1 ADDITIONAL STUDIES

1.1 QUANTITATIVE RISK ASSESSMENT

This section on Quantitative Risk Assessment (QRA) aims to provide a systematic analysis of the major risks that may arise as a result of onshore exploratory drilling activities by ONGC in 9 fields of West Tripura, Agartala Dome II & III, Manikanagar-Sonamura, Kunjaban, Sundalbari, Tulamura, Tulamura Additional, Gojali blocks. 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 exploratory activities in the 9 blocks has considered all aspects of operation of the drilling rig and other associated activities during the exploratory phase. Loss of well control / blow-out and process leaks constitute the major potential hazards that may be associated with the proposed onshore exploratory drilling of natural gas in the 9 blocks.

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.

1.1.1 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 exploratory drilling activities, following specific objectives need to be achieved.

- Identify potential risk scenarios that may arise out of proposed drilling and other associated activities like operation of ancillary facilities and equipment's, mud chemicals storage and handling etc.

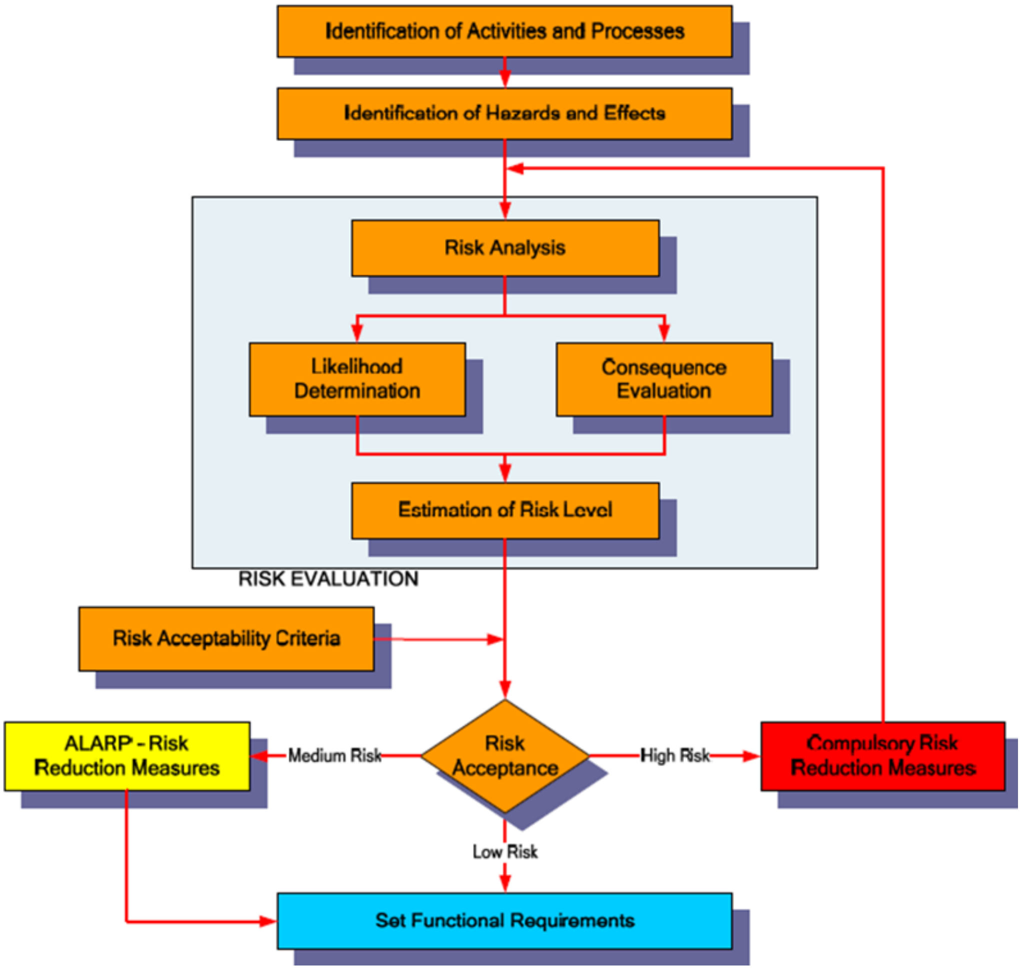
- Analyze the possible likelihood and frequency of such risk scenarios by reviewing historical accident related data for onshore oil and gas industries.
- Predict the consequences of such potential risk scenarios and if consequences are high, establish the same by through application of quantitative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

1.1.2 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 and fires; 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 exploratory drilling 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 ONGC. 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 exploratory drilling operations to be undertaken in the nine blocks of Tripura, 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
- 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;
- 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 ONGC.

