Environmental Impact Assessment Report for the proposed Onshore Oil & Gas Exploratory Drilling and Testing of Hydrocarbons in NELP IX Block: AA-ONN-2010/3 in Sadiya Area of Tinsukia District in the state of Assam.

Risk Assessment Report

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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 drilling of five (5) exploratory wells in AA-ONN-2010/3 block in Tinsukia district, Assam. 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 activities 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/pipeline leaks constitute the major potential hazards that may be associated with the proposed onshore exploratory well drilling at the identified well locations within the 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.

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 exploratory drilling activities including operation of associated equipment's, mud chemicals storage and handling etc..

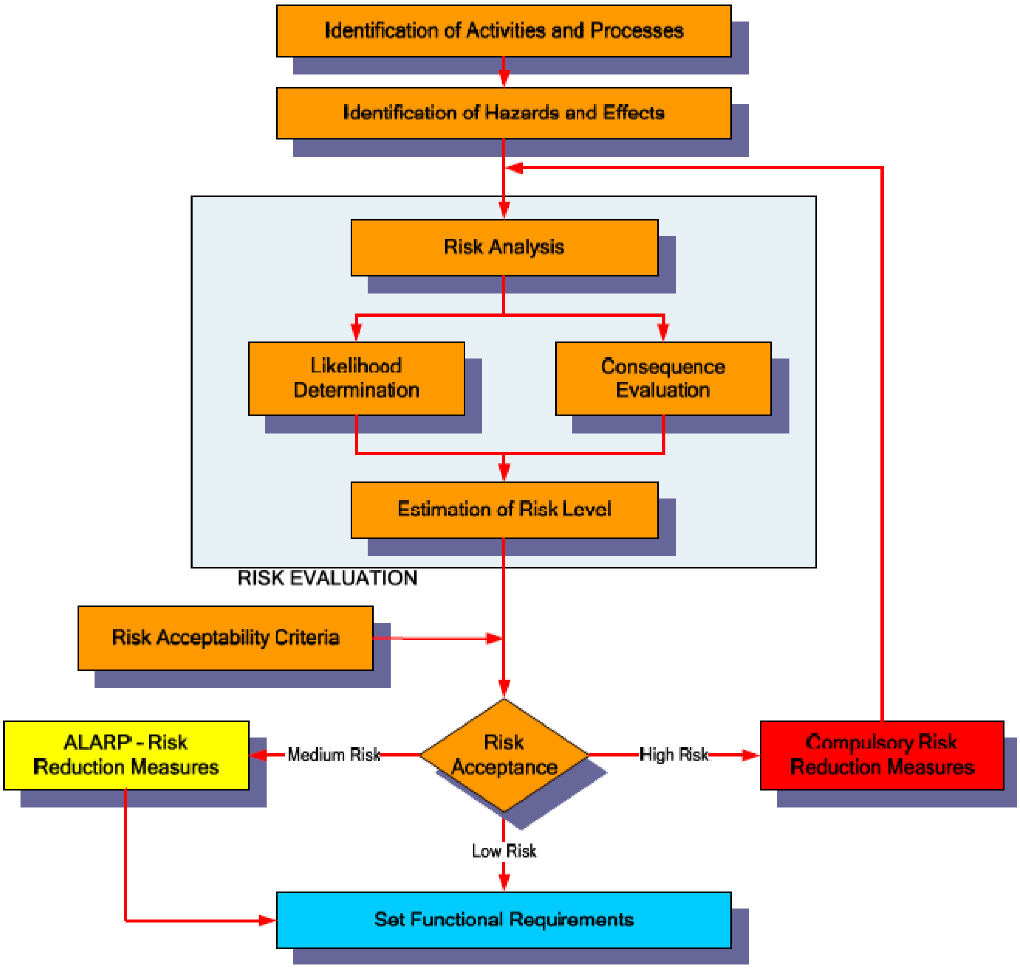
* Analyze the possible likelihood and frequency of such risk scenarios by reviewing historical accident related data for onshore oil and gas industries.
* Predict the consequences of such potential risk scenarios and if consequences are high, establish the same by through application of quantitative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

1.2 *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, hydrocarbon leaks due to loss of containment, non-process fire 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 OIL. 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 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;
- Hydrocarbon leaks due to loss of containment while drilling;
- 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; 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 OIL.

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

[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

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 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 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

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 a 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*** below.

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

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 drilling and operations, 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[1] report and are presented in ***Table 1.6*** below. The basis 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

[1] "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.

