID X 1981mm S/S)
- Pressure, kg/cm^2g : 10.68/ 7.7 / 14.06 (Max/ Min. / Design)
- Temperature, ºC : 16

Instrument Gas Drum is provided with automatic drain system through Level Control Valve to automatically remove the liquid, generated if any.

g) Drain system

Platform drain system shall consist of:

- Open deck drain to collect storm water and subsequent routing to Overboard;
- Open hydrocarbon drain to collect platform hydrocarbon maintenance drains and skid drains. Open hydrocarbon drains shall be routed to closed drain drum for onward transfer; and
- Closed hydrocarbon drain to collect all continuous and intermittent operational drains.

The closed drain system consists of a closed drain drum with associated piping and instrumentations. Closed drain drum evacuation is done with the help of closed drain transfer pump. Discharge line of the closed drain Transfer Pump is routed to departing well fluid pipeline.

h) Closed Drain Drum

- Purpose : To collect liquid from Closed Drain Header (CDH) and open Hydrocarbon Drain (OHD) Header.
- Hold-Up : 1.5m^3 - with 80% full
- Liquid Disposal : To departing well fluid pipeline
- Mode of Operation : Evacuation to be carried out using closed drain Transfer pump

i) Closed Drain Transfer Pump

- Purpose :To transfer liquid from Closed Drain drum to Oil Departing line.
- Type : Positive displacement pump
- Capacity : 200 LPH @ 400 psig
- Liquid Disposal : To departing well fluid pipeline
- Mode of Operation : Gas driven

j) Chemical injection system

j1) Oil Corrosion Inhibitor System

- Service : OCI injection to each flow arm.
- Mode of injection : Gas driven pump (1Standby + 1Duty).
- Pump capacity : 1.5LPH @ 400 psig
- Dosage rate : 60 ppm (wt) of maximum well fluid flow rate.
- Storage : OCI Storage Tank (One no.)
- Storage capacity : 1 m^3 (15 days @ 60 ppm (wt.) of max flow at each)

j2) Gas Corrosion Inhibitor System

- Service : GCI injection to each flow arm
- Mode of injection : Gas driven pump (1Standby + 1Duty).
- Pump capacity : 3.5LPH @ 900 psig
- Dosage rate : 60 ppm (wt.) of maximum well fluid flow rate.
- Storage : GCI Storage Vessel (One no.)
- Storage capacity : 1.5 m^3 (15 days @ 60 ppm (wt.) of max flow at each)

j3) Oil Scale Inhibitor System

- Service : OSI injection to each flow arm
- Mode of injection : Gas driven pump (1Standby + 1Duty).
- Pump capacity :1.5LPH @ 400 psig
- Dosage rate : 60 ppm (wt.) of maximum well fluid flow rate
- Storage : OSI Storage Vessel (One no.)
- Storage capacity :1 m^3 (15 days@60 ppm (wt.) of maximum flow at each)

All 3 Chemical Storage Tanks shall be given as combined Single Tank with 3 compartments.

k) Launchers/ Receivers

Following launchers / receivers is typically provided on the well platform:

Oil Pipeline Pig Launcher (8" X 12")

- Pipeline size : 8"
- Service : Well fluid to other platform

Gas Pig Launcher (8" X 12")

- Pipeline size : 8"
- Service : NANG to other platform

Lift Gas Pig Receiver (4" X 8")

- Pipeline size : 4"
- Service : Lift gas from other platform

l) Safety and Relief system

Platform Safety Relief System including ESD & FSD is designed as per API-RP-14C. All vents and relief valves is discharged to safety and relief system comprising of Vent knock out drum, flame arrestors, vent boom etc. Further, the vent boom is located at a safe distance and at a safe location from the platform in prevailing downwind direction. The vent connections from wellhead flow arms, production manifold, receivers/ launchers, crude condensate vessel etc. are hooked-up with vent header.

<u>Vent Knock Out Drum</u>

- Purpose : To collect liquid from Vent Header during Emergency/ Continuous relief before being discharge ito atmosphere through vent boom.

- Capacity : 1.02 m^3 (762mm I.D X 1981mm T/T)

- Liquid Disposal : To closed drain drum

- Relief disposal : To atm through flame arrestors and vent boom

The vent boom is so located that any H_2S and HC gas concentration on the platform remains within acceptable limits for personnel safety, under worst operating and environmental conditions.

m) Fire and Gas Detection and Suppression System

Fire and gas detection facilities is provided to ensure safe operation of the platform. The system can be clubbed in Pneumatic based well shut down panel with provision of local and remote monitoring. Pneumatic based system is designed to ensure system integrity and to reduce maintenance.

This includes:-
- Fusible plug loop with necessary ESD and FSD system
- Portable CO_2 and DCP fire extinguisher

n) Fresh Water Systems

Fresh water system is provided to supply the potable water to the Platform.
- Number : One
- Capacity, m^3 : 1 (1m x 1m x 1m)
- Pressure, kg/cm^2g : Atm
- Temperature, ºC : 15-40

o) Platform Crane

Platform Crane shall be provided to handle the materials at platform.
- Number : One
- Capacity : 5 MT Dynamic Load @ 10 m Radius

The holdup capacity of the Diesel Day Tank is provided for 24 Hrs continuous running of platform crane.

p) Diesel Electric Generator

Diesel Electric Generator is provided to fulfill the emergency power requirements.

- Number : One
- Capacity : 35 kW MT Dynamic Load @ 10 m Radius

The holdup capacity of the Diesel Day Tank is provided for 24 hours continuous running of Diesel Electric Generator.

q) Platform Demography

Wellhead Crew for Satellite Platforms: The case is modeled reflecting the normal operation and manning philosophy i.e. 3 people visiting the platform 2 days per week and work there during the day for an average 8 hours.

r) Helicopter Operations

The flying time from Ravva onshore terminal to RF and other wellhead platform is expected to be 10 minutes. On an average one landing en-route has been considered.

The helicopters used to transport personnel to and from the Ravva platforms are expected to be Bell, and the normal passenger level is considered as 7 passengers and 2 pilots. The average flight time to a Ravva field platform is 10 minutes. It is considered that on an average day the wellhead team will visit two platforms.

Methodology

a) Study Inputs

The main stages of QRA study are as follows:

Facilities Definition - This stage involves setting the boundary limits of the study and defining the facilities layouts, its process equipment, hydrocarbon inventories, safety systems and manning levels such that they can be entered into the risk model;

Hazard Identification - Categories of accidents that have the potential to cause fatalities such as hydrocarbon releases, vessel collisions, structural events and transport accidents were identified;

Development of Accident Scenarios – The accident scenarios for the hydrocarbon events and potential scenarios that could lead to loss of containment. Additional scenarios that could lead to fatalities associated with the non-hydrocarbon hazards were also assessed;

Frequency Analysis and Consequence Modeling - The initial frequency analysis and consequence modeling of the hydrocarbon release scenarios were conducted. The results were then used as inputs to the risk model;

Risk Integration - The ultimate frequencies and consequences of the various outcomes of the numerous accident scenarios associated with the platform were integrated at this stage to determine the risk results, i.e. Individual Risk Per Annum (IRPA) and Potential Loss of Life (PLL). Note that risk integration of the offshore Platform with the LQ at S.Yanam to determine the overall risk results for comparison with the acceptance criteria is excluded in this study;

Risk Reduction Measures (RRM) - Based on the QRA findings, additional RRM if required will be proposed for further reducing the risk, as an approach in fulfilling As Low as Reasonably Practicable (ALARP) principle in the design of the facilities.

b) Personnel Risk Measures

b1) Overview

The following personnel risk parameters were considered in the QRA Study:

- Location Specific Individual Risk (LSIR);
- Individual Risk Per Annum (IRPA); and
- Potential Loss of Life (PLL) per year.

b2) Fatality Phrases

In general, fatalities resulting from the various accident scenarios may be categorized as follows:

- Immediate fatalities which occur in the local area as an immediate result of the hazardous event;
- Escape fatalities of personnel who have survived the immediate effects of the accident but who are not able to reach a means of evacuation; and
- Evacuation fatalities which occur during emergency evacuation of personnel from the platform

b3) Location Specific Individual Risk (LSIR)

Location Specific Individual Risk (LSIR) indicates the risk at a particular location. It is the fatality risk for a hypothetical individual who remains at that particular location 24 hours per day for 365 days per year. It should be noted that the LSIR is independent of the manning level. No criterion is set for acceptability of LSIR, but rather it is used to compare risk levels in different areas of the facility.

b4) Individual Risk Per Annum (IRPA)

Individual risk is the combined risk to a single person, as a result of exposure to all identified hazards. Individual risk is normally calculated as the frequency of fatality per year. Individual risk is the risk to which an individual worker is exposed taking into account their movement around the facilities and the time spent offshore.

b5) Potential Loss of Life (PLL)

The Potential Loss of Life (PLL) is defined as the average annual number of fatalities expected amongst personnel arising from their work on the platform (and their travel to and from the platform).

The risk analysis process estimates the frequency (F) and fatality level (N) associated with each outcome from each initiating event. Therefore for each outcome, there is an F-N pair, where F is a frequency of occurrence per year and N is the predicted number of fatalities. The PLL can thus be calculated as follows:

PLL = F1N1 + F2N2 + F3N3 = ΣFnNn

The number of fatalities is then the product of the number of personnel in a given area and the probability of fatality given their presence in that area at the time of the initiating event.

c) Risk Acceptance Criteria

Due to the unavailability of the Company's Individual Risk Criteria, the generic UK Health and Safety Executive criteria of an average individual risk on offshore installations was proposed to be adopted for this Project:

- Maximum tolerable for installations in general - **1 x 10^{-3} per year**; and
- Broadly acceptable for any installation - **1 x 10^{-6} per year**.

Within the two limits, acceptance criterion is based on ALARP.

Hazard Identification

a) Overview

The following hazards were assessed in this study:

- Topside Hydrocarbon Releases;
- Riser and Pipeline Releases;
- Blowouts;
- Vessel Collisions;
- Transportation Accidents;
- Occupational Accidents;
- Structural Events; and
- Dropped Objects.

b) Topside Hydrocarbon releases

The accidental releases of flammable hydrocarbon on the Platform were assessed to have potential to lead to personnel fatalities. Detailed Consequence Analysis for topside process events is presented in subsequent sections.

The probability of an explosion is highly dependent on the gas cloud location and the level of platform congestion. In the case that significant quantities of flammable gas cover areas of congestion on the platform, then significant explosion consequences could be generated on ignition. In the platform, no explosions are expected due to the minimum facility installation where there are relatively low obstructions, hence the potential for explosion events which could generate significant overpressures on the platform was considered unlikely. Further quantification of risk was therefore not carried out.

c) Riskers and Pipeline Releases

Risks experienced by personnel due to failures of the riser/ pipeline sections were assessed in this QRA Study. The consequences for the pipeline and the associated riser are detailed in subsequent sections.

d) Blowouts

A blowout is defined as an uncontrolled release of well fluids from the wellhead. The blowout risk associated with the production phase from oil wells and gas wells during normal operations was assessed.

e) Vessel Collisions

The risks experienced by personnel due to collisions from in-field vessels were assessed. The facilities are located adjacent to the merchant shipping lanes and shipping routes. The platform is also visited by supply vessels. Details of the personnel risk calculations due to collision from in-field vessels are provided in ***Appendix 7.1 Ship Collision Risk Assessment.***

f) Transport Accidents

Personnel working on the Platforms are transferred from and to the platform via helicopter. The helicopter journey is approximately 10 minutes. The transportation risk associated with personnel travelling by helicopter to the Platforms was assessed and detailed in the ***Annex 3: Transport & Occupational Risk Assessment.***

g) Occupational Accidents

Occupational accidents are defined as those that do not have the potential to cause fatalities outside the immediate area of the incident. In the majority of such accidents no more than a single fatality is expected to occur. These accidents include a wide variety of events such as falls, falling overboard, mechanical impacts, etc. The occupational accident risks were quantified and the details are presented in ***Annex 3: Transport & Occupational Risk Assessment.***

h) Structural Events

The main cause of structural failures is extreme weather conditions. As the visit to the wellhead platform is restricted during severe weather conditions, the risk to personnel from structural failures is considered to be negligible and therefore not assessed further.

