Environmental Impact Assessment & Environment Management Plan For Pre-Drill of Khagarijan Oil and Gas Field Area in Dibrugarh and Tinsukia District of Assam

QUANTITATIVE RISK ASSESSMENT

Prepared for:

Oil India Limited

Prepared by:

ARCADIS Design & Consultancy for natural and built assets

Arcadis India Pvt. Ltd.
(Formerly SENES Consultants India pvt Ltd)
Accreditation No. – NABET/EIA/1417/SA 028 *dated 8th June 2017*

May 2017

1 Quantitative Risk Assessment

1.1 Quantitative Risk Assessment & Disaster Management Plan

This section on Quantitative Risk Assessment (QRA) aims to provide a systematic analysis of the major risks that may arise as a result of drilling and testing activities by OIL in the Khagarijan Field. 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.

Box 1.1: QRA – Integrated Risk Management Process

QRA as a part of integrated risk management process for the proposed project consists of the following iterative steps:

- ***Identification of hazards***
- ***Setting Acceptance Standards for the defined risks***
- ***Evaluation of likelihood and consequences and risks of possible events.***
- ***Confirmation of arrangements to mitigate the events and respond to the same on occurrence.***
- ***Establishment of performance standards***
- ***Establishment of continuous monitoring, review and auditing of arrangements***

The risk study for the drilling and testing activities has considered all aspects of operation of the drilling rig and other associated activities during the drilling phase. Oil spills, loss of well control / blow-out and process leaks constitute the major potential hazards that may be associated with the proposed drilling for oil and gas in the Khagarijan Field. The study however does not examine the risks or hazards associated with development and production program of the wells.

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 drilling activities, following specific objectives need to be achieved.

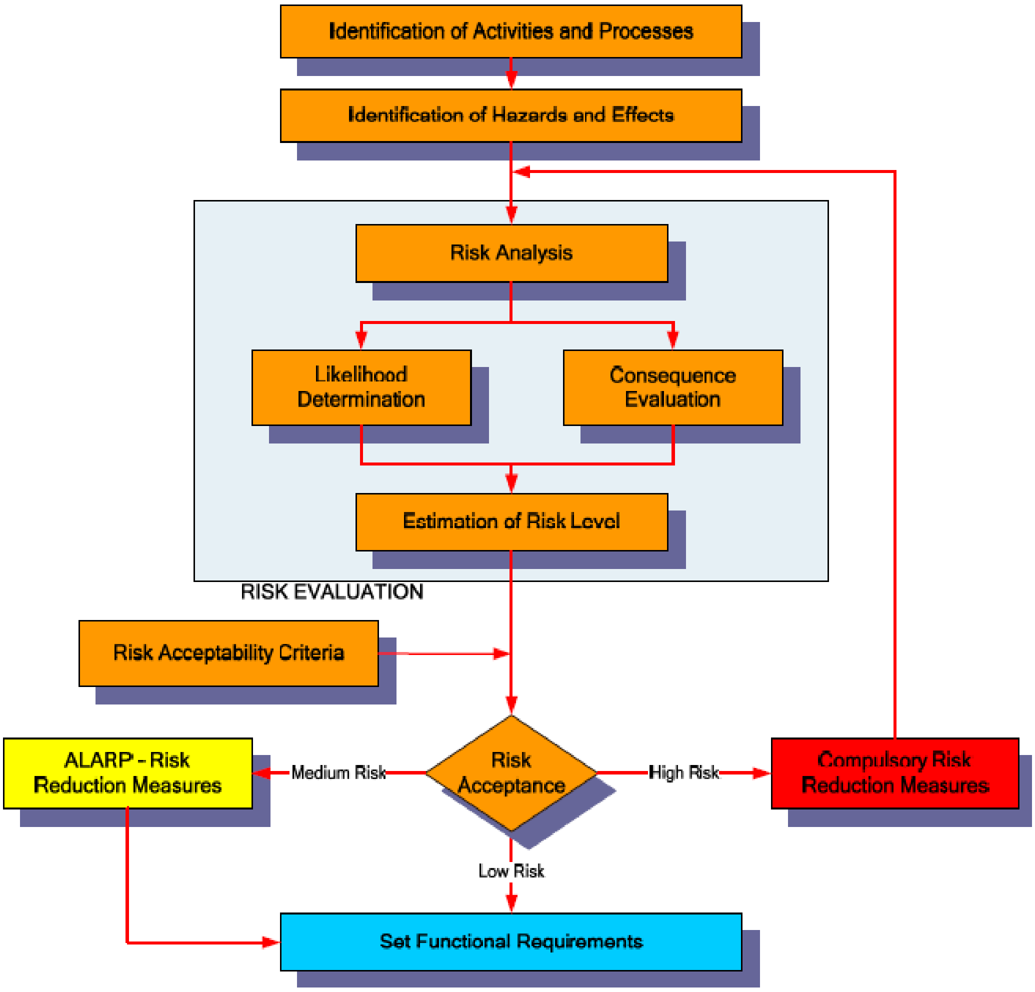
- Identify potential risk scenarios that may arise out of proposed drilling activities like operation of ancillary facilities and equipments, mud chemicals storage and handling etc.
- Analyze the possible likelihood and frequency of such risk scenarios by reviewing historical accident related data for 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, 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 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 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 as part of its Emergency Response Plan. In addition, guidance provided by knowledge platforms/portals of the upstream oil & gas industry including OGP, ITOPF 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 drilling operations to be undertaken in the Khagarijan Field, 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 pool fires/jet fires and oil spills
- Process leaks and fires
- Non-process fires / explosions