Based on the aforesaid frequency and information provided by OIL the blow out frequency for the proposed project has been computed as follows:

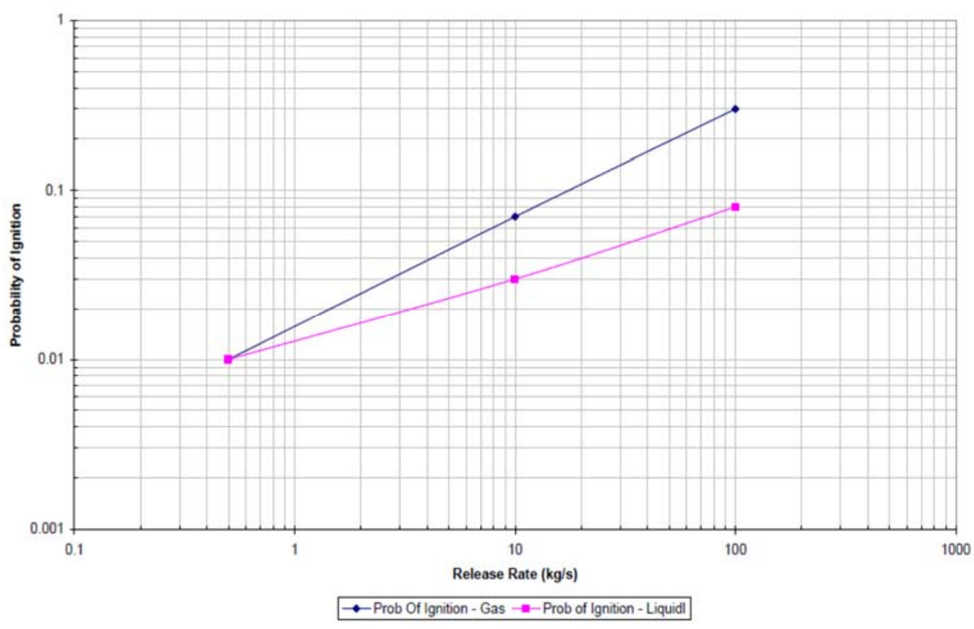
No of wells to be drilled per year = 5 (A) Blow out frequency for exploratory drilling (oil) = 1.23×10^{-4} per well drilled (B) Blow out frequency for exploratory drilling (gas) = 1.12×10^{-4} per well drilled (C) Frequency of blow out occurrence for the proposed project (oil) = (A X B) = $5 \times 1.23 \times 10^{-4}$ = 6.15×10^{-4} per well drilled Frequency of blow out occurrence for the proposed project (gas) = (A X C) = $5 \times 1.12 \times 10^{-4}$ = 5.6×10^{-4} per well drilled

Thus, the blow out frequency for the proposed project for oil and gas wells have been at **6.15×10^{-4} and 5.60×10^{-4} per well drilled per year respectively i.e. the likelihood of its occurrence is 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*).

Figure 1.2 *Ignition Probability Vs Release Rate*



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

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 per year = 5 (A)

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

Blow out frequency for exploratory drilling (gas) = 1.12 X 10^{-4} per well drilled (C)

Blow out ignition probability = 0.09 (D)

Probability of Blow out ignition for oil exploratory wells (oil) = (A X B X D) = 5 X 1.23 X 10^{-4} X 0.09

= 5.53 X 10^{-5}= ~ 0.0055%

Probability of Blow out ignition for gas exploratory wells = (A X C X D) = = 5 X 1.12 X 10^{-4} X 0.09

= 5.04 X 10^{-4}= ~ 0.0050%

Hence based on the aforesaid calculation the probability of ignition of blow out releases of hydrocarbons for the proposed project is computed to be around ~0.0055% and ~0.0050% respectively and can be considered to be as negligible.

Blowout Consequence Analysis

Blow out from a hydrocarbon exploratory 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 vapourizing hydrocarbon fuel where the fuel vapour 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 evapouration of hydrocarbons from a pool forms a cloud of vapour above the pool surface which, on ignition, leads to generation of pool fire.

For the purpose of consequence modelling 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/m²s)

The mass burning rate for crude oil has been considered to be 0.05 kg/m²s
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 modelling is provided in ***Table 1.9***.

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.

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

Where:

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

For crude oil **HC = 42600000 joules/kg; HV = 957144 joules/kg; CP = 1892 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.