A review of the structural design criteria document (PRJ-RI-473100) that covered proposal for new platform and modification works in existing pltforms indicated factors of safety considered as design criteria as stated in ***Table 1.25.***

Table 1.25 Factors of Safety Considered for the Structure Design Criteria

SN	Design Condition	Factor of Safety
A	Foundation	
2	Pile penetration - extreme storm	1.5
3	Pile penetration - operating storm	2.0
4	On-bottom stability - still water *	2.0
5	On-bottom stability - still water with wave *	1.5
B	Tubular member hydrostatic collapse	
1	Extreme storm	1.5
2	Operation storm	2.0
3	Earthquake	1.2
4	Installation - jacket lowering to seabed	2.0
5	Installation - jacket laying on-bottom (accidental complete submergence)	1.5
6	Buoyancy tanks	2.0

Source: Design Doc: PRJ-RI-473100, Cairn (Oil & Ga); Note * =Factor of safety against sliding, overturning, and bearing capacity.

i) Dropped Objects

There is a potential dropping of load on the topsides leading to equipment damage. The dropped object risks were quantified and the details are presented in ***Annex 4: Dropped object Hazards & Risk Assessment.***

Study Inputs

a) Hydrocarbon Fluid Properties

The fluid properties for different streams are summarised in ***Table 1.26.***

Table 1.26 Fluid properties for different streams

S.N.	Equipment / Sections	Pressure (psig)	Temperature(◦C)
1	Oil Well Fluid	287	90
2	Gas Well Fluid	839	90
3	Oil Production Manifold / Test Manifold	287	90
4	Gas Production Manifold / Test Manifold	839	90

S.N.	Equipment / Sections	Pressure (psig)	Temperature(◦C)
5	Oil Pipeline Pig Launcher	287	90
6	Gas Pipeline Pig Launcher	839	90
7	Lift Gas Manifold	1565	19
8	Lift Gas Heater Outlet	1565	60
9	Utility / Instrument Gas Supply	137	16
10	Instrument Gas Drum	137	16
11	CCD Pump Discharge	290	16

b) Isolatable Sections & Inventories

Isolation between sections is achieved by the ESD valves or non-return valves successfully operating on emergency shutdown.

The size of the inventories in terms of mass of hydrocarbon has been taken from an analysis of volumes in each inventory. ***Table 1.27*** presents a summary of the different isolatable sections, and section inventories.

Table 1.27 Isolatable Sections & Inventories

S. N.	Equipment / Section Name	Type	Mass Density Gas Phase (kg/m3)	Inventory of Gas Phase (kg)	Mass Density Liquid Phase (kg/m3)	Inventory of Liquid Phase (kg)
1	Christmas Tree Upstream of Choke Valve – Oil Well	L200m-D100mm Pipeline	40	53	788	198
2	Oil Production Manifold up to Oil Pipeline Pig Launcher SDV	L20m-D150mm Pipeline L40m - D200mm Pipeline	40	54	788	203
3	Oil Test Manifold	L50m - D150mm Pipeline	40	30	788	112
4	Oil Export Pipeline to RB - Downstream of Launcher	L2.1Km - D200mm Pipeline	50.44	1742	788	24777
5	Christmas Tree Upstream of Choke Valve – Gas Well	L200m - D100mm Pipeline	47.47	144	788	91
6	Gas Production Manifold up to Gas Pipeline Pig launcher SDV	L20m - D150mm Pipeline L40m - D200mm Pipeline	47.47	74	788	47
7	Gas Test Manifold	L50m - D150mm Pipeline	47.47	40	788	26
8	Utility / Instrument Gas Drum	L2m - D500mm Vessel L10m - D50mm Pipeline	8.6	4	788	0
9	Closed Drain Drum	L2.1m - D975mm Vessel	8.6	13	788	62
10	Closed Drain Transfer Pump	L20m - D50mm Pipeline	40	0	788	31

S. N.	Equipment / Section Name	Type	Mass Density Gas Phase (kg/m3)	Inventory of Gas Phase (kg)	Mass Density Liquid Phase (kg/m3)	Inventory of Liquid Phase (kg)
11	Gas Export Pipeline to RG - Downstream of Launcher	L3.9Km - D200mm Pipeline	44.61	5317	788	2626
12	Lift Gas Pipeline from RB to Lift Gas Receiver SDV	L2.2Km - D100mm Pipeline	117.35	2028	788	0
13	Lift Gas Manifold from Pig Receiver SDV to well SDV & up to inlet of Lift Gas Heater	L30m - D100mm Pipeline	117.35	39	788	0
		L50m - D50mm Pipeline				
14	Lift gas heater outlet up to Instrument gas drum inlet PCV	L30m - D100mm Pipeline	8.6	2	788	0

c) Meteorological – Weather Data

This is used to define the wind speed distribution for use in smoke modelling. The wind rose used in the analysis is shown in ***Table 1.28.***

Table 1.28 Meteorological data

Wind	Wind Blowing Toward Direction								
Speed	N	NE	E	SE	S	SW	W	NW	TOTAL
1.0 m/s	0.05	0.07	0.05	0.04	0.04	0.09	0.18	0.12	0.64
3.0 m/s	0	0	0.02	0.02	0.01	0.02	0.01	0	0.08
5.0 m/s	0	0.03	0.04	0.01	0	0.07	0.09	0.01	0.25
9.0 m/s	0	0.01	0	0	0	0.01	0.01	0	0.03
Total									1

d) Population Distribution & Helicopter Operation

d1) Population Distribution

Wellhead Crew for wellhead Platforms (RA to RF): The case is modelled reflecting the normal operation and manning philosophy i.e. 3 people visiting a platform 2 days per week and work there during the day for an average 8 hours.

d2) Population Distribution

Table 1.29 Manning Distribution & Helicopter Operation at the Platform

Platform	Average number of crew visit to wellhead	Average Number of visit to wellhead per week	Average intermediate landings	Average Travel time from Ravva Terminal to the platform	Average duration of stay on wellhead per visit
	Nos	Nos	Nos.	Minutes	Hours
RF	3	2	0	10	8

The flying time from Ravva onshore terminal to a wellhead platform (RA to RF) is expected to be in the region of 10 minutes. On an average one landing en-route has been considered.

The helicopters used to transport personnel to and from the Ravva platforms are expected to be Bell, and the normal passenger level is considered as 7 passengers and 2 pilots. The average flight time to a Ravva field platform is 10 minutes. It is considered that on an average day the wellhead team will visit two platforms.

e) Allocation of Failure Frequencies

e1) Process Release Frequencies

Process release frequencies are taken from Hydrocarbon Release (HCR) database. The sample failure frequencies are indicated in ***Table 1.30***.

Table 1.30 Process Release Frequencies- Extract from HCR Database

Equipment	Minor Leak		Medium Leak		Major Leak	FB Rupture	Total
	5mm	12.5mm	25 mm	50 mm	100 mm	>100 mm	
Process Pipe < 3"	1.90E-04	2.13E-05	8.26E-06	8.66E-07	1.73E-06		2.2 E-4
Process Pipe 3"-11"	5.10E-05	8.37E-06	1.83E-06	1.05E-06	5.20E-07	3.92E-06	6.7 E-5
Process pipe >11"	4.97E-05	1.01E-05	9.22E-07			5.52E-06	6.6 E-5
Flanges < 3"	2.83E-05	2.73E-06	2.10E-06	4.18E-07	2.11E-07	2.11E-07	3.4 E-5
Flanges 3"-11"	4.83E-05	2.36E-06	1.69E-06	3.38E-07	3.38E-07	2.36E-06	5.5 E-5
Flanges >11"	7.83E-05	2.24E-06		2.24E-06		6.71E-06	8.9 E-5
ESD Valves < 3" ESD	1.47E-04	2.94E-05			2.94E-05		2.1 E-4
Valves 3'-11" ESD	4.28E-04	2.14E-05					4.5 E-4
Valves >11" Control	7.99E-04						8.0 E-4
Valves < 3" Control	1.40E-03	6.98E-05	6.98E-05	2.32E-05			1.6 E-3
Valves 3'-11" Control	8.92E-04	2.55E-05	7.65E-05			5.10E-05	1.0 E-3
Valves >11" Relief	1.60E-03						1.6 E-3
Valves < 3" Relief	6.38E-04	1.51E-04					7.9 E-4
Valves 3'-11" Relief	8.71E-04	1.31E-04	4.36E-05			4.36E-05	1.1 E-3
Valves >11" Manual							
Valves < 3" Manual	1.56E-04			1.56E-05			1.7 E-4
Valves 3'-11" Manual	3.29E-05		1.64E-05	1.64E-05		3.29E-05	9.9 E-5
Valves >11"	5.85E-04		2.34E-04				8.2 E-4
Small Bore Fittings	4.22E-03	5.89E-04	3.86E-05	1.56E-05	7.81E-06	7.81E-06	4.9 E-3
Heat Exchanger HC in Shell	4.15E-03	4.88E-04	2.44E-04				4.9 E-3
Heat Exchanger HC in Tube	2.81E-03	5.36E-04				1.34E-04	3.5 E-3
Centrifugal Compressor	1.01E-02	2.12E-03	2.65E-04				1.2 E-2
Reciprocating Compressor	7.69E-02	8.01E-03	1.60E-03	1.60E-03			8.8 E-2
Centrifugal Pump Single Seal	8.49E-03	9.90E-04	1.41E-04				9.6 E-3
Centrifugal Pump Double Seal	6.86E-03	6.67E-04					7.5 E-3
Storage Tank	2.42E-03	2.42E-03	7.76E-04	2.91E-04		2.91E-04	6.2 E-3

Equipment	Minor Leak		Medium Leak		Major Leak	FB Rupture	Total
	5mm	12.5mm	25 mm	50 mm	100 mm	>100 mm	
Separator - Vertical	1.10E-03						1.1 E-3
Separator - Horizontal	8.83E-04	8.83E-04	1.47E-04	2.94E-04	1.47E-04		2.4 E-3
KOD - Vertical	1.08E-03	1.08E-03		7.17E-04			2.9 E-3
KOD - Horizontal	4.38E-03	4.56E-03		4.38E-03	2.19E-03		1.5 E-2
Scrubber - Vertical	8.40E-04	4.20E-04					1.3 E-3
Scrubber - Horizontal							
Metering - Oil	2.85E-02	5.34E-03	5.92E-04	5.92E-04	1.19E-03	5.92E-04	3.7 E-2
Metering - Gas	2.54E-02	2.80E-03	3.51E-04				2.9 E-2
Metering - Condensate	2.89E-02	3.77E-03					3.3 E-2
Xmas Tree P<=5000psi	3.23E-03	3.80E-04	4.77E-05			9.50E-05	3.8 E-3

f) Risers & Pipelines Leak frequencies:

OGP March 2010 database provides frequencies for risers and pipelines releases. Risers are considered to comprise three sections:

- Above water (often taken to be the topside section below riser ESDV/NRV as applicable);
- Splash Zone (exposed to aggressive corrosion conditions and ship collisions); and
- Below water (to the flange connection with the pipeline or a spool piece)

The frequencies given are based on analysis for pipelines conveying hydrocarbons. There is an implicit assumption that the pipelines are built to a recognised international standard such as ANSI/ASME B31.4/8 or for subsea pipelines DNV-OS-F101. An extract from OGP -2010 is provided in the ***Table 1.31, Table 1.32 & Table 1.33.***

Table 1.31 Riser & Pipeline Frequencies

Pipeline	Category	Failure Frequency	Unit
Subsea pipeline: in open sea	Well stream pipeline and other	5.0×10^{-4}	per km-yr^{-1}
	Small pipelines containing unprocessed fluid		
	Processed oil or gas, pipeline diameter ≤ 24 inch	5.1×10^{-5}	per km- yr^{-1}
	Processed oil or gas, pipeline diameter > 24 inch	1.4×10^{-5}	per km- yr^{-1}
Subsea pipeline: external loads causing damage in safety zone	Diameter ≤ 16 inch	7.9×10^{-4}	per year
	Diameter > 16 inch	1.9×10^{-4}	per year
Flexible pipelines: subsea	All	2.3×10^{-3}	per km- yr^{-1}
Risers	Steel - diameter ≤ 16 inch	9.1×10^{-4}	per year
	Steel – diameter > 16 inch	1.2×10^{-4}	per year
	Flexible	6.0×10^{-3}	per year
Oil pipelines onshore	Diameter < 8 inch	1.0×10^{-3}	per km- yr^{-1}
	8 inch ≤ diameter ≤ 14 inch	8.0×10^{-4}	per km- yr^{-1}
	16 inch ≤ diameter ≤ 22 inch	1.2×10^{-4}	per km- yr^{-1}
	24 inch ≤ diameter ≤ 28 inch	2.5×10^{-4}	per km- yr^{-1}