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.

Further, taking into account vulnerability of the project region to floods as discussed in **section 3.1.12 of EIA Report** due consideration has been given in identifying hazards and risks arising out of such natural calamities/hazards in the risk assessment study undertaken for the drilling activities.

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*

[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.*

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.*

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 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 as per the HSE management system of OIL 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 well bore. 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 Preventor (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 1.2** below.

BOX 1.2: 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 Technica 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[3] 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
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 operations, blow out frequencies per well drilled have been considered. However due to the lack of availability of representative data on onshore blow out incidents relevant offshore accident database *viz*. SINTEF Offshore Blowout Database, OGP Risk Assessment Data Directory (RADD) and Scandpower which have been referred. The blow out frequency per operation as calculated is based on the SINTEF Offshore Blowout Database for oil and gas extraction industry has been presented in the **Figure 1.2** below.

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

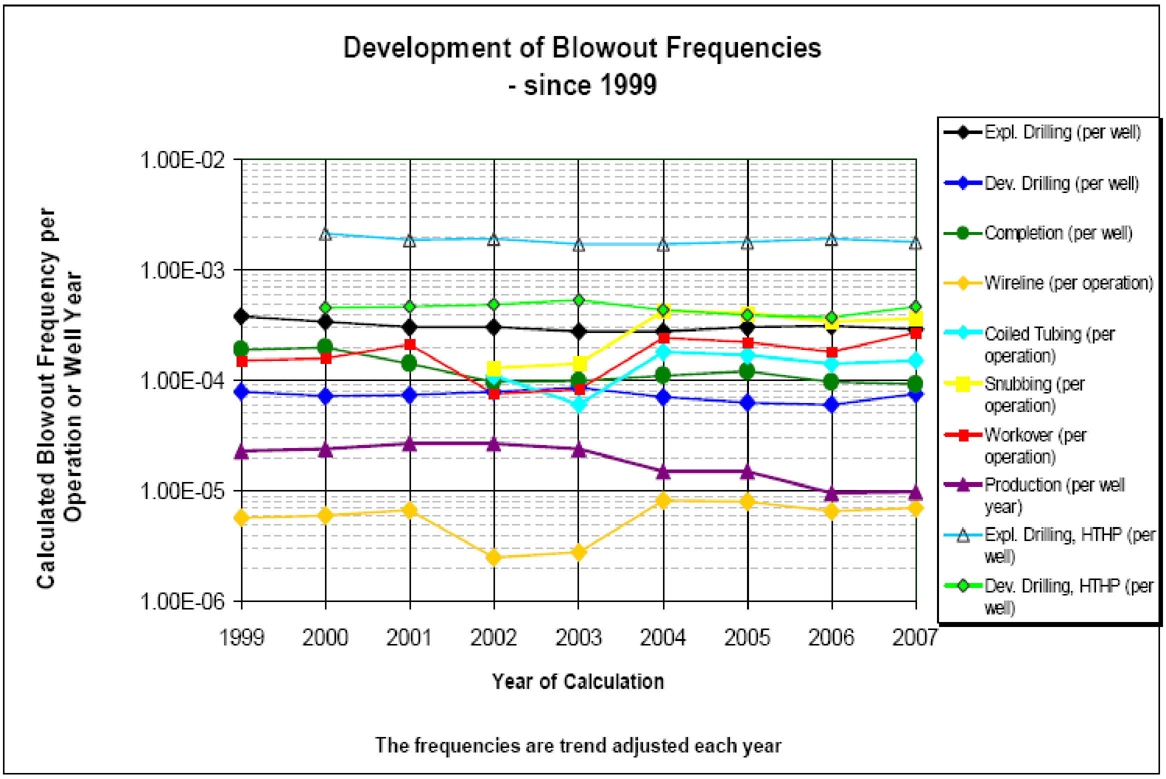


FIGURE 1-2: BLOW OUT FREQUENCIES IN OIL & GAS INDUSTRY

With respect to the proposed project, the blow out occurrence frequency as based on analysis of historical data[4] has been considered to be **7.5 X 10^{-3} per well drilled.** Based on the given frequency and information provided by OIL on the proposed project drilling program the blow out frequency is calculated as follows:

No of wells to be drilled = 30 (A)

Blow out frequency for drilling = 7.5 X 10^{-3} per well drilled (B)

Frequency of blow out occurrence for the proposed project = (A X B) = 30 X 7.5 X 10^{-3}

= 2.25 X 10^{-1} per well drilled

Thus, the blow out frequency for the proposed project is calculated at **2.25 X 10^{-1} per well drilled i.e. the likelihood of its occurrence is "Probable"**

Blowout Consequence Analysis

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

- Pool fires and smoke plumes resulting from ignited oil blow outs

[4] *Analysis of the SINTEF database for the US GoM OCS/North Sea for the period 1980-92 by Scandpower (1995)*

- Jet fires resulting from ignited gas blow outs
- Oil slicks resulting from un-ignited oil pools.

Pool fire

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

For the purpose of consequence modeling for pool fires resulting from blow outs, following hypothetical scenarios in terms of hydrocarbon (particularly crude oil) release rates (**Table 1.6**) have been considered based on DNV Technica's FLARE program.

TABLE 1-6: POOL FIRE MODELING SCENARIOS

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