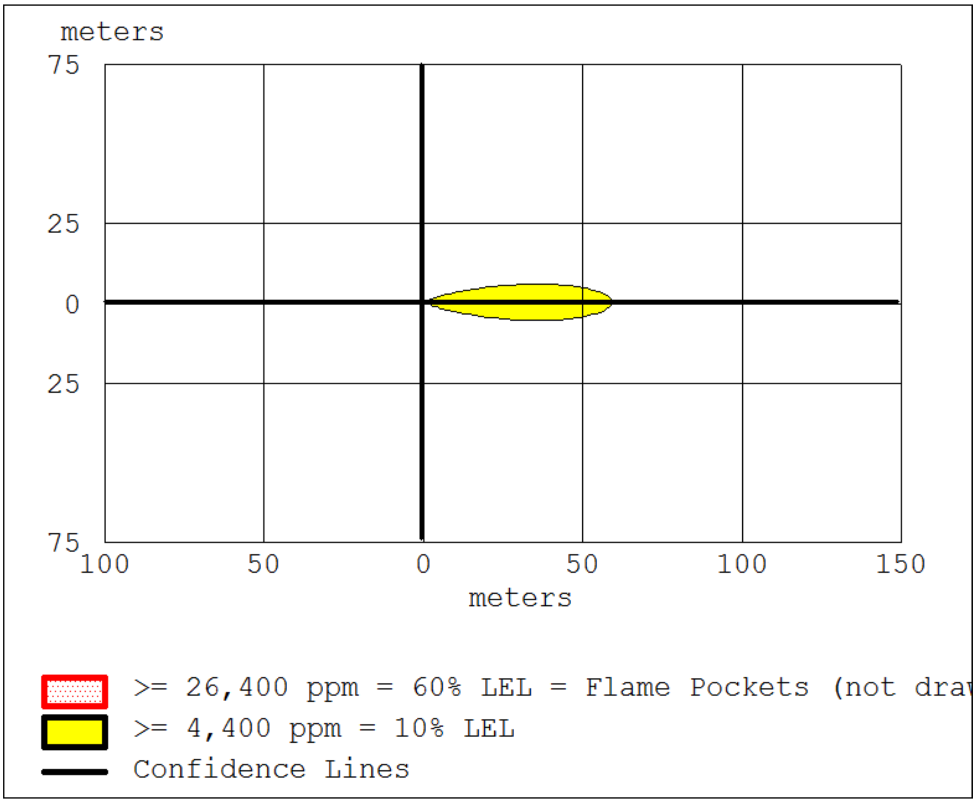
The flammable area is the part of a flammable vapour cloud where the concentration is in the flammable range, between the Lower and Upper Explosive Limits (LEL and UEL). These limits are percentages that represent the concentration of the fuel (that is, the chemical vapour) in the air. If the chemical vapour 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 vapour 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 1.3-1.5*** below.

Figure 1.3 Scenario I: Risk Contour Map



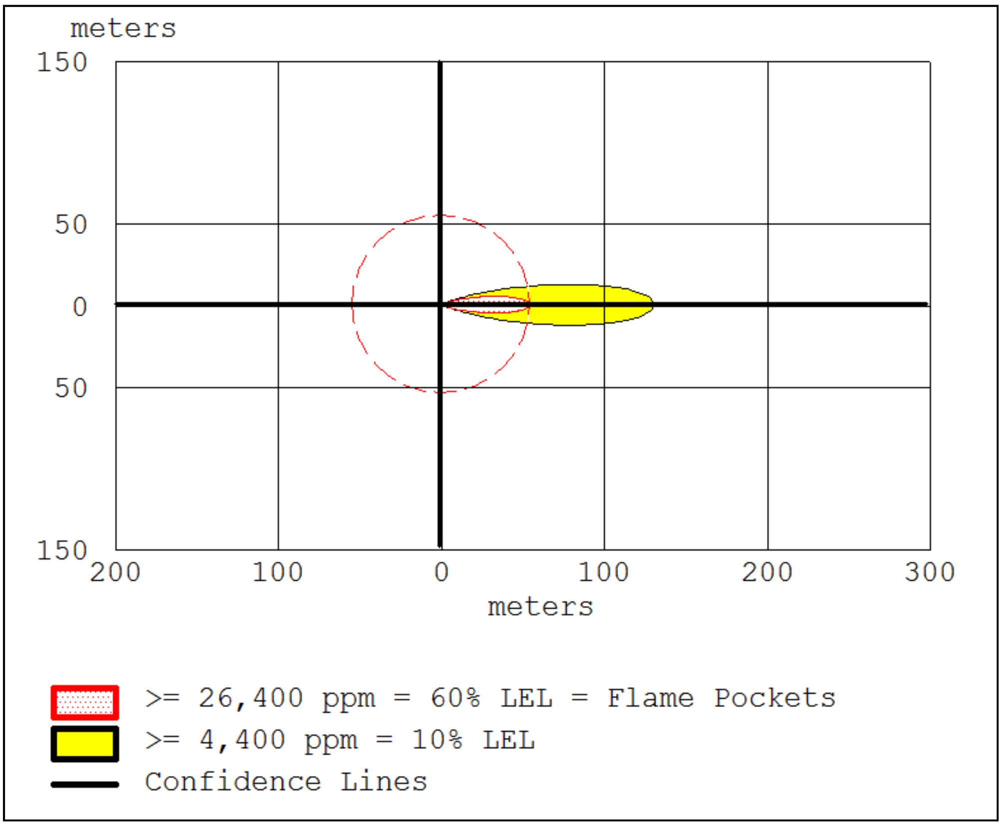
THREAT ZONE:
Threat Modelled: Flammable Area of Vapour Cloud