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 ONGC'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 ofcomponent probabilities derived on basis of reliabilitydata and /or statistical analysis of historicaldata.

[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 drilling 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 modeling 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 exploratory drilling 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

1.1.3 *Risk Assessment of Identified Project Hazards*

As already discussed in the previous section, three major categories risk have identified in relation to proposed 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:

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.)
- 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*** below.

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

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

Sl. No.	Causal Factors	Blow Out Incidents (Nos.)
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 drilling and operations, blow out frequencies per well drilled have been considered.

For onshore blowouts, the Alberta Energy and Utilities Board (EUB) maintain a database of onshore drilling incidents. The database includes drilling occurrence data for Alberta from 1975 till 1990 with a total of 87994 wells drilled. During 2002-2006, there were 39 blowouts and 88856 wells drilled. Of the 39 blow outs, 7 involved release of gas, the remainder released only fresh water. Taking the full number of blowouts gives a frequency of 4.4×10^{-4} blowouts per well drilled.

Based on the given frequency and information provided by ONGC on the proposed project drilling program the blow out frequency for the proposed project has been:

No of wells to be drilled per year = 10 (A)

Blow out frequency for exploratory drilling = 4.4×10^{-4} per well drilled (B)

Frequency of blow out occurrence for the proposed project = (A X B) = $10 \times 4.4 \times 10^{-4}$

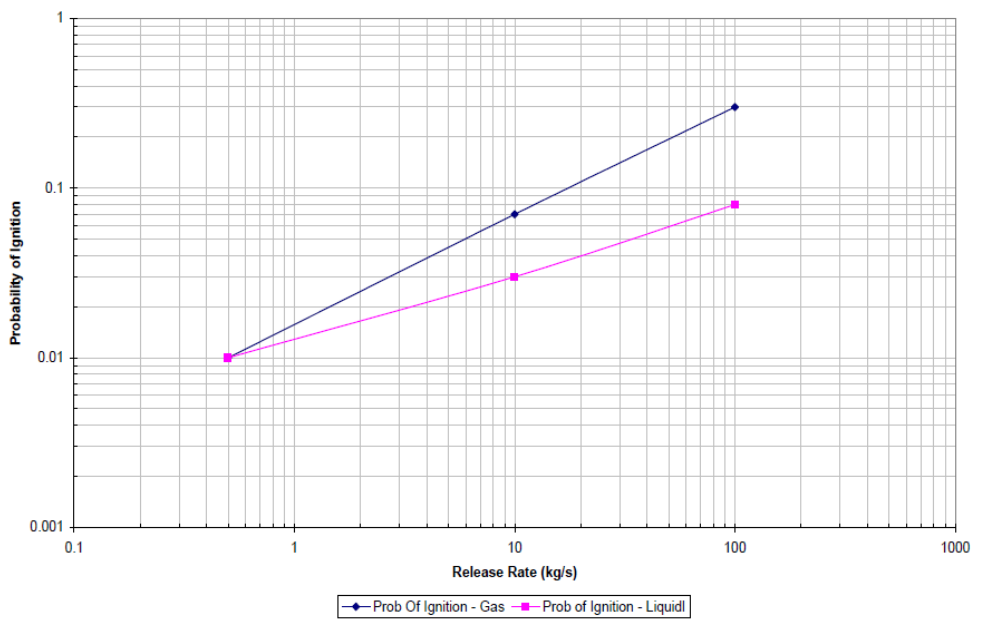
= 4.40×10^{-3} per well drilled

Thus, the blow out frequency for the proposed project is calculated at **4.40 X 10^{-3} per well drilled i.e. the likelihood of its occurrence is "Occasional/Rare"**

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***).