Pipeline	Category	Failure Frequency	Unit
	Diameter > 28 inch	2.5×10^{-4}	per km- yr^{-1}
Gas pipelines onshore	Wall thickness ≤ 5 mm	4.0×10^{-4}	per km- yr^{-1}
	5 mm < wall thickness ≤ 10 mm	1.7×10^{-4}	per km- yr^{-1}
	10 mm < wall thickness ≤ 15 mm	8.1×10^{-5}	per km- yr^{-1}
	Wall thickness > 15 mm	4.1×10^{-5}	per km- yr^{-1}

Table 1.32 Hole Size distribution for Risers & Pipelines

Hole size	Subsea pipeline	Onshore Pipeline		Riser
		Gas	Oil	
Small (< 20 mm)	74%	50%	23%	60%
Medium (20 to 80 mm)	16%	18%	33%	15%
Large (> 80 mm)	2%	18%	15%	-
Full rupture	8%	14%	29%	25%

Table 1.33 Release Location Distribution for Risers

Riser Location	Distribution
Above water	20%
Splash zone	50%
Subsea	30%

The calculated Riser frequencies for different hole-sizes are as per ***Table 1.34.***

Table 1.34 Riser Failure Frequency

Leak Size	Above Water		Splash Zone	
	<=16″ Diameter	>16″ Diameter	<=16″ Diameter	>16″ Diameter
5 mm Leak	1.09E-04	1.44E-05	2.73E-04	3.60E-05
25mm Leak	2.73E-05	3.60E-06	6.83E-05	9.00E-06
100mm Leak	4.55E-05	6.00E-06	1.14E-04	1.50E-05

Blowouts Frequencies

Blowout frequencies are used from OGP Risk assessment Data Directory Report No. 434-2, March 2010. It provides data in two categories. One is for North Sea and in other offshore areas where the equipment is of 'North sea standard'. The second category is for well operations in other areas of world where 'North sea standard' is not used.

North Sea standard operations in OGP database refers to operation performed with BOP installed including shear ram and two barrier principle followed. It is assumed that well operations in Cairn (Oil & Gas) will follow this standard and hence Blow out frequencies indicated for 'North sea standard' are used in present study.

Following definitions are taken from OGP report:

Blowout: An incident where formation fluid flows out of the well or between formation layers after all the predefined technical well barriers or the activation of the same has failed.

Well release: An incident here hydrocarbon flow from the well at some point where flow was not intended and the flow was stopped by use of the barrier system that was available on the well at the time of incident.

Base frequency for blowout and well releases are selected as producing wells (excluding external causes) are as under.

For Oil Wells:

- Well Blowout frequency : 2.60E-06
- Well Release frequency : 2.90E-06

For Gas Wells:

- Well Blowout frequency : 1.80E-05
- Well Release frequency : 2.00E-05

Possible external causes of blowouts include:

- Escalation from process fire or riser fire such as at Piper Alpha;
- Ship collision;
- Structural collapse in severe weather; and
- Military or pirate attacks.

These are not included in the analysis of blowouts if they are separately modelled under the other hazard categories, as is the case in present study. However, for simple studies that do not model such escalations in full, it is appropriate to include them as blowouts.

The calculations for frequencies therefore are as under:

For Oil Well

Blow out: [Blow out frequency from producing well/per year] x No. of producing wells [2.6 x 10-6] x 3 = 7.8 x 10^{-6} per year

Well Release: Same way the well release frequency calculated is [2.9 x 10-6] x 3 = 8.7 x 10-6 per year

For Gas Well

Blow out: [Blow out frequency from producing well/per year] x No. of producing wells [1.8 x 10-5] x 3 = 5.40 x 10^{-5} per year

Well Release: Same way the well release frequency calculated is [2.0 x 10-5] x 3 = 6.0 x 10-5 per year

Consequence Analysis

The Consequence Analysis results for jet fire, pool fire and flash fire are presented as following:

Jet Fire Results

Ignited gaseous hydrocarbon releases have been modelled as jet flames. The flame length is based on the release rate and is calculated using the Shell Chamberlain model. Using the flame length, contours can be determined for different radiation levels using factors derived from the Shell Chamberlain model within DNV's PHAST software package. For this RA, 100% fatalities are assumed if personnel are inside the 37.5kW/m2 radiation contour. The fatality rate for a given area is assumed to be equal to the ratio of the area of the 37.5kW/m2 radiation contour and the floor area of the module.

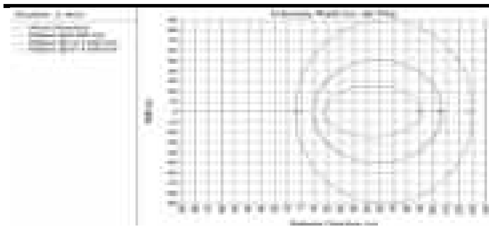
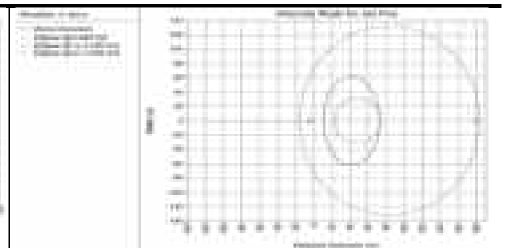
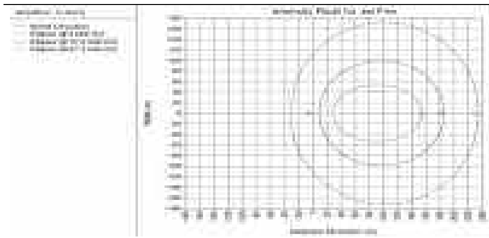
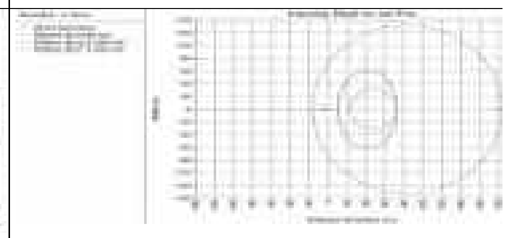
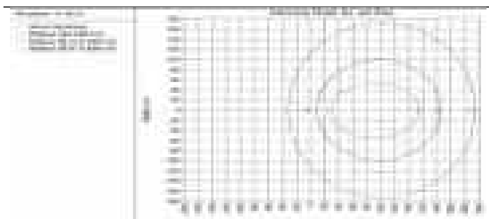
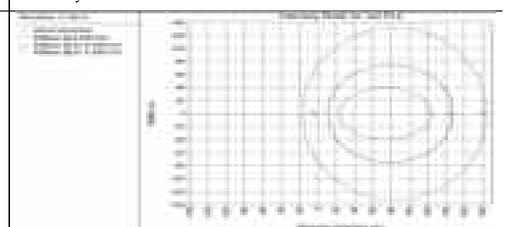
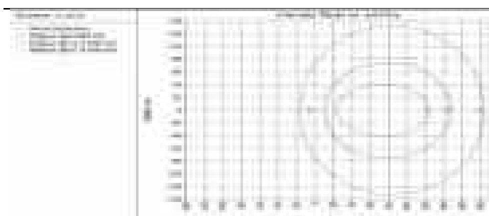
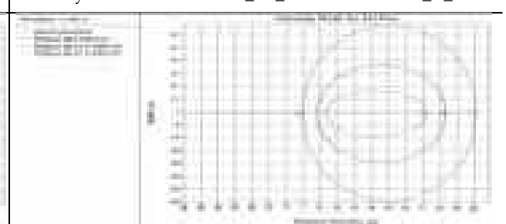
The Jet fire results are presented in the ***Table 1.35.*** The maximum distance of jet fire for 12.5 kW/m2 of heat flux will be at 177.6 m of length and 198.5 m of width while for 4 kW/m2 of heat flux, the maximum distance has been worked out as 267.9 m of length and 344.4 m of width.

Table 1.35 Jet Fire Radiation Results (in meters) for all weather conditions

S N	Leak Size	Event Name	Release Rate (kg/s)	Jet Fire Flame Length	1 m/s F Stability				5 m/s D Stability				9 m/s C Stability			
					12.5 kW /m² length	12.5 kW/m² width	4 kW/m² length	4 kW/m² width	12.5 kW/m² length	12.5 kW/m² width	4 kW/m² length	4 kW/m² width	12.5 kW/m² length	12.5 kW/m² width	4 kW/m² length	4 kW/m² width
1	S	ISO05_PL_L200m-D100 mm _V_S	0.16	5.6	0.0	0.0	4.3	3.6	0.0	0.0	3.8	2.8	0.0	0.0	3.1	1.7
2	M	ISO05_PL_L200m-D100 mm_V_M	4.04	70.1	23.2	22.6	32.8	42.2	24.7	21.9	33.0	41.8	26.1	20.6	33.2	40.6
3	L	ISO05_PL_L200m-D100 mm_V_L	64.67	22.7	90.8	99.7	154.	177.7	93.1	100.7	144.2	178.5	96.8	100.8	134.8	179.5
4	R	ISO05_PL_L200m-D100 mm_V_R	64.67	70.07	90.8	99.7	154.4	177.7	93.1	100.7	144.2	178.5	96.8	100.8	134.8	179.5
5	S	ISO06_PL_L20m-D150mm_V_S	0.16	5.65	0.0	0.0	4.3	3.6	0.0	0.0	3.8	2.8	0.0	0.0	3.1	1.7
6	M	ISO06_PL_L20m-D150 mm_V_M	4.04	70.07	23.2	22.6	32.8	42.2	24.7	21.9	33.0	41.8	26.1	20.6	33.2	40.6
7	L	ISO06_PL_L20m-D150 mm_V_L	64.67	22.71	90.8	99.7	154.4	177.7	93.1	100.7	144.2	178.5	96.8	100.8	134.8	179.5
8	R	ISO06_PL_L20m-D150 mm_V_R	145.50	95.08	134.3	146.3	235.0	259.2	136.0	149.3	219.7	261.3	62.6	123.9	200.9	263.5
9	S	ISO06_PL_L40m-D200 mm_V_S	0.16	5.65	0.0	0.0	4.3	3.6	0.0	0.0	3.8	2.8	0.0	0.0	3.1	1.7
10	M	ISO06_PL_L40m-D200 mm_V_M	4.04	70.07	23.2	22.6	32.8	42.2	24.7	21.9	33.0	41.8	26.1	20.6	33.2	40.6
11	L	ISO06_PL_L40m-D200 mm_V_L	64.67	22.71	90.8	99.7	154.4	177.7	93.1	100.7	144.2	178.5	96.8	100.8	134.8	179.5
12	R	ISO06_PL_L40m-D200 mm_V_R	258.66	119.04	177.1	190.9	314.0	337.3	179.3	196.1	295.7	340.9	177.6	198.5	267.9	344.3
13	S	ISO07_PL_L50m-D150 mm_V_S	0.16	5.65	0.0	0.0	4.3	3.6	0.0	0.0	3.8	2.8	0.0	0.0	3.1	1.7
14	M	ISO07_PL_L50m-D150 mm_V_M	4.04	70.07	23.2	22.6	32.8	42.2	24.7	21.9	33.0	41.8	26.1	20.6	33.2	40.6
15	L	ISO07_PL_L50m-D150 mm_V_L	64.67	22.71	90.8	99.7	154.4	177.7	93.1	100.7	144.2	178.5	96.8	100.8	134.8	179.5
16	R	ISO07_PL_L50m-D150 mm_V_R	145.50	95.08	134.3	146.3	235.0	259.2	136.0	149.3	219.7	261.3	62.6	123.9	200.9	263.5
17	S	ISO08_PL_L3900m-D200 mm_V_S	0.16	5.65	0.0	0.0	4.3	3.6	0.0	0.0	3.8	2.8	0.0	0.0	3.1	1.7
18	M	ISO08_PL_L3900m-D200 mm_V_M	4.04	70.07	23.2	22.6	32.8	42.2	24.7	21.9	33.0	41.8	26.1	20.6	33.2	40.6
19	L	ISO08_PL_L3900m-D200 mm_V_L	64.67	22.71	90.8	99.7	154.4	177.7	93.1	100.7	144.2	178.5	96.8	100.8	134.8	179.5
20	R	ISO08_PL_L3900m-D200 mm_V_R	258.66	119.04	177.1	190.9	314.0	337.3	179.3	196.1	295.7	340.9	177.6	198.5	267.9	344.3
21	S	ISO09_PL_L2200m-D100 mm_V_S	0.37	7.98	4.5	2.4	8.3	8.1	7.6	0.4	8.1	7.2	1.3	0.7	7.7	6.0
22	M	ISO09_PL_L2200m-D100 mm_V_M	9.16	32.32	35.4	36.8	53.3	67.2	37.8	36.4	51.5	66.9	40.0	35.2	51.7	66.3
23	L	ISO09_PL_L2200m-D100 mm_V_L	146.59	95.35	134.8	146.8	235.9	260.1	136.5	149.8	220.6	262.3	137.7	150.9	201.6	264.5
24	R	ISO09_PL_L2200m-D100 mm_V_R	146.59	95.35	134.8	146.8	235.9	260.1	136.5	149.8	220.6	262.3	137.7	150.9	201.6	264.5
25	S	ISO10_PL_L30m-D100 mm_V_S	0.37	7.98	4.5	2.4	8.3	8.1	7.6	0.4	8.1	7.2	1.3	0.7	7.7	6.0
26	M	ISO10_PL_L30m-D100 mm_V_M	9.16	32.32	35.4	36.8	53.3	67.2	37.8	36.4	51.5	66.9	40.0	35.2	51.7	66.3
27	L	ISO10_PL_L30m-D100 mm_V_L	146.59	95.35	134.8	146.8	235.9	260.1	136.5	149.8	220.6	262.3	137.7	150.9	201.6	264.5
28	R	ISO10_PL_L30m-D100 mm_V_R	146.59	95.35	134.8	146.8	235.9	260.1	136.5	149.8	220.6	262.3	137.7	150.9	201.6	264.5
29	S	ISO10_PL_L50m-D50 mm_V_S	0.37	7.98	4.5	2.4	8.3	8.1	7.6	0.4	8.1	7.2	1.3	0.7	7.7	6.0
30	M	ISO10_PL_L50m-D50mm_V_M	9.16	32.32	35.4	36.8	53.3	67.2	37.8	36.4	51.5	66.9	40.0	35.2	51.7	66.3
31	L	ISO10_PL_L50m-D50mm _V_L	36.65	56.58	69.2	75.6	114.4	135.7	72.0	76.0	107.5	135.9	75.9	75.5	102.5	136.3
32	R	ISO10_PL_L50m-D50mm_ V_R	36.65	56.58	69.2	75.6	114.4	135.7	72.0	76.0	107.5	135.9	75.9	75.5	102.5	136.3