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:

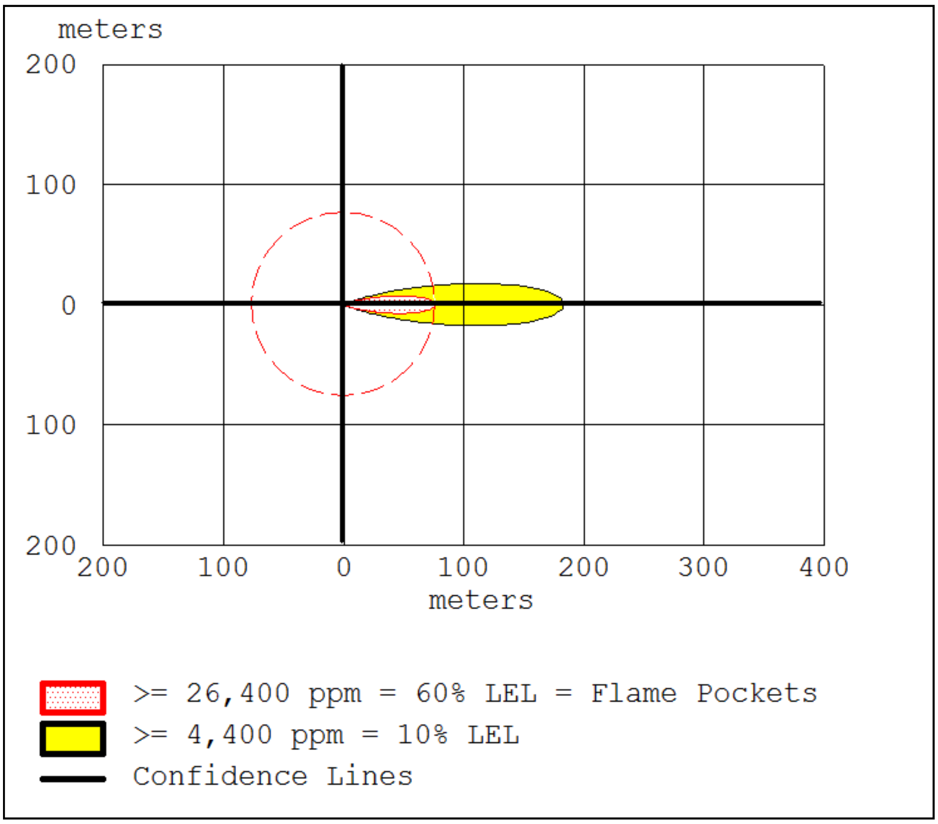
Threat Modeled: Flammable Area of Vapour Cloud

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 Modelled: Flammable Area of Vapour 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***.

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

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 vapour cloud zone/flame pockets' resulting from accidental release of natural gas from a well 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 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 "***5.60 X 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 & 1.2).

Risk Ranking – Blowout Natural Gas Release (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.			

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 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***.

Figure 1.7 ***Overpressure Risk Modelling – 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)

Well Fluid Fires during Testing

Well testing is the only time when formation fluids are intentionally brought to surface on the drilling rig. There is therefore a hazard from possible releases of flammable fluids whilst they are flowing or stored. All testing operations will be in line with predetermined procedures. There will be a number of safe working conditions that must be in place before testing is commenced to protect personnel from flammable and toxic hazards.

When required, well testing equipment is brought onto the rig on a skid and positioned on the pipe deck. It typically comprises of a heater, a test separator, an oil pump, metering and associated pipe work.