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 wells to be drilled = 50 (A) Blow out frequency for exploratory drilling = 4.4 X 10^{-4} per well drilled (B) Blow out ignition probability = 0.09 (C) Probability of Blow out ignition for the proposed project = (A X B X C) = 50 X 4.4 X 10^{-4} X 0.09 = 1.98 X 10^{-3}= ~ 0.198%

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

Hence based on the aforesaid calculation the probability of ignition of blow out releases of hydrocarbons for the proposed exploratory drilling Project will be about ~0.198% and can be considered to be as negligible.

Blowout Consequence Analysis

Blow out from a hydrocarbon exploratory well may lead to the following possible risk consequences:

a. Jet fires resulting from ignited gas blow outs

The proposed project involving exploration of gas wells for natural gas releases leading to jet fire, modelling has been based considering methane which has been identified as the principal constituent (~ 95%) of natural gas.

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 1.6***) have been considered for nature gas release consequence modelling:

Table 1.6 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 modeling 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 modeling the release of a flammable gas that may catch fire—but which is not currently burning—ALOHA can predict the flammable area of the vapor cloud so that flammability hazard can be established.

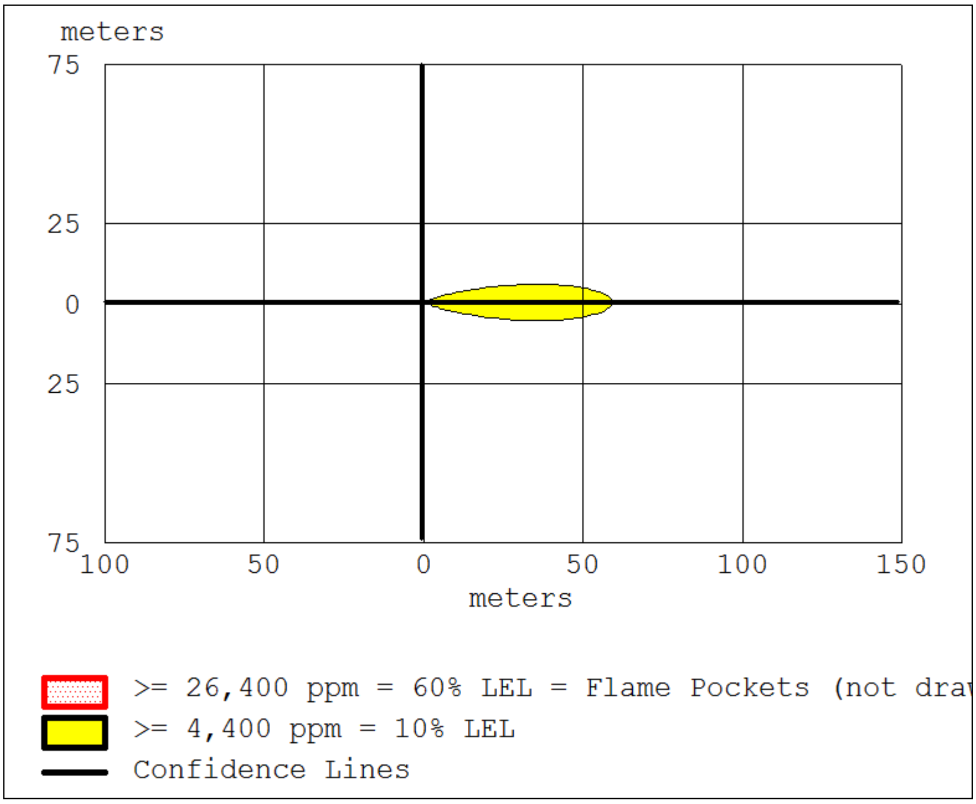
The flammable area is the part of a flammable vapor cloud where the concentration is in the flammable range, between the Lower and Upper Explosive Limits (LEL and UEL). These limits are percentages that represent the concentration of the fuel (that is, the chemical vapor) in the air. If the chemical 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 ***Figures 6.3-6.5*** below.