The Jet Fire Intensity Radii for Rupture cases for wind speed 9 m/s and stability class C have been presented as per ***Figure 1.24.***

Figure 1.24 Intensity Radii of Jet Fire Scenarios

	
Intensity Radii for case ISO05_PL_L200m-D100mm_V_R	Intensity Radii for case ISO06_PL_L20m-D150mm_V_R
	
Intensity Radii for case ISO06_PL_L40m-D200mm_V_R	Intensity Radii for case ISO07_PL_L50m-D150mm_V_R
	
Intensity Radii for case ISO08_PL_L3900m-D200mm_V_R	Intensity Radii for case ISO09_PL_L2200m-D100mm_V_R
	
Intensity Radii for case ISO10_PL_L30m-D100mm_V_R	Intensity Radii for case ISO10_PL_L50m-D50mm_V_R

Pool Fire Results

Pool fire dimensions and surrounding radiation contours are generated based on models within RA model. The flame is assumed to be a cylinder sheared by the wind and has a circular cross section parallel to the ground. The flame height is based on the bund size, leak rate and drainage rate. If personnel are within the 37.5kW/m² radiation contour, then a 100% fatality rate is applied. Personnel outside of the contour are assumed to evacuate the area and hence survive. Significant pool fires are expected to happen only in case of large leaks and ruptures and the heat radiations are not expected to vary for different weather conditions. Hence, the results have been presented for large and rupture cases for 1 F weather condition.

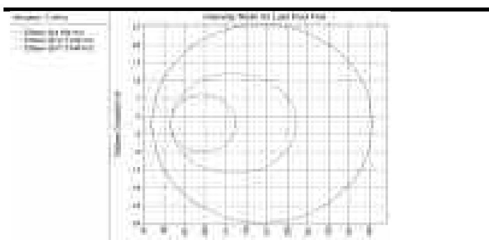
The pool fire results are presented in the ***Table 1.36***. The maximum distance of pool fire for 12.5 kW/m2 of heat flux will be at 112.1 m while for 4 kW/m2 of heat flux, the maximum distance has been worked out as 189.0 m.

Table 1.36 Pool Fire Radiation Results (in meters) for 1F weather condition

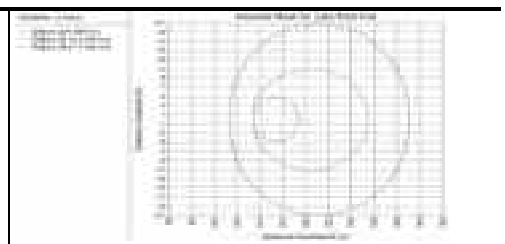
S.N	Leak Size	Event Name	Release Rate (kg/s)	Pool Fire dia (m)	Flame Height (m)	37.5 kW/m2 length	37.5 kW/m2 width	12.5 kW/m2 length	12.5 kW/m2 width	4 kW/m2 length	4 kW/m2 width
1	L	ISO01_PL_L200m-D100mm_L_L	261.94	14.62	27.23	16.62	16.62	22.46	21.48	52.96	51.51
2	R	ISO01_PL_L200m-D100mm_L_R	261.94	14.62	27.23	16.62	16.62	22.46	21.48	52.96	51.51
3	L	ISO02_PL_L20m-D150mm_L_L	261.94	7	17	9.31	9.31	19.01	17.84	40.74	40.22
4	R	ISO02_PL_L20m-D150mm_L_R	589.38	7	17	9.48	9.48	19.16	17.99	41.19	40.65
5	L	ISO02_PL_L40m-D200mm_L_L	261.94	13	25	15.08	15.08	22.04	21.00	51.25	49.98
6	R	ISO02_PL_L40m-D200mm_L_R	1047.78	15	28	17.27	17.27	22.59	21.67	53.60	52.08
7	L	ISO03_PL_L50m-D150mm_L_L	261.94	11	22	12.97	12.97	21.30	20.21	48.35	47.35
8	R	ISO03_PL_L50m-D150mm_L_R	589.38	12.32	24.16	14.32	14.32	21.81	20.73	50.28	49.11
9	L	ISO04_PL_L2100m-D200mm_L_L	261.94	94.31	99.45	0.00	0.00	96.31	96.31	164.92	160.07
10	R	ISO04_PL_L2100m-D200mm_L_R	1047.78	110.07	110.72	0.00	0.00	112.07	112.07	189.00	183.69

The pool Fire Intensity Radii for Rupture cases for wind speed 9 m/s and stability class C have been presented as per ***Figure 1.25.***

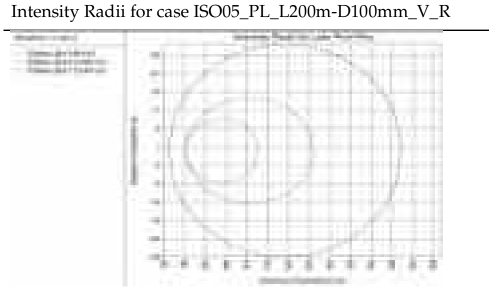
Figure 1.25 Intensity Radii of Pool Fire Scenarios



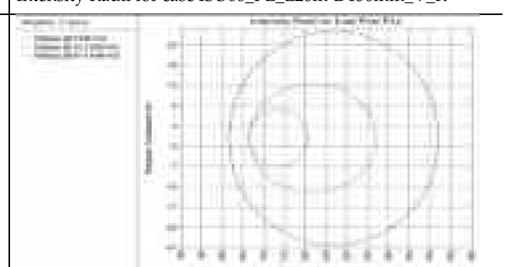
Intensity Radii for case ISO05_PL_L200m-D100mm_V_R



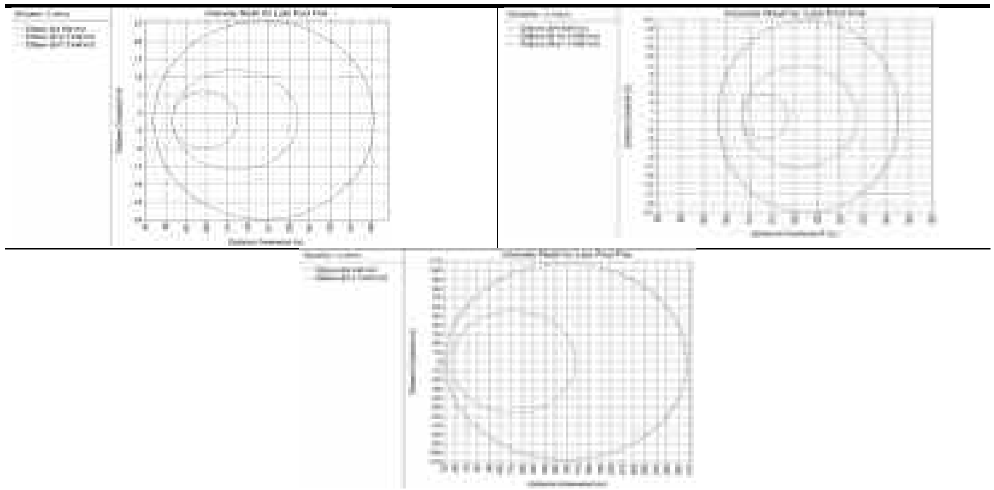
Intensity Radii for case ISO06_PL_L20m-D150mm_V_R



Intensity Radii for case ISO02_PL_L40m-D200mm_L_R



Intensity Radii for case ISO03_PL_L50m-D150mm_L_R



Intensity Radii for case ISO04_PL_L2100m-D200mm_L_R

Flash Fire Results

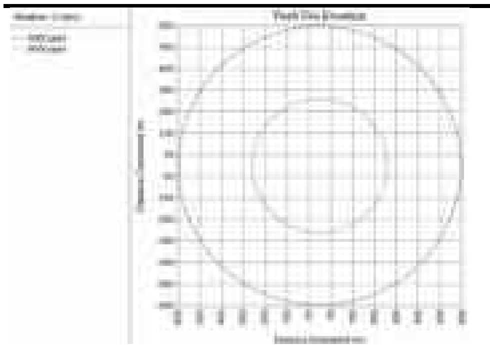
The flash fire consequence results are presented in ***Table 1.37***. The maximum distance of flash fire related LFL distance has been worked out as 294 m.