In the case of leakage from the separator or associated pipe work, the release may be on the liquid or vapour side. In the case liquid release, there will be a pressurised liquid release followed by gas depressurisation. In case of a gas release, there will be a gas release with little liquid entrained assumed. Isolation from the reservoir is possible via the well head master valve, topsides BOP or by the emergency shut down (ESD) valve at the inlet to the separator.

b) Jet Fire

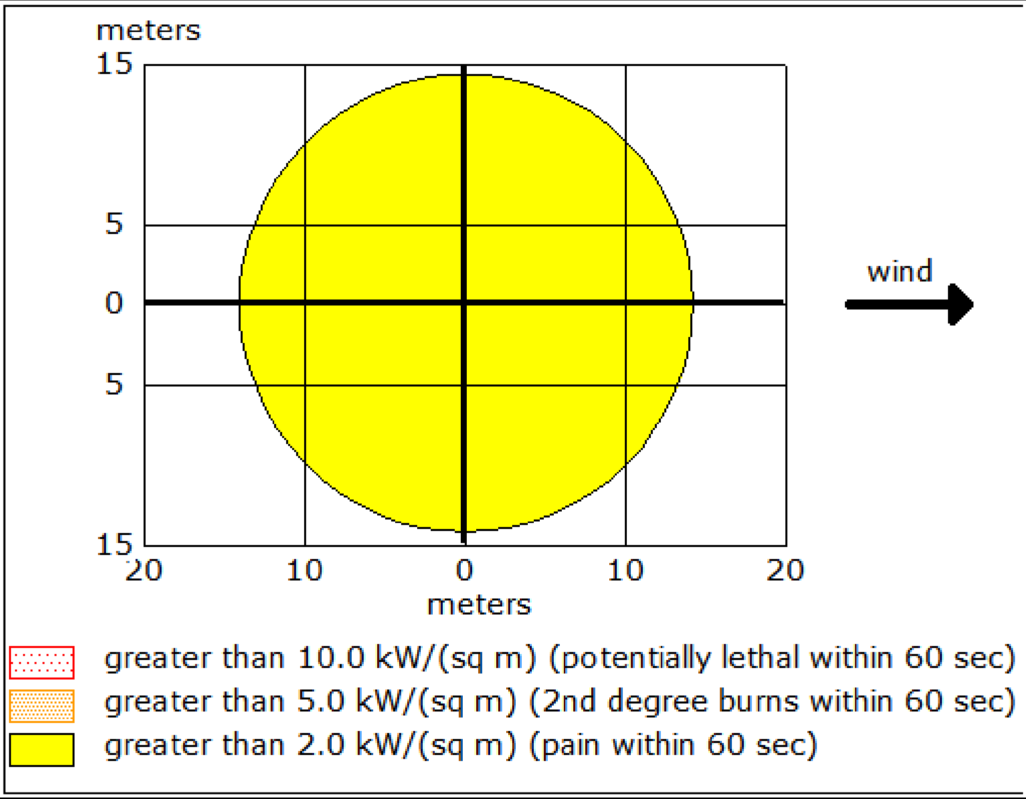
The term jet fire is used to describe the flame produced due to the ignition of a continuous pressurised leakage from the pipe work. Combustion in a jet fire occurs in the form of a strong turbulent diffusion flame that is strongly influenced by the initial momentum of the release. Flame temperatures 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 hypothetical scenarios considered for evaluating the risks related to jet fire has been presented in ***Table 1.13***.

Table 1.13 Failure Scenarios – Well Testing

Well Test Separator Pressure, kg/ cm^2	Leak size, mm	Gas release rate, Kg/s
20.04	25	1.460
	50	5.86

The thermal radiations distances due to jet fire has been presented 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 Modelled: Thermal radiation from jet fire