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

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

Where D = pool diameter (m)

Q = release rate (kg/s)

b = burning rate (kg/m^2s)

The mass burning rate for crude oil has been considered to be 0.05 kg/m^2s

Based on above equation, the pool fire diameter and the steady study burning areas computed for various release types have been presented in the **Table 1.7** below.

TABLE 1-7: POOL FIRE DIAMETER & STEADY STATE BURNING AREA

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

The impact zone for long duration fires is conveniently described by thermal radiation contours and its effects on the people who are exposed to such radiation levels for one minute

(60sec). The thermal radiation threshold values (measured in kilowatts per square meter) defined for crude oil pool fire consequence modeling is provided in **Table 1.8** below:

TABLE 1-8: 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 vaporization 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 1.9** below

TABLE 1-9: DISTANCE TO THERMAL RADIATION THRESHOLD LEVELS

Release Type	Pool fire diameter (m)	Pool fire area (m^2)	Distance to 5.0 kW/m² (m)	Distance to 12.5 kW/m² (m)	Distance to 37.5 kW/m² (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/m²** 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"			

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_4H1_0). Other gases such as CO_2, nitrogen and hydrogen sulfide (H_2S) are also often present. Methane is typically 70-90 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 modeling. The following risk scenarios (**Table 1.10**) have been considered for jet fire consequence modeling:

TABLE 1-10: JET FIRE MODELING SCENARIOS

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

Gas release rates for each scenario have been utilized in the calculating jet fire flame length. Flame length calculation is done using API RP521 (API 1982) model and is based on the fuel type

$$L_f = 0.00326 (Q H_c)^{0.41}$$

Where

L_f = flame length (m)

Q = release rate (kg/s)

H_c = heat of combustion (J/kg) i.e. (5.0 X 10^7 J/kg for methane)

The flame length calculated based on the above equation for jet fire is presented in the **Table 1.11** below.

TABLE 1-11: JET FIRE FLAME LENGTH FOR RISK SCENARIOS CONSIDERED

Scenario	Release Rate (kg/s)	Release Type	Flame Length (m)
Scenario - I	1	Small	4.68
Scenario - II	5	Medium	9.04
Scenario – III (Worst Case)	10	Large	12.02

The thermal radiation intensity threshold values and its possible impacts for jet fire is similar to that considered for pool fire (Refer **Table 1.8**) The distance to the radiation intensity levels for risk scenarios have been predicted based on the *Chamberlain* model calculation. The following relationships for distance along the flame axis to various thermal radiation levels have been calculated:

- **For 5.0 kW/m²; $L_f = 19.50 (Q)^{0.447}$**
- **For 12.5 kW/m²; $L_f = 16.15 (Q)^{0.447}$**
- **For 37.5 kW/m²; $L_f = 13.37 (Q)^{0.447}$**

Where **L_f = flame length (m)**

Q = release rate (kg/s)

Based on equation specified for thermal radiation intensities the distance of flame calculated for various gas release rates under risk scenarios discussed have been presented in the **Table 1.12** below.