Table 1.37 Flash Fire distances (in meters) for all weather conditions

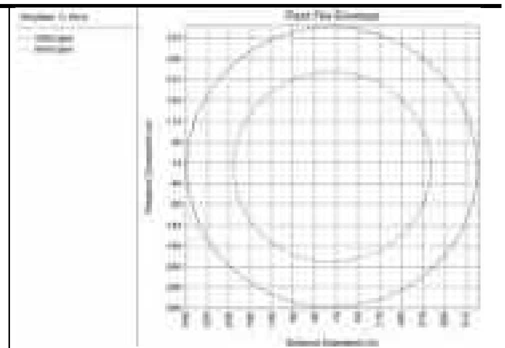
S. N	Leak Size	Event Name	Release Rate (kg/s)	1F	1F	5D	5D	9C	9C
				Length (LFL Distance)	Length (1/2 LFL Distance)	Length (LFL Distance)	Length (1/2 LFL Distance)	Length (LFL Distance)	Length (1/2 LFL Distance)
1	S	ISO01_PL_L200m-D100mm_L_S	0.65	12	22	12	21	10	17
2	M	ISO01_PL_L200m-D100mm_L_M	16.37	86	153	91	200	91	191
5	S	ISO02_PL_L20m-D150mm_L_S	0.65	12	22	12	21	10	17
9	S	ISO02_PL_L40m-D200mm_L_S	0.65	12	22	12	21	10	17
10	M	ISO02_PL_L40m-D200mm_L_M	16.37	86	153	0	200	0	191
13	S	ISO03_PL_L50m-D150mm_L_S	0.65	12	22	12	21	10	17
17	S	ISO04_PL_L2100m-D200mm_L_S	0.65	12	22	12	21	10	17
18	M	ISO04_PL_L2100m-D200mm_L_M	16.37	86	153	91	200	91	191
19	L	ISO04_PL_L2100m-D200mm_L_L	261.94	215	370	262	506	294	620
20	R	ISO04_PL_L2100m-D200mm_L_R	1047.78	97	563	0	710	0	855

The flash fire envelope for rupture cases for wind speed 9 m/s and stability class C have been shown in ***Figure 1.26.***

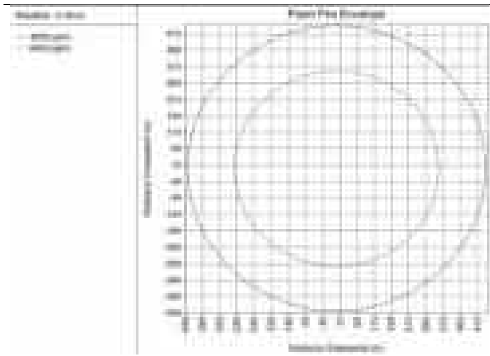
Figure 1.26 Intensity Radii of Flash Fire Envelop Scenarios



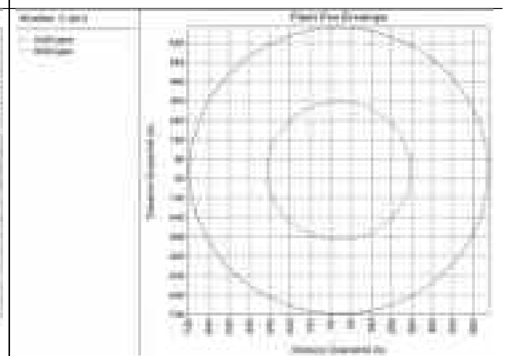
Flash Fire Envelope for case ISO01_PL_L200m-D100mm_L_R



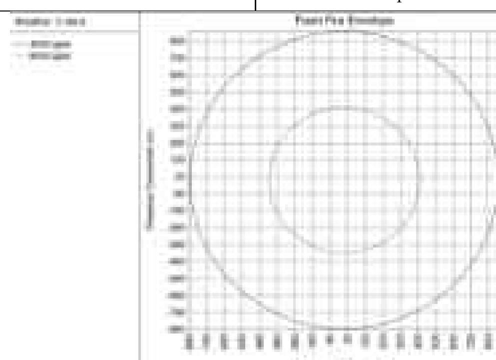
Flash Fire Envelope for case ISO02_PL_L20m-D150mm_L_R



Flash fire Envelop for case ISO02_PL_L40m-D200mm_L_R



Flash Fire Envelope for case ISO03_PL_L50m-D150mm_L_R



Flash Fire Envelope for case for ISO04_PL_L2100m-D200mm_L_R

Results of the QRA Study

The distribution of frequency based on 6 hole sizes (5mm, 12.5mm, 25mm, 50mm,100mm & 200mm) ranging from 5 to 200 mm (or maximum pipe diameter) is considered for each leak source.

Grated floors are assumed to offer no resistance to fire or smoke. A plated floor in topside offers a barrier against smoke, fire and liquid until its specified resistance is exceeded. These barriers can lead to liquid hold up and thus, pool fire generation is possible.

Fatality rates of Jet / Pool fire, Platform damage, smoke in module & Flash fire.

Table 1.38 Fatality Rates

Fatality Rates	Fraction
Fatality rate Explosion	0.5
Fatality rate Damage	0.2
Fatality rate Jet Fire	0.15
Fatality rate Pool Fire	0.05
Fatality rate Flash Fire	0
Fatality rate Smoke	0.25

Explosion Overpressure failure of piping, vessel, wall & floor [Ref OGP-March 2010]:

Table 1.39 Explosion Overpressure for structural failure

Component	Failure Overpressure (bar g)
Fire Wall	0.5
Pipe Section	1 to 2
Floors	2
Tanks	0.35
Vessel	2
Wall	0.1 to 0.25

The highest explosion overpressure is assumed to be 3bar g which lasts for a few seconds and is generally accepted 2 bar g. taking this as the peak explosion overpressure; probability distribution is used to compute explosion overpressure in each module.

On wellhead platform by life rafts as primary means and followed by transfer to OSV.

The open well flow rate in case of blow out is considered 5 times the normal flow rate. Risk summation and assessment

a) Potential loss of life

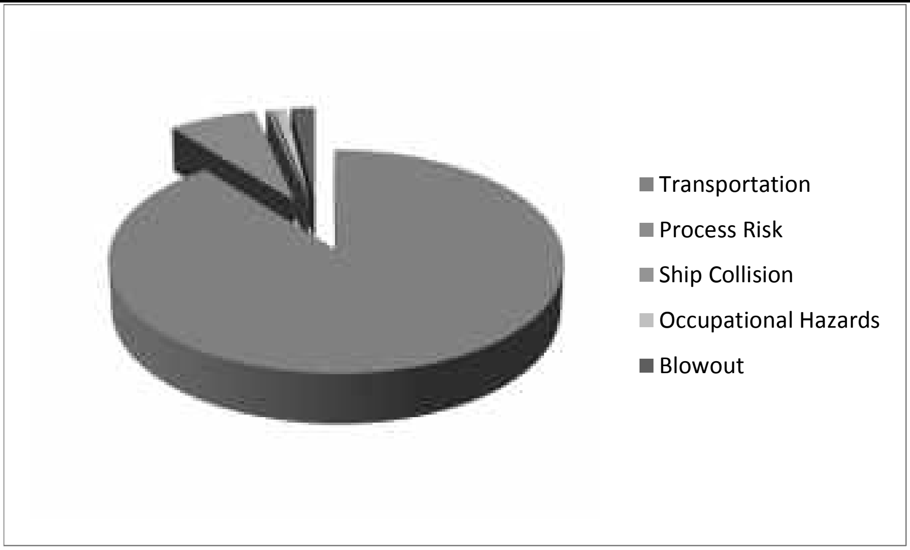
The overall PLL for the Platform operations was estimated to be 5.89E-04 per year, taking into account the presence factor of the personnel at the Platform during normal operations only. The breakdown of PLL results by hazard categories are presented in ***Table 1.40*** and ***Figure 1.27***.

Table 1.40 Overall PLL for the Platform

Hazard Category	PLL (per year)	% Contribution
Transportation	4.1E-04	89.38%
Process Risk	3.3E-05	7.19%
Ship Collision	2.0E-06	0.44%
Occupational Hazards	4.7E-06	1.02%
Blowout	1.5E-06	1.96%
Total	4.50E-04	100.00%

The major contributor was found to be the transportation risk, which accounted for approximately 91% of the overall risks. Personnel are currently anticipated to visit the platform daily (duration for a single trip is anticipated to be 10 minutes, resulting in higher risk exposure compared to other hazard categories, particularly where the hydrocarbon related risks are low due to minimum facilities comprising mainly piping and riser.

Figure 1.27 PLL Breakdown by Different Hazard Categories



b) Potential Loss of Life (PLL) due to Hydrocarbon Releases

The process hydrocarbon releases events, which include topside process, riser/pipeline and blowout, were assessed to have minor risk contribution, approximately 7.0% of the total PLL. The breakdown of PLL by immediate, escape and evacuation fatality phrases for the Platform due to hydrocarbon releases is summarised in ***Table 1.41*** and shown graphically in ***Figure 1.28.***

Table 1.41 Platform Hydrocarbon Risk Breakdown by Fatalities Phases

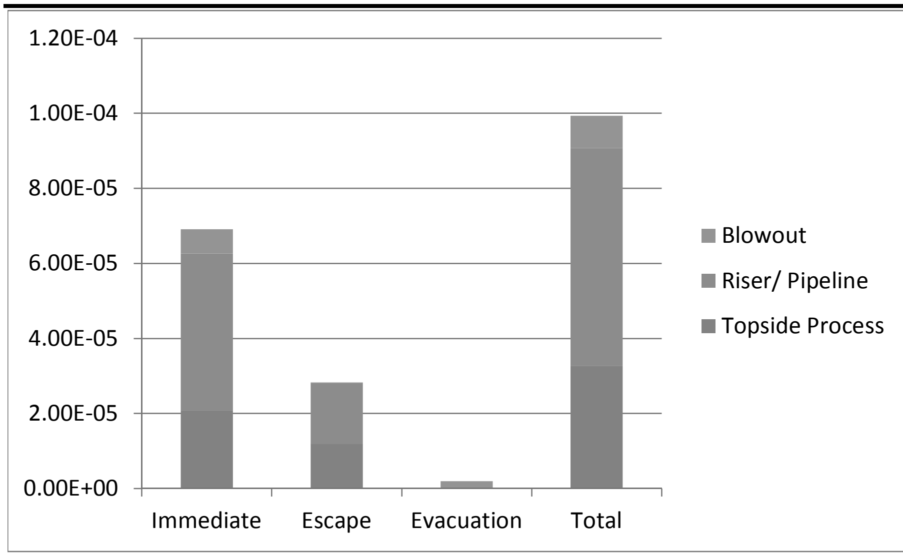
Phases	PLL (per year)				% Contribution
	Topside Process	Riser/ Pipeline	Blowout	Total	
Immediate	2.09E-05	4.17E-05	6.54E-06	6.91E-05	69.55%
Escape	1.19E-05	1.62E-05	1.51E-07	2.83E-05	28.42%
Evacuation	7.22E-11	6.64E-09	2.02E-06	2.02E-06	2.03%
Total	3.28E-05	5.79E-05	8.71E-06	9.94E-05	100.00%

The PLL during immediate fatality phase was found to be the highest contributor among the hydrocarbon releases associated PLL, accounting for approximately 69%. This is due to the relatively small deck areas on the platform, where an initial medium or large jet flame can potentially engulf the entire platform, resulting in immediate fatality of personnel located within the exposed area.

The fatalities associated with escape phase were estimated to contribute approximately 28% to the total hydrocarbon PLL. Although stairways are provided on the platform on each of the decks, they are likely to be impaired by scenarios originating from the deck itself and riser/ pipeline failure events where the entire platform could possibly be engulfed by the fire impeding escape of personnel. The resulting thermal radiation associated with fire due to riser/ pipeline failures is anticipated to engulf all the decks leading to escape routes impairment. However, the contribution of riser and pipeline failures to the overall PLL is not very high due to lower initiating event frequencies.

Due to the relatively small platform, the effects of fire are considered to cause fatality during immediate and escape phases. As such, there might be very low number of personnel that would need to go through evacuation and to subsequent fatality due to inability to reach evacuation means. The contribution from this phase was therefore found to be insignificant.

Figure 1.28 PLL Breakdown by Fatalities Phases due to Hydrocarbon Events



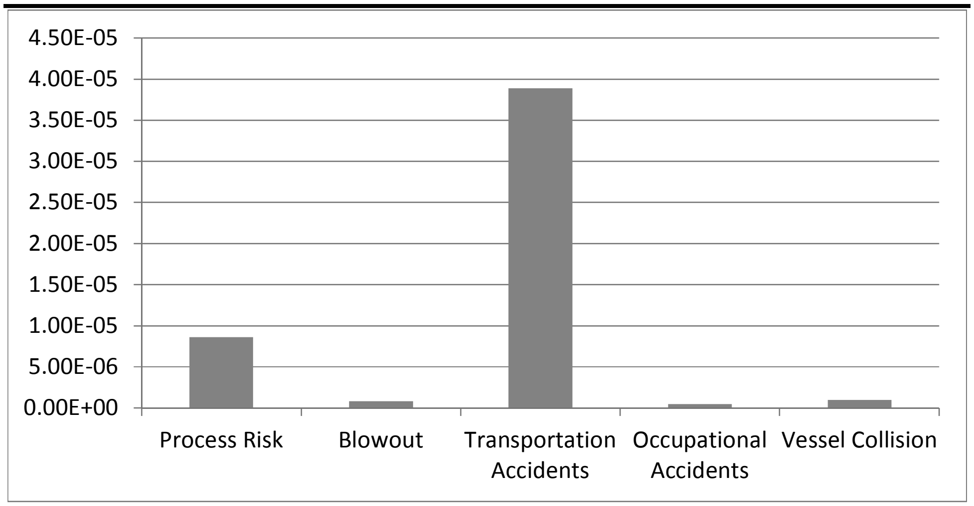
c) Individual Risk per annum (IRPA)

The Individual Risk per Annum (IRPA) for the different worker groups is presented in ***Table 1.42*** and shown graphically in ***Figure 1.29***. The results show that each of the personnel working on the Platform will be exposed to an Individual Risk of 4.98 x 10^{-5} per since these personnel are having the same amount of time spent in each area.