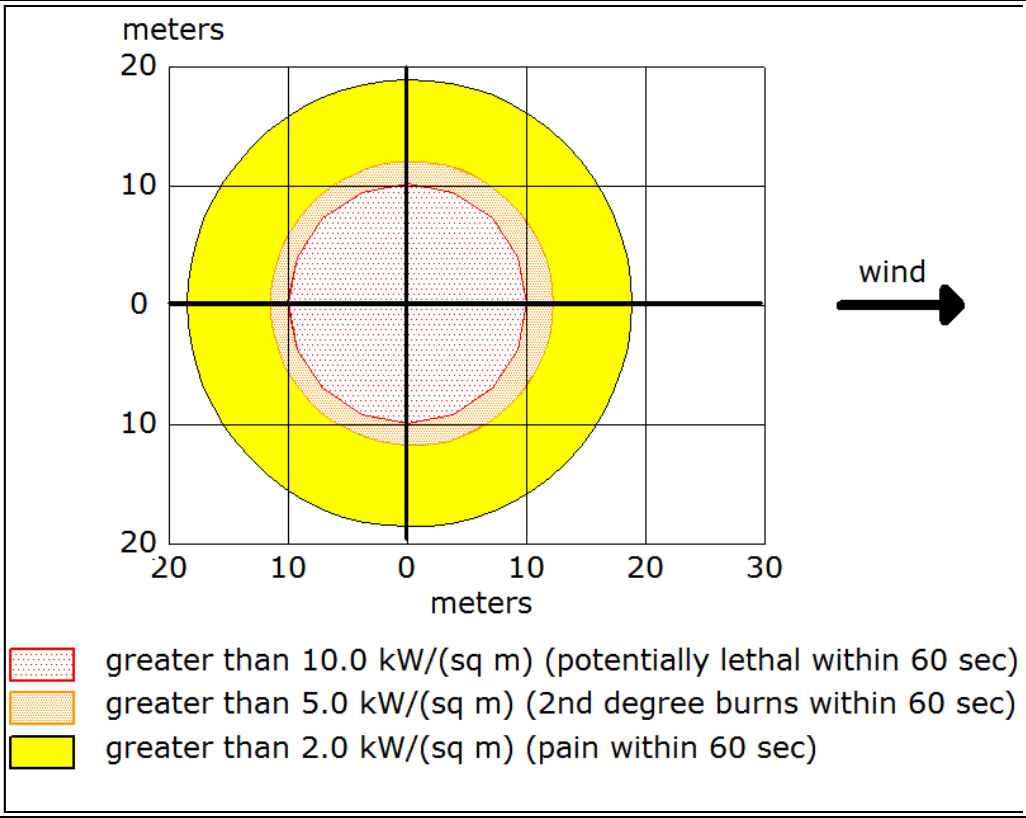
Model Run: Gaussian

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 Modelled: 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 1.14*** below.

Table 1.14 *Thermal Radiation Zone -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 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 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 "3" as the frequency analysis for blow outs incidents for gas exploratory well is computed at "***5.60 X 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 any multiple fatalities (For criteria ranking please refer to Table 1.1 & 1.2).

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.			

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.

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

1.2.2 *Disaster Management Plan*

Disaster Management is a process or strategy that is implemented when any type of catastrophic event takes place. The Disaster Management Plan envisages the need for providing appropriate action so as to minimize loss of life/property and for restoration of normalcy within the minimum time in event of any emergency. Adequate manpower, training and infrastructure are required to achieve this.

The objectives of Disaster Management Plan are as follows:

- Rapid control and containment of the hazardous situation;
- Minimising the risk and impact of occurrence and its catastrophic effects;
- Effective rehabilitation of affected persons and prevention of damage to Property and environment;
- To render assistance to outside the factory.

The following important elements in the disaster management plan (DMP) are suggested to effectively achieve the objectives of emergency planning:

- Reliable and early detection of an emergency and careful response;
- The command, co-ordination, and response organization structure along with efficient trained personnel;
- The availability of resources for handling emergencies;
- Appropriate emergency response actions;
- Effective notification and communication facilities;
- Regular review and updating of the DMP;
- Proper training of the concerned personnel.

Emergency Identified

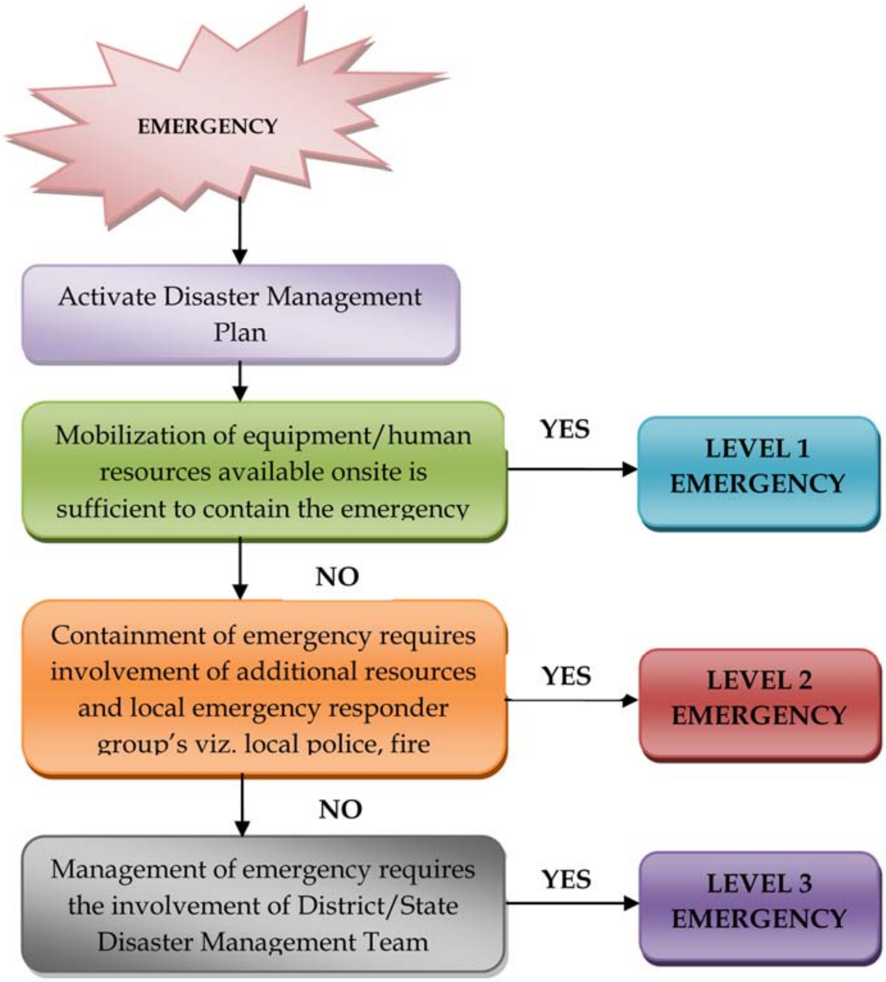
Emergencies that may arise:

- Such an occurrence may result in on-site implications like :
  - Fire or explosion;
  - Leakage of natural gas; and
  - Oil spillage and subsequent fire.
- Incidents having off-site implications can be:
  - Natural calamities like earthquake, cyclone, lightening, etc.
- Other incidents, which can also result in a disaster, are :
  - Agitation / forced entry by external group of people;
  - Sabotage.

Emergency Classification

Due consideration is given to the severity of potential emergency situation that may arise as a result of accident events as discussed in the **Risk Analysis (RA)** study. Not all emergency situations call for mobilization of same resources or emergency actions and therefore, the emergencies are classified into three levels depending on their severity and potential impact, so that appropriate emergency response procedures can be effectively implemented by the Emergency Response Team. The emergency levels/tiers defined with respect to this project based on their severity have been discussed in the subsequent sections with 'decision tree' for emergency classification being depicted in ***Figure 1.10.***

Figure 1.10 Emergency Classification "Decision Tree"



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 classified as:

Level 1 Emergency

The emergency situation arising in any section of one particular plant / area which is minor in nature, can be controlled within the affected section itself, with the help of in-house resources available at any given point of time. The emergency control actions are limited to level 1 emergency organization only. But such emergency does not have the potential to cause serious injury or damage to property / environment and the domino effect to other section of the affected plant or nearby plants/ areas.

Level 2 Emergency

The emergency situation arising in one or more plants / areas which has the potential to cause serious injury or damage to property / environment within the affected plant or to the nearby plants / areas. This level of emergency situation will not affect surrounding community beyond the power plant facility. But such emergency situation always warrants mobilizing the necessary resources available in-house and/or outsources to mitigate the emergency. The situation requires declaration of On – Site emergency.

Level 3 Emergency

The emergency is perceived to be a kind of situation arising out of an incident having potential threat to human lives and property not only within the power plant facility but also in surrounding areas and environment. It may not be possible to control such situations with the resources available within OIL facility. The situation may demand prompt response of multiple emergency response groups as have been recognized under the off-site district disaster management plan of Tinsukia district.

Risk Reduction Measures - Blowouts

Risk reducing measures include:

- Kick simulation training for personnel;
- Presence of well-trained engineers;
- Appropriate well design;
- Good well control procedures;
- Appropriate mud weight formulations;
- Installation of primary and secondary blow out preventors; and
- Trained and skilled operation staff.

Well Control System

The programme of drilling of wells will include integration of the drilling process to meet with any situation related to well kick situation (kicks), blowouts etc. as per the following description:

- *Well Kick Situation*: While drilling, if the formation pressure exceeds the hydrostatic pressure exerted by the drilling fluid, formation fluid flows in to the well bore. This is called kick. Primary means of well control is to have sufficient over-balance above the formation pressure. For some reasons if an unexpected over-pressurised formation is encountered while

drilling and if the well control situation arises, rig is equipped with equipment & personnel to control such situations;
- *Blowout*: Uncontrolled "well fluid flow situation" eventually leads to a blowout. Blow out can cause a partial or total destruction of drilling rig. Blowouts are often associated with hydrocarbon spill followed by fire.
- *Well Control Equipment*: This set of equipment is called "Blowout Preventers (BOP)" Blow Out Preventer consists of:
  a) *Annular Preventer*, which can generally close on any size or shape of tubular in the well bore, which closes the annular space between drill string and casing;
  b) *Ram Preventer*, which either can be Pipe Rams or Shear Rams. Pipe rams also close the annulus between drill string and casing, but they have a fixed size. As such a specific pipe rams can be closed on a specific size of pipe. Shear rams are generally the last choice of preventer to be operated as they shear drill string and shut off the well bore.