Figure 1.3 Scenario I: Risk Contour Map



THREAT ZONE:
Threat Modelled: Flammable Area of Vapor Cloud

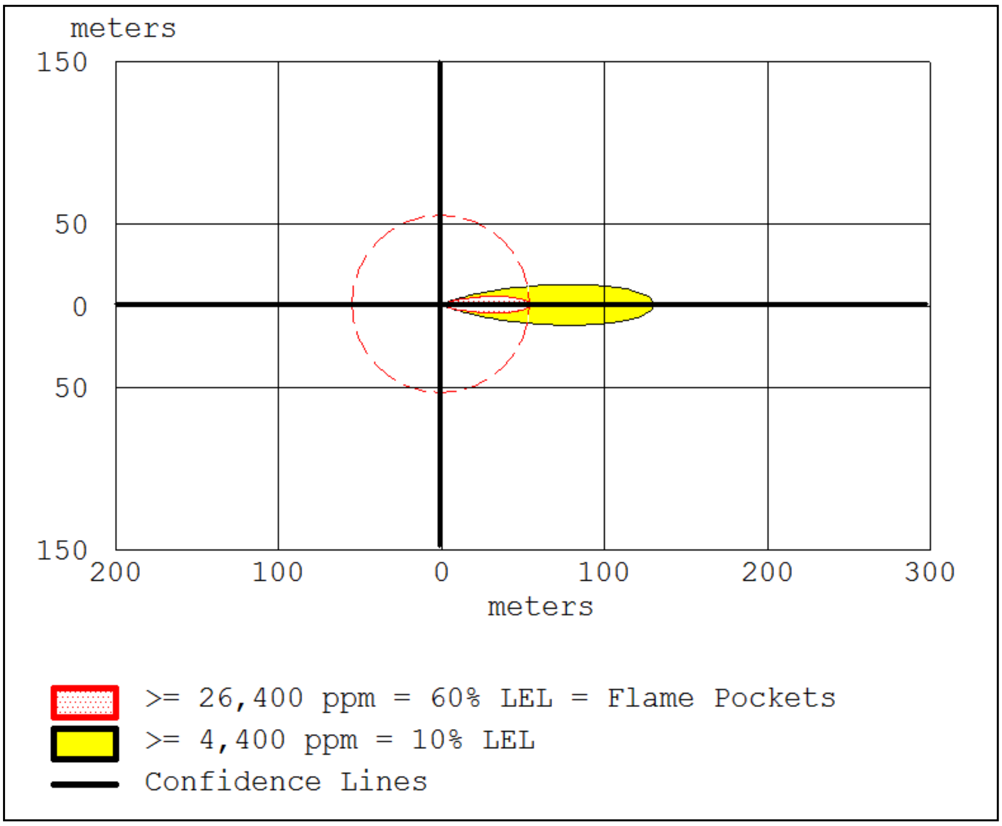
Model Run: Gaussian

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:

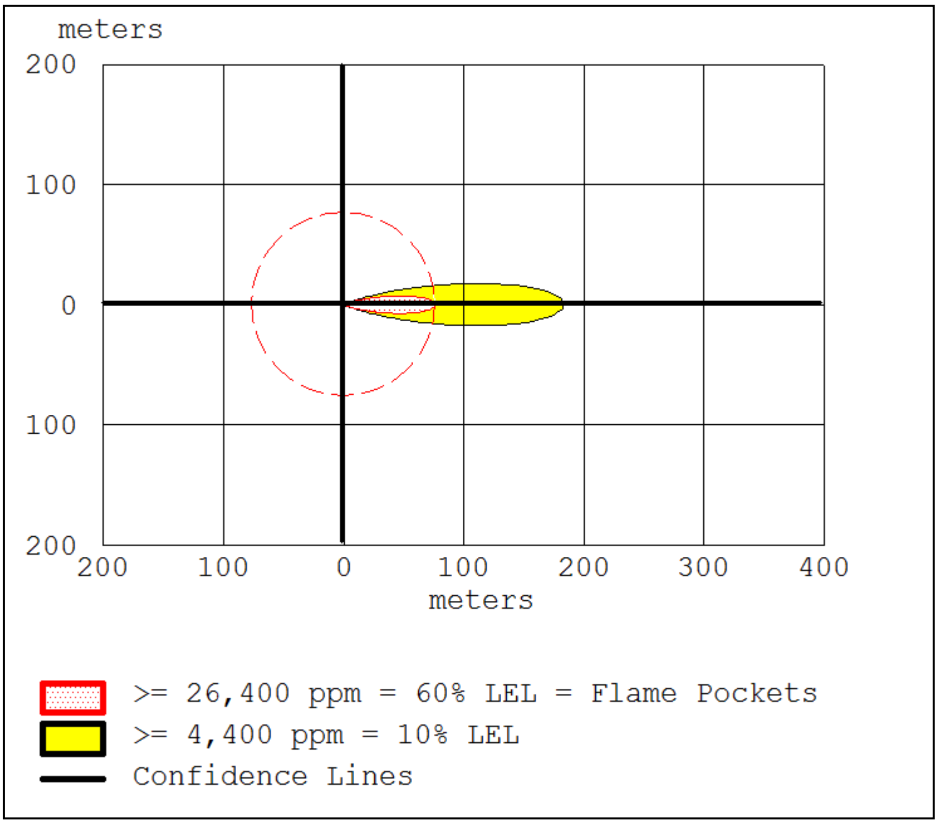
Threat Modeled: Flammable Area of Vapor Cloud

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 1.7*** below.

Table 1.7 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 modeled 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 modeling using ALOHA a delayed ignition time of 5 minutes was considered of the vapour cloud mass. However the threat modeled 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 drilling has been presented below. For calculating the risk significance, the likelihood ranking is considered to be "3" as the frequency analysis for blow outs incidents is computed at "*$4.4 X 10^{-3}$*" whereas the consequence ranking has been identified to be as "4" given the worst case scenario modedling (blast overpressure) indicates that the LOC was never exceeded leading to multiple fatalities (For criteria ranking please refer to Table 7.1 & 7.2).

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

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

1.1.4 *Hydrocarbons Leaks Due to Loss of Containment While Drilling*

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 **6.0×10^{-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 immediatelyignited, 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 modeling using ALOHA a delayed ignition time of 5 minutes was considered of the vapour cloud mass. However the threat modeled 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 7.7 below.

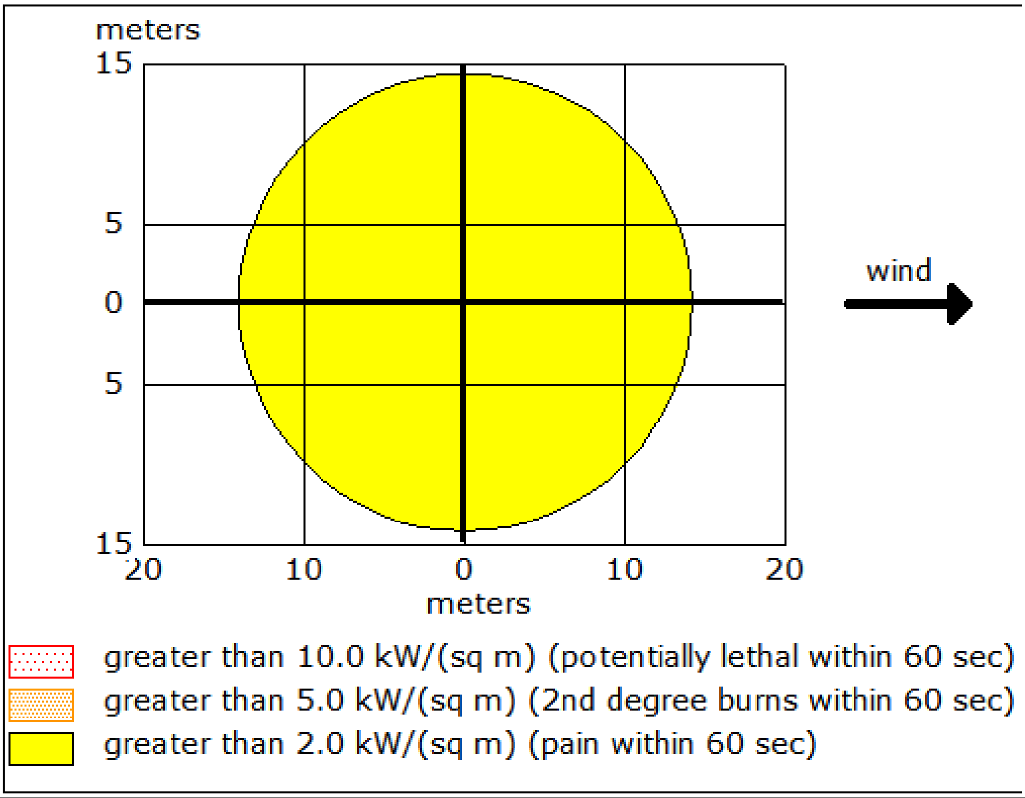
Figure 1.7 ***Overpressure Risk Modeling – Well Releases during drilling***