Table 1.42 Individual Risk Per Annum for different hazard categories on the Platform

No of worker on board	Process Risk	% Contribution	Blowout	% Contribution	Transportation Accidents	% Contribution	Occupational Accidents	% Contribution	Vessel Collision	% Contribution	Total
3	8.60E-06	17.28%	8.40E-07	1.69%	3.89E-05	78.16%	4.50E-07	0.90%	9.78E-07	1.97%	4.98E-05

Figure 1.29 Individual Risk Per Annum for different hazard categories on the Platform



d) Uncertainties in Risk Assessment

There are a number of sources of uncertainty in the risk assessment process. The points below highlight some of the uncertainties that exist within the platform risk analysis:

- Statistical uncertainty in data sources – the risks on the Platform have been calculated using industry generic event frequency or leak frequency data as a basis. The databases reflect the experience of the industry over a large number of exposure years. As offshore systems are designed not to suffer catastrophic failure, however, the "population" of failure data is generally small and hence introduces a degree of uncertainty.
- Applicability of the data sources and models to the Platform – the data sources for the assessment has been selected from both offshore experience and marine experience as appropriate. In general, the hazards identified for the Platform are common to other installations intended for similar service and the use of existing databases representing good practice is considered appropriate for assessing those hazards for which there is wide experience.

- When considering explosion overpressures, the risk assessment model is conservative in that it uses the worst case predicted explosion overpressure exceedance curve for a given release rate, for a specific area / module and applies it to all releases (of the same release rate and material) within the entire process area.
- Engineering judgement is applied to a large number of areas and assumptions within the risk assessment model. In areas where engineering judgement is applied, there is always a large degree of uncertainty. Where uncertainty exists, however, a conservative (worst case) approach has been taken and subsequently this has an influence on the risk results generated.

Conclusion – Risk Assessment

a) Hydrocarbon Hazards Analysis

The total leak frequency from topside hydrocarbon sections was estimated to be 2.2×10^{-1} per year. The total leak frequency for the riser and pipeline was estimated to be 2×10^{-3} per year;

The total fire frequency for topside hydrocarbon releases was estimated to be 8.6×10^{-4} per year. The total fire frequency for the riser and pipeline estimated at 8.7×10^{-6} per year was found to be dominated by the releases from the riser above sea section;

Taking into account oil & gas production wells, the total ignited blowout frequency was estimated to be 7.8×10^{-6} for oil well & 5.4×10^{-5} for gas wells per year;

The Consequence Analysis results are presented in ***Section* 7.2.7**.

b) Non-Flammable Hazard Analysis (NFHA)

b1) Vessel Collision

Collision frequency of visiting vessel for fixed platform: 7.6 E-05 per year.
Collision frequency of visiting supply vessel for fixed platform: 5.4 E-04 per year

The estimated Individual Risks associated with a ship collision with the Platform is 9.78×10^{-7}. The estimated PLL associated with a ship collision with the Platform is 1.97×10^{-6}

B2) Transportation Risk

The PLL for the risk arising from helicopter transfers was estimated to be 4.1×10^{-4} per year; and IRPA due to transportation risk was estimated to be 3.98×10^{-5} per year. It is highlighted that the risk presented only accounted for the risk when personnel are required to work on the platform and their transportation to and from the platform.

B3) Occupational Risk

All of the personnel on the Platform will be exposed to similar occupational risk with an estimated individual risk of 4.5×10^{-7} per year and PLL of 4.7×10^{-6}.

B4) Quantitative Risk Assessment (QRA)

The main conclusions of the QRA Study are as follows:

The overall PLL for the Platform operations was estimated to be 4.59×10^{-4} per year. The transportation accident risk was found to be the highest risk contributor to the overall risk which accounts for approximately 89% of the total PLL due to the high frequency;

The Individual Risk for workers working on the Platform was calculated to be 4.98×10^{-5} per. Again the transport risk is the highest contributor.

1.3 EMERGENCY RESPONSE PLAN FOR RAVVA FIELD

Cairn (Oil & Gas) has the following protection priorities in the event of an emergency:

1. *Safety of employees and local community.*
2. *Minimizing the impacts on environment.*
3. *Safeguarding of commercial considerations with respect to assets / production.*

A **Ravva Field Emergency Response Plan (RFERP)** has been specifically developed by Cairn (Oil & Gas) for operations associated to the Ravva field.

Purpose of RFERP

The purpose of this RFERP is to define and detail Emergency Response Organizational roles, responsibilities, actions, reporting requirements and support resources available to ensure effective and timely management of emergencies at, or affecting, any of Ravva operations, which are associated to Cairn (Oil & Gas)'s Production Operations activity at Ravva Offshore & Onshore Facilities.

It achieves this by:

- Defining the roles and responsibilities of supervisory personnel at the Ravva field
- Describing procedures to deal with emergencies affecting personnel, equipment, third party contractors, local communities or the environment.

Scope of RFERP

This plan applies to the emergency situations that are likely to arise in the following operations at Ravva:

- On-shore Terminal
- Off-shore Platforms

- Marine Operations
- Helicopter Operations
- Living Quarters and
- Vehicle Transport Operations (Including RJY to site operations & KKD to site operations)

It is intended for the RFERP to act as an emergency support tool to standard operating policies and procedures of Cairn.

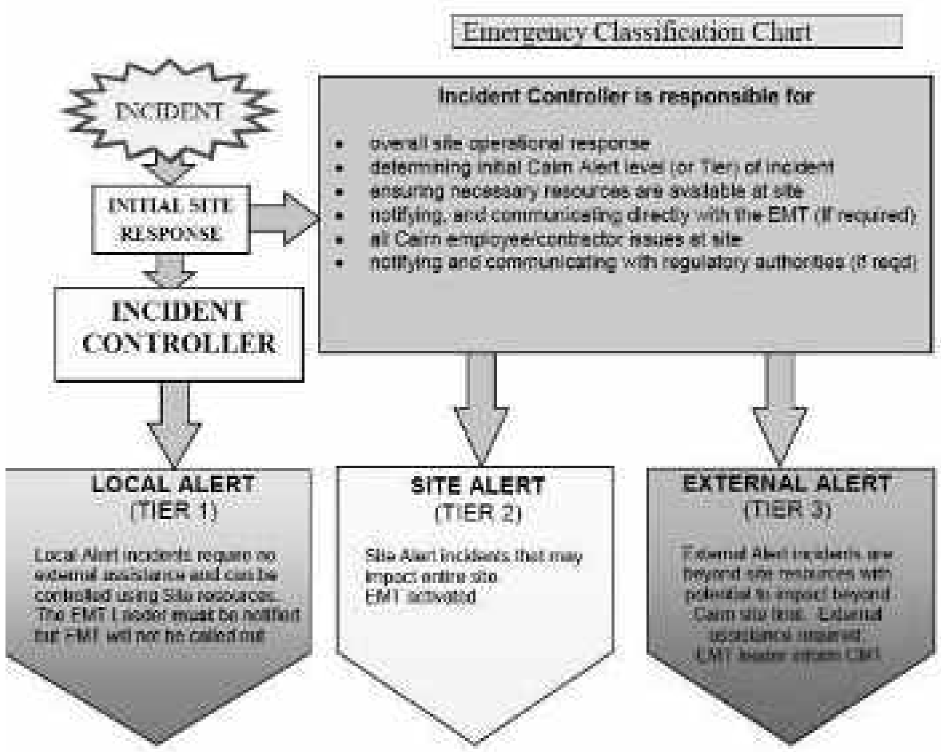
Temporary Additional Facilities

From time to time additional facilities may be brought to the Ravva Field to carry out particular work. These may include drilling rigs, work-over barges, Pipe laying barges, diving support vessels, construction barges, Drilling/Pipe laying support vessels etc. Additional emergency procedures will be generated to cover these activities, either a stand-alone documents or as addendum to RFERP. In the present case, additional procedures associated with onshore and offshore drilling have to be developed prior to initiation of works.

Emergency Classification

Cairn defines emergency situations in three tiers of severity, related to the scale of the incident and the capability of the organisation to respond effectively. The following two figures shows the details of the tier levels and is based on the Cairn Risk Evaluation guidelines.

Figure 1.30 Emergency Classification Chart



Source: Ravva Field Emergency Response Plan (RFERP-000-001), Date of Issue: 01 Dec 2017

The emergency situations have been classified in three categories depending upon their magnitude and consequences. Different types of emergencies that may arise at the project site can be broadly defined in

Table 1.43 Emergency Calssification

Emergency Levels	Category	Response	Health & Safety	Environment	Security
Tier 3 Strategic	Crisis situation appear likely Duty CMT leader's decide to call out CMT Members Duty CMT leader must notify the Chief Executive Officer	Crisis Management Team (CMT)	• Incident leading to loss of facility • Incident leading to significant financial loss • Incident leading to multiple injuries or fatality • Total loss of marine vessel • Well blowout • Incident which could lead to international media interest • Major traffic incident with multiple casualties	• 1000T (7000bbls) • Effluent discharge / flaring beyond acceptable limits • Flood or Cyclone warning Yellow alert – within 12 hours • Major Earthquake	• Terrorist activities / bomb threat • Kidnap or extortion / threat • Major civil unrest
Tier 2 Tactical	Substantial incident Duty EMT leaders decision to call out EMT leaders Duty EMT leader must notify duty CMT Leader	Emergency Management Team (EMT	• Fire or Explosion • Injury or illness requires evacuation • Traffic accident requires external assistance • Marine incident e.g. Vessel collision	• Oil spill from > 100T but < 1000T (700 – 7000BBLS • Offshore environmental exposure contained with outside help • Earthquake • Flood or Cyclone warning Blue alert – within 48hrs	• Civil unrest or security breach • Major criminal activity
Tier 1 Field & regional Support Reactive	A minor incident where site / location requires no external assistance and can control the incident with local resources Incident Controller must notify the leader of the ERT or EMT of the situation	Emergency Response Teams (INT)/(ERT)	• Minor medical or injury case requires no external support • Equipment damage with loss of product on • Minor fire without injury or plant damage • Rescue of trapped and injured personnel	• Minor oil spill < 100T(700bbls) • Onsite environmental exposure contained with internal efforts e.g. chemical spill • Notification of cyclone within 72 hrs	• Minor security breach • Theft from site • Local unrest

Source: Ravva Field Emergency Response Plan (RFERP-000-001), Date of Issue: 01 Dec 2017

Emergency Response Team

The following teams constitutes the Emergency Response Team:

Medical Response team: A team of Cairn personnel comprising of trained & certified first aiders (by St. John Ambulance Association), assist site Occupational Health Physician during medical emergency situations. These personnel shall be on stand-by at the first aid centre and respond immediately to the scene along with the Medical Support on call.

Fire and rescue team: A team of Cairn personnel comprising of

- Emergency Response Technicians (ERTs) and
- Personnel trained in Fire Training Modules and listed as ERT

- Any other personnel deployed at the incident location as required under this plan.

This team is responsible for Search and Rescue as well as fire fighting at the scene of the incident. This team will be lead by Fire Chief.