All pipe fittings, valves and unions placed on or connected to BOP equipment, well casing, casing head housing, drill pipe or tubing will have a working pressure rating at least equivalent to that of the component to which it is fitted. Drilling or workover operations will not proceed until BOP equipment is found to be serviceable by visual inspection and appropriate pressure testing.

In addition to the instrumentation to indicate the availability of air pressure and fluid pressure, the following safety features will be considered for the well control system:

- Relief valve,
- Accumulator low pressure alarm
- Reservoir low level alarm
- Air driven hydraulic fluid charge pumps
- Electric driven hydraulic pump to be connected to emergency generator
- Fire resistant hydraulic control hoses, tested to rated pressure of the unit and control fluid
- Appropriate location of remote operating panels
- Redundant function plugged off.

Leaks from Equipment

Accidents related to leaks from equipment can be minimised by:
- Ensuring that equipment is designed, installed and maintained as per international standards;
- Implementing a robust preventive maintenance system of all safety critical equipment; and
- Efficient test separator;
- Installing H_2S gas detection system at the drilling site prior to drilling activities to rapidly detect leaks.

Storages

Leaks from the storage of diesel tank can be reduced by proper preventive maintenance and robust safety management and security systems. For the storage tank, secondary containment to be provided to contain loss of containment in case of leaks / failure of the storage tank as per the recommendation and approval of Chief Controller of Explosives, Nagpur.

For handling and use of well logging tools containing radioactive material is to be subject to handling by authorised personnel, containers and procedures as specified by Atomic Energy Regulatory Board.

Fire Safety Arrangements

In case of discovery of hydrocarbons, the test separator and other related equipment will be adequately instrumented & suitably interlocked to take care of any eventuality due to pressure and/or level in the separator. The gases are led to the flare system while the oily water to the oil water separator. The oil recovered and treated water will be led to recovery pit.

A hydrocarbon gas detection system with suitable alarm system will be provided at the drilling site for two alarm levels at 20% and at 60% LEL.

All running equipment will be provided with overload relays, which will trip-off breakers at the MCC. All motors will have a local FP type Start-Stop push button. Dry chemical type fire extinguishers will be conveniently located at the drilling rig.

Management of Oil Spills/Leaks and Soil contamination

The following measures shall be implemented to prevent contaminations from oil spills and leaks:

- Potentially contaminated surface run-off from the drilling site to be routed via an oil trap system where oils to be skimmed off and put in drums for removal from site while non-contaminated run-off will be routed, possibly via a silt trap, through a discharge pipeline to a suitable off-site location;
- Contained area for storage of chemicals and hazardous materials and wastes;
- Channels, gutters, and drip pans followed by oil trap to be installed to control small operational spills that may occur around pumps, test separator, etc.
- Areas susceptible to potential spills of contaminants, such as diesel fuel loading will be covered in an impermeable layer (hard cover) with drainage to a suitable holding, separation or treatment facility.

In the event of a spill occurs the order of priority is:

- to ensure human safety;
- eliminating the source of the spill;
- monitoring of the spill;

   - minimise risk of fire or explosion;
   - contain the spill to minimise the environmental and material damage;
   - recover spilt material;
   - store recovered material safely;
- Update as further communications received;
- Inform all OIL radio stations of incident, and to clear non-essential traffic in case any spill extends offsite;
- Confirm the sighting, source and extent of spill;
- Initiate actions to stop or reduce any discharge of oil, if safe to do so;
- Ensure all possible ignition sources are isolated (i.e. engines, equipment, etc.); Consider need for evacuation of any facility affected;
- Ensure all actions to eliminate/minimize discharge of oil have been initiated; monitor measures to contain spill;
- Notify Emergency Response Team Leader, Notify Incident Controller of incident and send radio and other communications on instruction from Incident Controller.
- Provide full incident briefing and likely requirements; Complete Pollution Report;
- Activate containment and clean-up as required, mobilize equipment /personnel;
- Determine likely waste management requirements and dispose recovered material as per authorisation for hazardous wastes from SPCB.

The details for implementation mechanism of the above measures are described in Disaster Management Plan.

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.



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