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

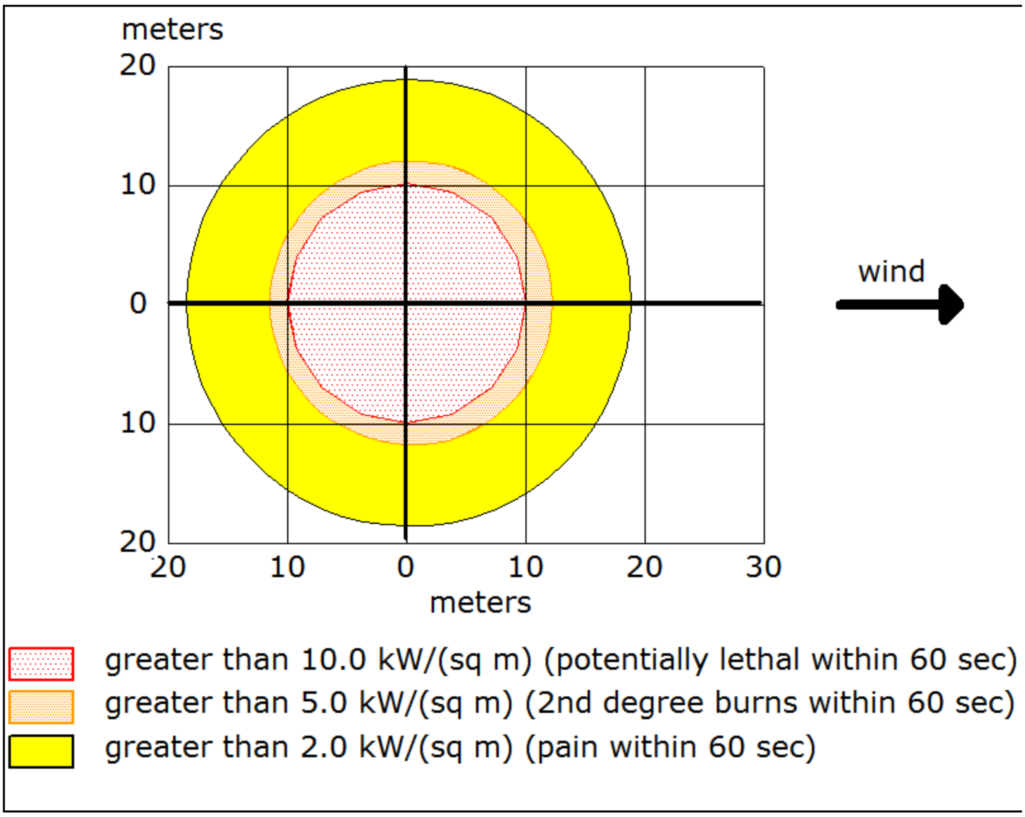
Model Run: Gaussian

Red : 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: 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 1.8* below.

Table 1.8 Thermal Radiation Zone -Natural Gas Release Scenario - 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 during well testing) 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 occurence.