Table 1.44 Communication Protocol during Emergencies

On-shore Emergencies	Channel 3	HSE support, Doctor, Muster Point Controller, Security & Asst Manager-HR. Technical Support if required to communicate with the respective maintenance staff.
	Channel 13	Production Support, Fire Chief, Site Support, Control Room
Off-shore Emergencies	Channel 11	Production Support, Platform Support, MUV/Supply vessels.
Tanker Emergencies	Channel 77	RO, Mooring master, Mooring support vessels, Tug Boats and Oil tanker

Source: Ravva Field Emergency Response Plan (RFERP-000-001), Date of Issue: 01 Dec 2017

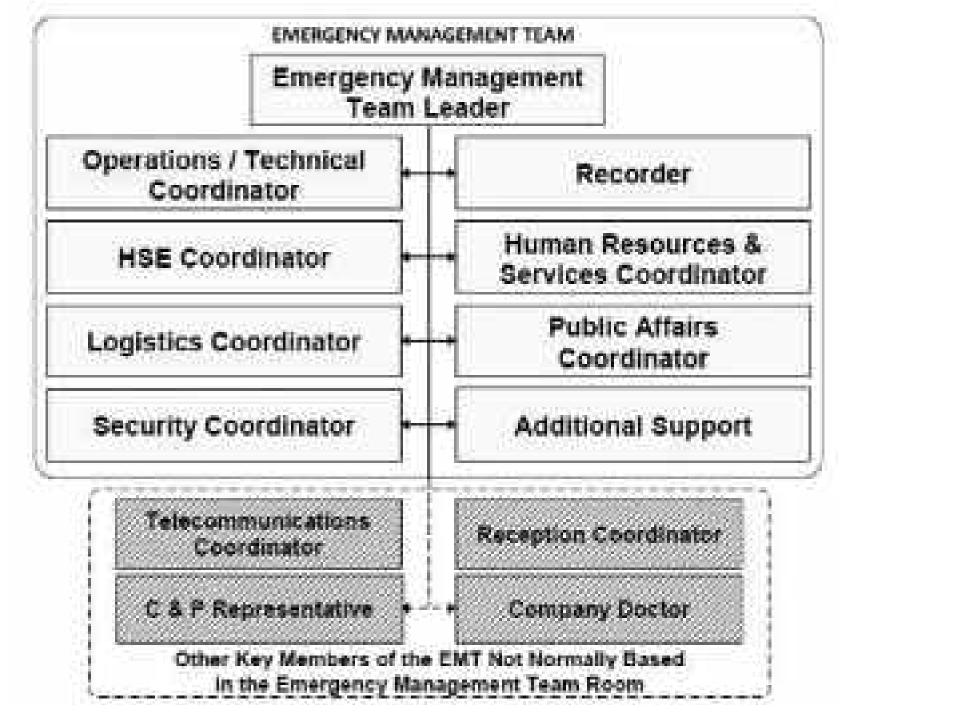
Gurgaon Emergency Management Organization

The Gurgaon Emergency Management Organisation consists of the following:
- Emergency Management Team (EMT)
- Crisis Management Team (CMT)

Depending on the seriousness of the incident EMT or CMT will be activated. The contact details of EMT and CMT are updated on a weekly basis and displayed in the Incident Response Center.

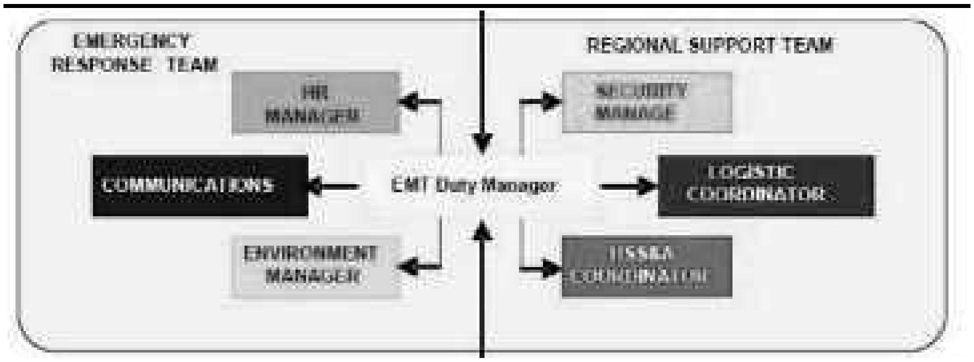
The structure of the Emergency Management Team at Cairn Corporate (i.e. the Gurgaon Emergency Management Organisation) including the EMT and CMT, the Emergency Management Organisation Reltionship and the Emergency Management Organisation's structure and linkages are represented through **Figure 1.31 to Figure 1.35.**

Figure 1.31 Emergency Management Team – Cairn Corporate



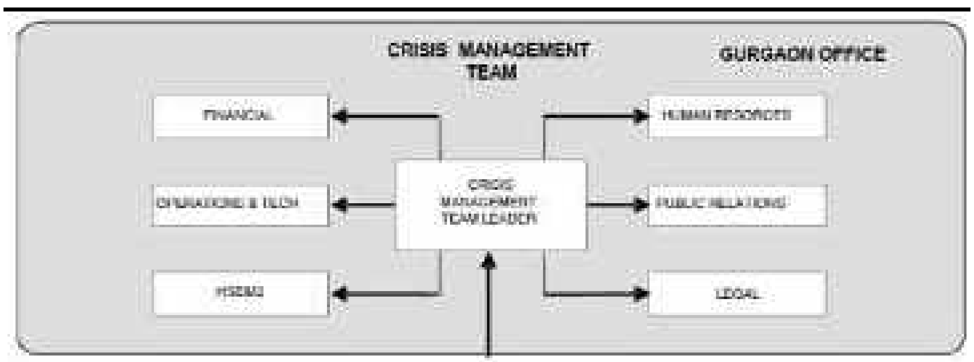
Source: Ravva Field Emergency Response Plan (RFERP-000-001), Date of Issue: 01 Dec 2017

Figure 1.32 Emergency Management Team – Flow Chart



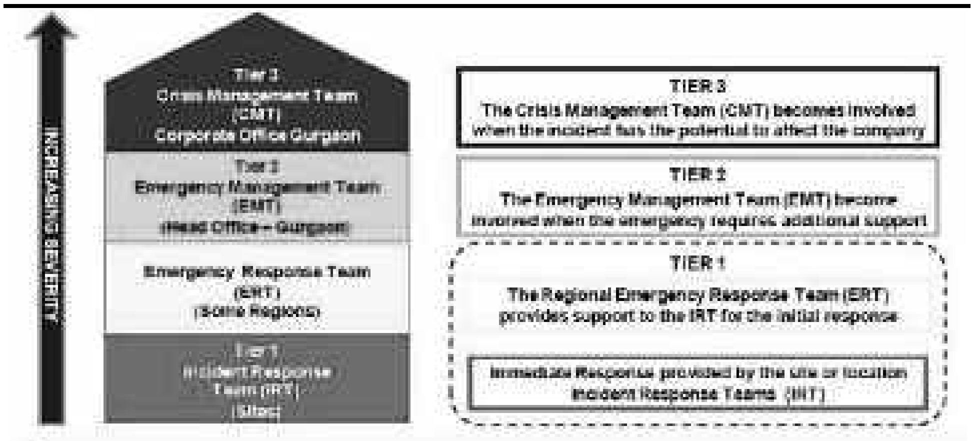
Source: Ravva Field Emergency Response Plan (RFERP-000-001), Date of Issue: 01 Dec 2017

Figure 1.33 Crisis Management Team – Flow Chart



Source: Ravva Field Emergency Response Plan (RFERP-000-001), Date of Issue: 01 Dec 2017

Figure 1.34 Emergency Management Organisation Relationship



Tier 1 Incident Response Team (IRT)

* The emergency or incident can be effectively and safely managed, and contained within the site, location or facility by operations staff
* Emergency or incident has no impact outside the site, location or facility
* There is unlikely to be danger to life, the environment, the assets or

Tier 1 incidents are managed by the site Incident Response Team (IRT). Each site will have its own IRT.

Tier 1 Emergency Response Team (ERT)

* The ERT provide assistance and local support to the IRT's in their area.
* The ERT have access to local emergency services throughout the state.
* For Tier 2 events the ERT acts as the interface between the EMT and IRT

Tier 1 In some states or districts the IRT's are supported by an additional organisation the Emergency Response Team (ERT).

Tier 2 Emergency Management Team (EMT)

* The incident cannot be effectively and safely managed or contained at the site, location or facility by operational staff and additional support is required
* The incident is having, or has the potential to have an effect beyond the site, location or facility and external support may be involved
* There is likely to be danger to life, to the environment, assets or reputation

Tier 2 The Emergency Management Teams (EMT) role is primarily for tactical response to the incident but may on occasions act in a reactive mode. Presently there is only one EMT organisation responsible for supporting all Cairn India businesses.

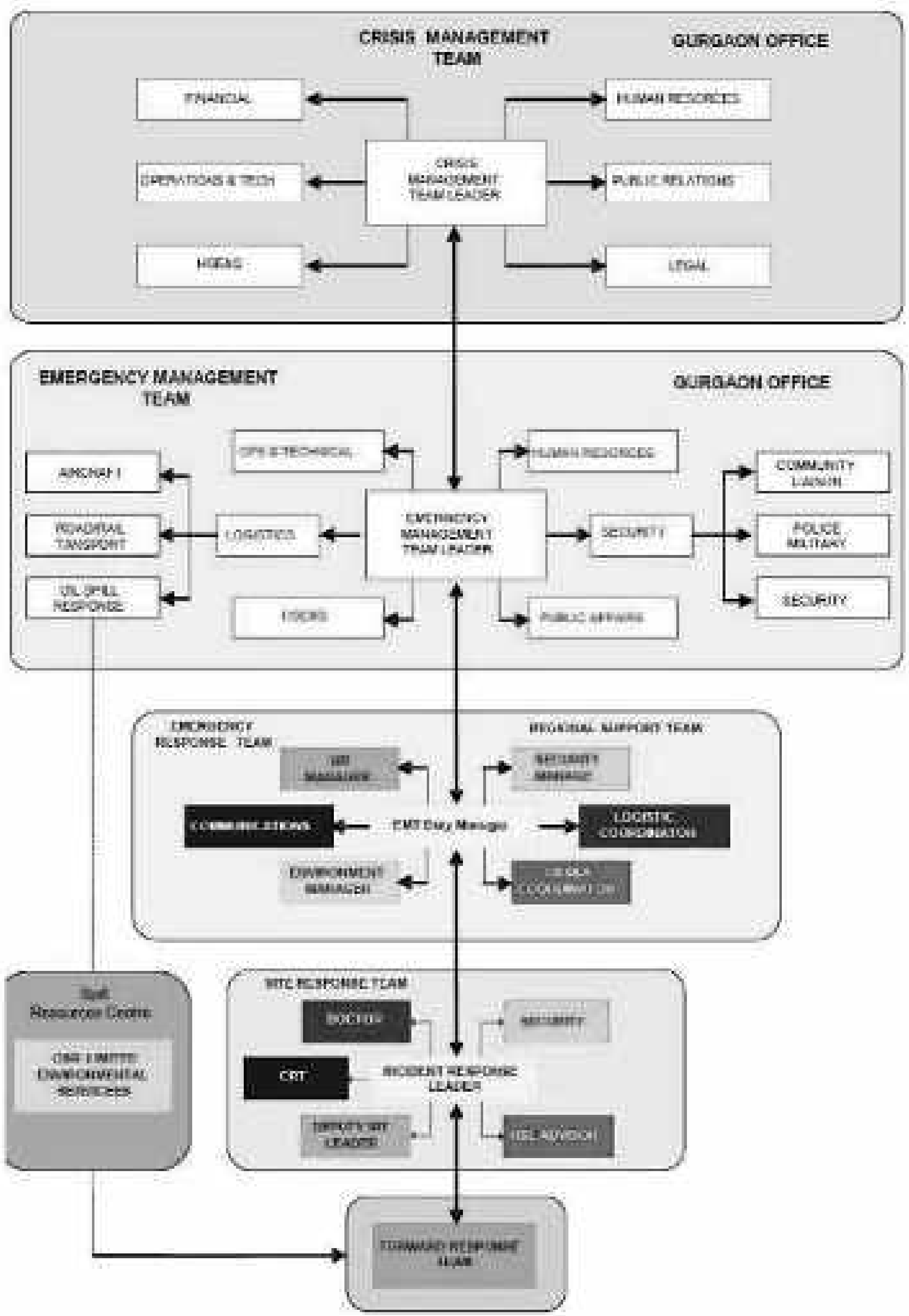
Tier 3 Crisis Management Team (CMT)

* The incident has ESCALATED to a level where it has, or has the potential to adversely affect the public, the company's operations or its reputation
* The incident will have technical, media, public affairs and personnel implications which require immediate action

Tier 3 covers incidents that have escalated to the point where the Crisis Management Team (CMT) need to be involved. There is only one CMT responsible for dealing with any crisis in any of Cairn's areas of operation.

Source: Ravva Field Emergency Response Plan (RFERP-000-001), Date of Issue: 01 Dec 2017

Figure 1.35 Emergency Management Organisation – Structure and Linkages



Source: Ravva Field Emergency Response Plan (RFERP-000-001), Date of Issue: 01 Dec 2017

Emergency Communication

Communications that can be utilised during a Cairn incident include any, or all, of the following:

- Land VHF mobile radio (walkie-talkies)
- VHF Marine radio
- Aero VHF radio
- HF radio

- AIS (Automatic Identification System)
- Digital Weather Monitoring System
- PA System(Paging System within the onshore operational areas and control room)
- Public Switched Telephone Network (PSTN)
- V-SAT
- INMARSAT
- Mobile phones-IS

Site ERO-communications arrangement chart with the designated emergency radio channels indicated has been included in the RFERP. It is essential that all emergency communications are relayed to the Incident Controller (or Alternate) and/or the EMT Leader (or Alternate) as soon as possible after an emergency situation has occurred. All nominated and dedicated emergency response staff will carry VHF radios programmed with the relevant Watch Keeping / Emergency Frequency.