TABLE 1-12: JET FIRE HAZARD RANGES

Release Type	Release Rate (kg/s)	Distance to 5.0 kW/m² (m)	Distance to 12.5 kW/m² (m)	Distance to 37.5 kW/m² (m)
Small	1	19.5	16.2	13.4
Medium	5	40.0	33.2	27.5
Large	10	54.6	45.2	37.4

As provided in the above table the flame length for the jet fire risk scenarios considered at respective threshold radiation intensity values is likely to vary from

- **19.5 – 54.6m for 5.0 kW/m² thermal radiation**
- **16.2 – 45.2m for 12.5 kW/m² thermal radiation**
- **13.4 – 37.4m for 37.5 kW/m² thermal radiation**

The worst hazard for release and ignition of natural at a rate of **10kg/s** for a thermal radiation intensity of **37.5 kW/m²** is likely to be experienced to a maximum distance of **37.4m** from the source with potential lethal effects likely to be experienced within 8 sec.

Risk Ranking – Blowout Jet Fire (Worst Case Scenario)

Likelihood ranking	**3**	**Consequence ranking**	**4**
Risk Ranking & Significance = 12 i.e. "Medium"			

Oil Spill

Crude oil spills resulting from blow out may result in the formation of un-ignited pools of liquid the spreading of which is governed by physical factors *viz*. wind speed, sea currents (for offshore spills), release rates and spilled chemical characteristics *viz*. density. Near to the source of a continuous release, the spreading is dominated by gravity and limited by internal forces with thickness generally varying within 10-20 mm. The spill movement is then resisted by the viscous shear forces which then continue until the spill thickness is about 1.0 mm. Subsequently, surface tension takes over as the dominant spreading mechanism and it continues until the thickness has reduced to 0.01 – 0.1 mm which may take about 7-10 days for a large spill depending on various factors as discussed earlier.

With respect to the QRA study hypothetical release rates of **1.0kg/s, 5.0 kg/s** and **10.0 kg/s** for **1 day**, **4days** and **7days** respectively have been considered as the possible risk scenarios for modeling the spread of oil spill following a blow-out incident. The diameter of the pool in the first phase of an unignited continuous release is obtained by the following equation:

$$\mathbf{D = 2\ [g\ X\ Q/\rho_L\ 2\pi]\ t^{3/4}}$$

Where

D = pool diameter (m)

g = acceleration due to gravity (m/s^2)

Q = release rate (kg/s)

ρ_L = liquid density (kg/m^3) (crude oil density is 790 kg/ m^3)

t = time since start of release (s)

The pool fire diameter so calculated for the aforesaid risk scenarios have been presented in the **Table 1.13** below.

TABLE 1-13: POOL DIAMETER FOR OIL SPILL RISK SCENARIOS

Release Type	Release Rate (kg/s)	Release Time (s)	Oil Spill Pool Diameter (m)
Small	1	86400	19.9
Medium	5	259200	226.9
Large	10	432000	665.7

Hence, for a worst case spill scenario involving a crude oil release rate of **10kg/s for a period of 7 days** the pool diameter for an un-ignited continuous release is predicted to be about

665.7 m. The ignition of the oil pool may lead to the formation of pool fires - consequences of which have been discussed earlier under the risk related to pool fires. Although the un-ignited pool is not considered to be of major significance, it may gain significance based on the environmental impacts that may result from it depending on sensitive receptors identified abutting the proposed project well sites.

Risk Ranking – Blowout Oil Spills (Worst Case Scenario)

Likelihood ranking	**3**	**Consequence ranking**	**4**
Risk Ranking & Significance = 12 i.e. "Medium"			

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 Preventor) 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 OIL.
- 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 and development drilling and their possible mitigation measures.
- Installation of mass communication and public address equipment.
- Good layout of well site and escape routes.