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 "3" as the frequency analysis for blow outs incidents is computed at "*6.0 X* 10^{-3}" whereas the consequence ranking has been identified to be as "4" given the worst case scenario modedling (blast overpressure)/jet fire indicates that the LOC was never exceeded leading to multiple fatalities (For criteria ranking please refer to Table 7.1 & 7.2).

Risk Ranking – Jet Fire/Blast Overpressure from Well Releases (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 and technologies.			

1.1.5 Hazardous Material Releases or Mishaps

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.

1.1.6 External Hazards

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.

Other natural hazards, such as earthquake are predominan inTripuar region. The risk of external hazards causing blowouts has been considered in the frequency estimation of oil and gas blowouts in section 6.4.1.

1.1.7 *Individual Risk*

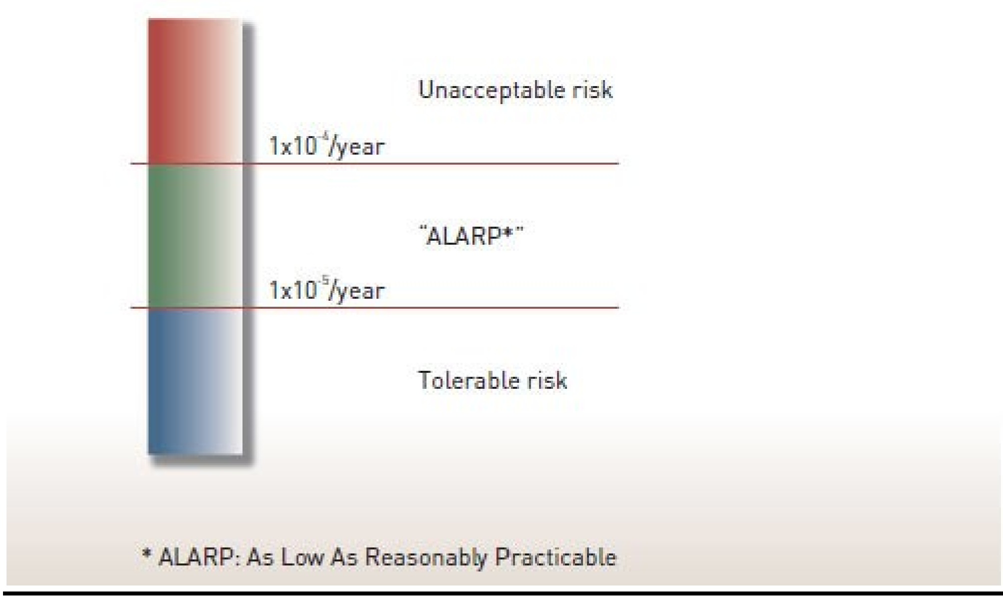
Individual risk is the probability at which an individual may be expected to sustain a given level of harm from the realization of specified hazards. In simple terms it is a measure to assess the overall risk of the area concerned thus to protect each individual against hazards involving hazardous chemicals, 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 1.10*** below.

Figure 1.10 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 tesing. Based on the above equation the individual risk as calculated including the tolerance criteria has been presented in the ***Table 1.9*** below.

Table 1.9 ***Individual Risk – Blow Out & Loss of Containment***

Accident Scenarion-Frequency	Fatality Probability	Individual Risk	Individual Risk Criterion
A. Blow Outs			
$4.4 X 10^{-4}$	0.10	$4 X 10^{-5}$	ALARP
$4.4 X 10^{-4}$	0.01	$4 X 10^{-6}$	Tolerable
B. Well Releases			
$6.0 X 10^{-3}$	0.01	$6 X 10^{-5}$	ALARP

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 equipments etc will be adopted by ONGC to minimise the risk further (Refer *Section 6.6* for details).

1.1.8 Preventive and Mitigation Measures

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 ONGC.
- 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, ONGC 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

The contingency plan of ONGC for onshore blowout of drilling rig is presented schematically in ***Figure 7.11***.

Figure 1.11 Schematic presentation of contingency plan for blow out of drilling rig