All emergency communication telephone numbers have been listed out as part of the RFERP. As far as possible, all Emergency Calls from Offshore, Helicopter and Plant should be channelled on through the Site Radio Room. The Radio Officer will allocate a dedicated emergency frequency and will advise the Incident Controller of the emergency situation and frequency. · Upon the commencement of an emergency, the Radio Officer will inform Cairn radio stations that there is an emergency and to clear all non-essential radio traffic on the designated emergency radio channel/frequency. The Radio Officer will further inform all respondents to use the designated emergency radio channel/frequency for communications.

If an incident occurs after normal business hours, the Site Radio Room will make contact with the Gurgaon Radio Room who will inturn activate the EMT Leader and other personnel as advised. Irrespective of the working hours, IC will call the EMT leader directly or through Radio Officer to Establish contact in all emergencies.

Emerency Response Procedures

The RFERP has included a list of compiled emergency response procedures to identified threats and hazards/risks to Ravva field operations. The procedures are not designed as hard and fast prescribed rules, merely suggested prompts to encourage respondents to address potential hazards or actual incidents.

The following are a series of Emergency Response Procedures that provide a template for dealing with emergencies, which the Company requires the designated personnel to follow when called upon to deal with an emergency situation. The Company requires all personnel to be familiar with the content of these Emergency Response Procedures.

Table 1.45 Emergency Events & Procedures

SN.	Emergency Events & Procedures	Refernce to RFERP
A.	*Introduction*	
B.	*Offshore Emergency Events*	
1	Vessel Collision - Offshore	004-003
2	Fire or explosion - Offshore	004-004
3	Gas release - Offshore	004-005
4	Platform Evacuation / Abandonment	004-006
5	Helicopter missing	004-007
6	Helicopter emergency landing/crash - Offshore	004-008
7	Person overboard	004-009
8	Structural failure - Offshore	004-010
9	Vessel Emergency	004-011
10	Well Control Incident	004-012
11	Radioactive Material Spill	004-013
12	Loss of Telemetry in Offshore	004-014
C.	*Pollution Response Procedures*	
1	Oil Spill –Offshore	004-015
2	Tanker Oil Spill	004-016
3	Oil spill- Onshore	004-017
D.	*On-shore Emergency Events*	
1	Fire or explosion - Onshore	004-018
2	Gas leak - Onshore	004-019
3	Helicopter emergency landing/crash -Onshore	004-020
4	Road transport accident	004-021
5	Tank fire	004-022
6	Evacuation - Onshore	004-023
7	Search and Rescue (SAR)	004-024
8	Fire at Living Quarters	004-025
E.	*Medical Emergency Response Procedures*	
1	Serious illness / injury / death	004-026
2	Medevac (Medical Evacuation)	004-027
3	Radioactive material spill emergency	004-028
F.	*Weather Emergency Procedures*	
1	Storm Threat	004-029
2	Torrential Rains	004-030
3	Tsunami	004-031
G.	*Security Events*	
1	Bomb Threat	004-032
2	Criminal Acts	004-033
3	Kidnap / Extortion	004-034
4	Terrorist Activity Onshore	004-035
5	Terrorist Activity Offshore	004-036
H.	*Additional Emergency Events*	
1	Hydrogen Sulphide Release in RB Platform – Offshore Event	004 – 037
2	Loss of Flare Ignition – Onshore Event	004 – 038
3	PLC Failure	004 – 039
4	Liquid Carry over to flare	004 – 040
5	Radioactive Source Damage due to Fire on Platform	004 – 041
6	Radioactive Source Fall from height	004 – 042
7	Radioactive Source Theft	004 – 043
8	Receipt of an IRGD/nucleonic device from the supplier in a damaged condition	004 – 044

Source: Ravva Field Emergency Response Plan (RFERP-000-001), Date of Issue: 01 Dec 2017

The Emergency Response Procedures have been developed for a number of possible emergency situations. However, emergencies by their very nature are unpredictable and do not always follow a predictable route. The best course of action to prevent emergencies escalating and becoming out of control is to take early response and decisive action.

The Emergency Response flow charts are made for all emergency situations, developed with a series of actions by the Incident Controller and his Response Teams, which should result in a successful resolution/control of the situation. There are a number of decision points where the emergency situation is either successfully resolved or continues to deteriorate. If the emergency continues to deteriorate, the procedure authorizes the Incident Controller, through a series of processes, to eventually abandon the facility.

Additional Emergency Measures

As stated earlier the scope of the RFERP presently does not cover additional events like drilling, pipeline laying, etc. Additional emergency procedures will be generated to cover these activities, either a stand-alone documents or as addendum to RFERP. Key preventing and mitigation measure associated with site development, drilling of onshore wells and laying of pipelines have been listed below and will be duly considered by Cairn prior to developing the additional emergency procedures required for the present oil and gas development program.

<u>Preventive and Mitigation Measures for Blow Outs</u>

Blowouts being events which may be catastrophic to any well operation, it is essential to take up as much a preventive measures as feasible. This includes:

- Necessary active barriers (eg. Well-designed Blowout Preventer) be installed to control or contain a potential blowout.
- Weekly blow out drills be carried out to test reliability of BOP and preparedness of drilling team.
- Close monitoring of drilling activity be done to check for signs of increasing pressure, like from shallow gas formations.
- Installation of hydrocarbon detectors.
- Periodic monitoring and preventive maintenance be undertaken for primary and secondary barriers installed for blow out prevention, including third party inspection & testing
- An appropriate Emergency Response Plan be finalized and implemented by Cairn.
- Marking of hazardous zone (500 meters) around the well site and monitoring of human movements in the zone.
- Training and capacity building exercises/programs be carried out for onsite drilling crew on potential risks associated with exploratory drilling and their possible mitigation measures.
- Installation of mass communication and public address equipment.
- Good layout of well site and escape routes.

Additionally, Cairn will be adopting and implementing the following Safe Operating Procedures (SOPs) developed as part of its Onsite Emergency Response Plan to prevent and address any blow out risks that may result during drilling and work over activities:

- Blow Out Control Equipment
- Choke lines and Choke Manifold Installation with Surface BOP
- Kill Lines and Kill Manifold Installation with Surface BOP
- Control System for Surface BOP stacks
- Testing of Blow Out Prevention Equipment
- BOP Drills

Preventive Measures for Handling of Natural Gas

- Leak detection sensors to be located at areas prone to fire risk/ leakages;
- All safety and firefighting requirements as per OISD norms to be put in place;
- High temperature and high pressure alarm with auto-activation of water sprinklers as well as safety relief valve to be provided;
- Flame proof electrical fittings to be provided for the installation;
- Periodical training/awareness to be given to work force at the project site to handle any emergency situation;
- Periodic mock drills to be conducted so as to check the alertness and efficiency and corresponding records to be maintained;
- Signboards including emergency phone numbers and 'no smoking' signs should be installed at all appropriate locations;
- Plant shall have adequate communication system;
- Pipeline route/equipment should be provided with smoke / fire detection and alarm system. Fire alarm and firefighting facility commensurate with the storage should be provided at the unloading point;
- 'No smoking zone' to be declared at all fire prone areas. Non sparking tools should be used for any maintenance; and
- Wind socks to be installed to check the wind direction at the time of accident and accordingly persons may be diverted towards opposite direction of wind.

Preventive Measures for Interconnecting Pipeline Risk Management

- Design all pipes and vessels to cope with maximum expected pressure;
- Install pressure transmitters that remotely monitor high- and low-pressure alarms;
- Design equipment to withstand considerable heat load;
- Conduct regular patrols and inspections of pipeline easements;
- Fit pumps with automatic pump shutdown or other safety devices;
- Minimise enclosed spaces where flammable gas may accumulate;
- Where necessary, automate emergency shutdown systems at production facilities;
- Consider installing flow and pressure instrumentation to transmit upset conditions and plant shutdown valves status;
- Install fire and gas detection systems;

- Implement security controls;
- Install emergency shutdown buttons on each production facility;
- Bury gathering lines at a minimum depth of 600 mm and where above ground, maintain a clear area;
- Implement management of change processes; and
- Conduct pressure testing and inspection of equipment and pipelines.

Preventing Fire and Explosion Hazards

- Proper marking to be made for identification of locations of flammable storages;
- Provision of secondary containment system for all fuel and lubricating oil storages;
- Provision of fire and smoke detectors at potential sources of fire and smoke;
- Storing flammables away from ignition sources and oxidizing materials;
- Providing specific worker training in handling of flammable materials, and in fire prevention or suppression;
- Equipping facilities with fire detectors, alarm systems, and fire-fighting equipment;
- Fire and emergency alarm systems that are both audible and visible;
- For safety of people the building, regulations concerning fire safety to be followed. Some of the requirements include:
- Installation of fire extinguishers all over the building;
- Provision of water hydrants in operative condition;
- Emergency exit;
- Proper labelling of exit and place of fire protective system installation;
- Conducting mock drills;
- Trained personnel to use fire control systems.

General Health and Safety

- The facility will adopt a total safety control system, which aims to prevent the probable accidents such as fire accidents or chemical spills.
- Fire fighting system, such as sprinklers system, portable extinguishers (such as CO_2) and automated fire extinguishers shall be provided at strategic locations with a clear labelling of the extinguisher so the type of the extinguisher is easily identifiable. Also a main hydrant around the buildings will be available. On all floors an automated fire detection system will be in place.
- The site operations manager will take steps to train all emergency team members and shall draw up an action plan and identify members. The appointed emergency controller shall act as the in-charge at the site of the incident to control the entire operation.
- The staff shall be trained for first-aid and firefighting procedures. The rescue team shall support the first-aid and firefighting team.
- A first-aid medical centre will be onsite to stabilise the accident victim. The emergency team will make contact with a nearby hospital for further care, if required.

- A training and rehearsal of the emergency response by emergency team members and personnel on site will be done regularly.
- A safe assembly area will be identified and evacuation of the premises will be practised regularly through mock drills.
- In case an emergency is being declared, the situation shall be reported to the authorities such as local police, the chief inspector of factories and the state pollution control board as per rules and regulation of law of the land.
- Safety manual for storage and handling of Hazardous chemicals shall be prepared.
- All the personnel at the site shall be made aware about the hazardous substance stored and risk associated with them.
- Personnel engaged in handling of hazardous chemicals shall be trained to respond in an unlikely event of emergencies.
- A written process safety information document shall be compiled for general use and summary of it shall be circulated to concerned personnel.
- MSDS shall be made available and displayed at prominent places in the facility. The document compilation shall include an assessment of the hazards presented including (i) toxicity information (ii) permissible exposure limits. (iii) Physical data (iv) thermal and chemical stability data (v) reactivity data (vi) corrosivity data (vii) safe procedures in process.
- Safe work practices shall be developed to provide for the control of hazards during operation and maintenance
- In the material storage area, hazardous materials shall be stored based on their compatibility characteristics.
- Near miss and accident reporting system shall be followed and corrective measures shall be taken to avoid / minimize near miss incidents.
- Safety measures in the form of DO and Don't Do shall be displayed at strategic locations.
- Safety audits shall be conducted regularly.
- Firefighting system shall be tested periodically for proper functioning.
- All hydrants, monitors and valves shall be visually inspected every month.
- Disaster Management Plan shall be prepared and available with concerned personnel department.

Personal Protective Equipment

In certain circumstances, personal protection of the individual maybe required as a supplement to other preventive action. It should not be regarded as a substitute for other control measures and must only be used in conjunction with substitution and elimination measures. PPEs must be appropriately selected individually fitted and workers trained in their correct use and maintenance. PPEs must be regularly checked and maintained to ensure that the worker is being protected.

First Aid

First aid procedures and facilities relevant to the needs of the particular workforce should be laid down and provided in consultation with an occupational physician or other health professional.

Health assessment should form a part of a comprehensive occupational health and safety strategy. Where employees have to undergo health assessment, there should be adequate consultation prior to the introduction of such program. Medical records should be kept confidential. Site should be able to relate employee health and illness data to exposure levels in the workplace.