Additionally, OIL will be adopting and implementing the following Safe Operating Procedures (SOPs) developed as part of its Onsite Emergency Response Plan (currently in draft stage) to prevent and address any blow out risks that may result during drilling 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*

Process Leaks/Fires

Process leaks are can be defined as hydrocarbon releases from process equipments excluding blowouts and are relatively frequent events. In most cases they are small in nature and can be effectively controlled. However, if this is not possible, they can trigger events like fire or explosions which may potentially have higher consequences.

Process Leaks – Frequency Analysis

The frequency of process leaks can be estimated directly from analysis of historical data obtained from E & P Forum hydrocarbon leak database (E&P forum 1992), World Offshore Accident Database (WOAD) and OREDA. Although onshore data is available for process leaks, the information is not considered representative of the actual scenario. Under such circumstances historical data available on hydrocarbon leaks in the OGP authenticated offshore accident databases have been considered for purpose of process leak frequency analysis. Review of HSE hydrocarbon release database indicates that majority of the leaks (approx 45%) occurred during production with drilling/well operation contributing is only 10%. Range of frequencies for various possible events is presented in the **Table 1.14** below.

TABLE 1-14: LEAK FREQUENCIES FOR PROCESS EQUIPMENT

Equipment Type	Frequency (per equipment item year)
Flanges	8.8×10^{-5}
Valves	2.3×10^{-4}
Small Bore Fitting	4.7×10^{-4}
Pressure Vessel	1.5×10^{-4}
Pumps, centrifugal, double seal	1.7×10^{-2}
Pumps, reciprocating, double seal	3.1×10^{-1}
Compressors, centrifugal	1.4×10^{-2}
Compressors, reciprocating	6.6×10^{-1}

Source: HSE Hydrocarbon Release Database

Hence, with the proposed project span over a period of **2 years,** frequency analysis for the process leaks from various process equipments are calculated as follows (**Table 1.15**)

TABLE 1-15: PROJECT PROCESS EQUIPMENT'S LEAK FREQUENCIES

Equipment Type	Frequency (A) (per item year)	Drilling Period (yrs) –(B)	Occurrence Frequency (A x B)	Frequency Class
Flanges	8.8×10^{-5}	2	1.76×10^{-4}	Not Likely
Valves	2.3×10^{-4}	2	4.60×10^{-4}	Not Likely
Small Bore Fitting	4.7×10^{-4}	2	0.94×10^{-3}	Not Likely
Pressure Vessel	1.5×10^{-4}	2	3.00×10^{-4}	Not Likely
Pumps, centrifugal, double seal	1.7×10^{-2}	2	3.40×10^{-2}	Occasional/Rare
Pumps, reciprocating, double seal	3.1×10^{-1}	2	6.20×10^{-1}	Probable
Compressors, centrifugal	1.4×10^{-2}	2	2.80×10^{-2}	Probable
Compressors, reciprocating	6.6×10^{-1}	2	1.32	Frequent

Thus, as discussed above in most of the cases the frequency of occurrence of process leaks for the proposed project is either "**Not Likely**" or "**Probable**" with hydrocarbon release from reciprocating pumps and compressor is predicted to be "**Frequent**". Further, taking into account that OIL plans to undertake periodic monitoring and preventive maintenance of such process equipment's occurrence of such process leaks is likely to be less frequent.

Process Leaks – Consequence Analysis

The potential consequences of a hydrocarbon leak from process equipments will depend, to a large extent on steps that can be taken to control or mitigate effect. There is considerable chance that a process leak might be ignited (either immediate or delayed) resulting in a fire or explosion. The following scenarios can occur if a hydrocarbon leak is ignited:

- Jet fires resulting from gas releases ignited early
- Pool fires and smoke plumes from ignited oil releases.

The evolution of a fire or explosion scenario as a result of a process leak can follow a complex chain of events which can be studied in further detail through a fault tree or what-if analysis. Fires or explosions resulting from ignition of hydrocarbon leaks can cause severe consequences, if it goes out of control and can damage equipment's, including the drilling rig itself.

The process leak consequences *viz*. jet fire and pool fire is likely to arise out of an ignition of the oil pool/vapour cloud formed. However, the same is dependent on the ignition probabilities accounted in relevant databases maintaining records of accidental events occurring over the years with respect to oil and gas industry. Review of the SINTEF database for major and minor process leaks indicated the following generic ignition probabilities (**Table 1.16**).

TABLE 1-16: GENERIC IGNITION PROBABILITIES

Release Rate Category	Release Rate (kg/s)	Gas Leak Probability	Oil Leak Probability
Minor	<1	0.01	0.01
Major	1-50	0.07	0.03
Massive	>50	0.30	0.08

Although records review of the OCS and Norwegian oil and gas installations indicated ignition delay for process leaks whereas the OCB/Technica (1988) revealed that for about 50% of the cases the ignition was delayed by about 5 minutes or more allowing escape of onsite crew and drilling personnel.

However, as similar consequences *viz*. pool fire and jet fires are anticipated from process leaks as in blow outs, identical risk scenarios have been considered (in terms of oil and gas release rates) for leak consequence modeling based on professional judgment and analysis of process leak accident database. Hence, consequence modeling for process leaks/fires will be similar to that undertaken for well blow outs as discussed in the earlier section (Refer **section 5.3.1 of EIA Report**).

Risk Ranking – Process Leak Pool fire and Jet fire (Worst Case Scenario)

Likelihood ranking	**2**	**Consequence ranking**	**4**
Risk Ranking & Significance = 8 i.e. "Low"			

Preventive and Mitigation Measures

The preventive and mitigation measures for process leaks, fires and explosions will be implemented. Mitigative measures include the following:

- Provision for adequate leak and fire detection alarm systems;
- Installation of firefighting equipments, portable and fixed.
- Potential sources of ignition like welding/hot works, compressors, electrical equipment, compressors etc. be minimized, as far as practicable;
- Proper ventilation be arranged for in hazardous area to allow for inflammable gases to dissipate, when a release has occurred;
- Proper mechanisms like ESDs which can isolate leaks effectively need to be installed, in high risk process trains.
- Effective barriers in the form of blast walls, blast relief panels, etc. be installed to shield workers from high risk area where explosions may occur.
- Strict implementation of permit to work system and hazardous zone classification.
- Basic firefighting training to all working on the drilling rig.
- Installation of electrical equipment as per the hazardous zone classification.

Non-process fires/explosions

Non-process fires are any fires and explosions that involve material other than hydrocarbons (e.g. electrical fires, diesel fires, accommodation fires, DG set fires, miscellaneous sources etc.). Most non-process fires are small incidents which can be managed within the facility using existing firefighting equipment's. Such fires have however a higher frequency of occurrence compared to process fires and explosions as recorded by HSE database and World Offshore Accident Database (WOAD). Due to the absence of veritable data source recording non-process fire/explosion incidents for onshore installations the aforesaid databases for upstream oil and gas sector have been referred in an effort to analyze non-process fire/explosion risks with respect to the proposed project.

Historically, few fatalities have been reported from non-process fires and most of them have been successfully managed at the installation level. Based on the WOAD 1996 statistical report, the average fatality rate for non-process fires is estimated at 10^{-3} platform year. Again, these fatalities have already been addressed under risks covered under personal accidents and need not be considered for fatalities due to non-process fires. However, as they have a higher probability to occur such incidents may cause inconveniences and come in the way of smooth operation of the drilling activities. The frequency of occurrence of fires due to possible non-process accident has listed in the **Table 1.17** below:

TABLE 1-17: FREQUENCY OF OCCURRENCE - NON-PROCESS FIRES

Non-Process Accidents	Frequency (per year)
Electrical fires	7.0×10^{-2}
Diesel fires	9.2×10^{-3}
Machinery fires	2.2×10^{-3}
Miscellaneous fires	2.1×10^{-3}

Source: WOAD

As a result, though the damage potential is low, it is important to take appropriate safeguard measures to minimize their occurrence. Many of these measures can be implemented through the stipulation of simple work instructions and procedures.

Risk Ranking for Non-Process Fires

Likelihood ranking	**3**	**Consequence ranking**	**1**
Risk Ranking & Significance = 3 i.e. "Low"			

Preventive and Mitigation Measures

The preventive and mitigation measures for small non-process fires would be implemented by delineating appropriate operational procedures through the existing safety management system.

1.1.4 Disaster Management Plan

Objective

The primary objective of the DMP is to provide a safe, timely, effective and coordinated response by the onsite Emergency Response Team (ERT), along with the other local and government agencies/departments to prevent or minimize any major emergencies that may arise from possible failures/risks *viz*. blow outs, oil spill, fire & explosion etc. associated with drilling.

The main objectives of this plan are:

- To minimize the risk for human life, environment and common property resources, by means of an effective and efficient intervention;
- Protection of the environment;
- Protection of public safety;
- To initiate the early and efficient response throughout the utilization of all available resources.

Purpose

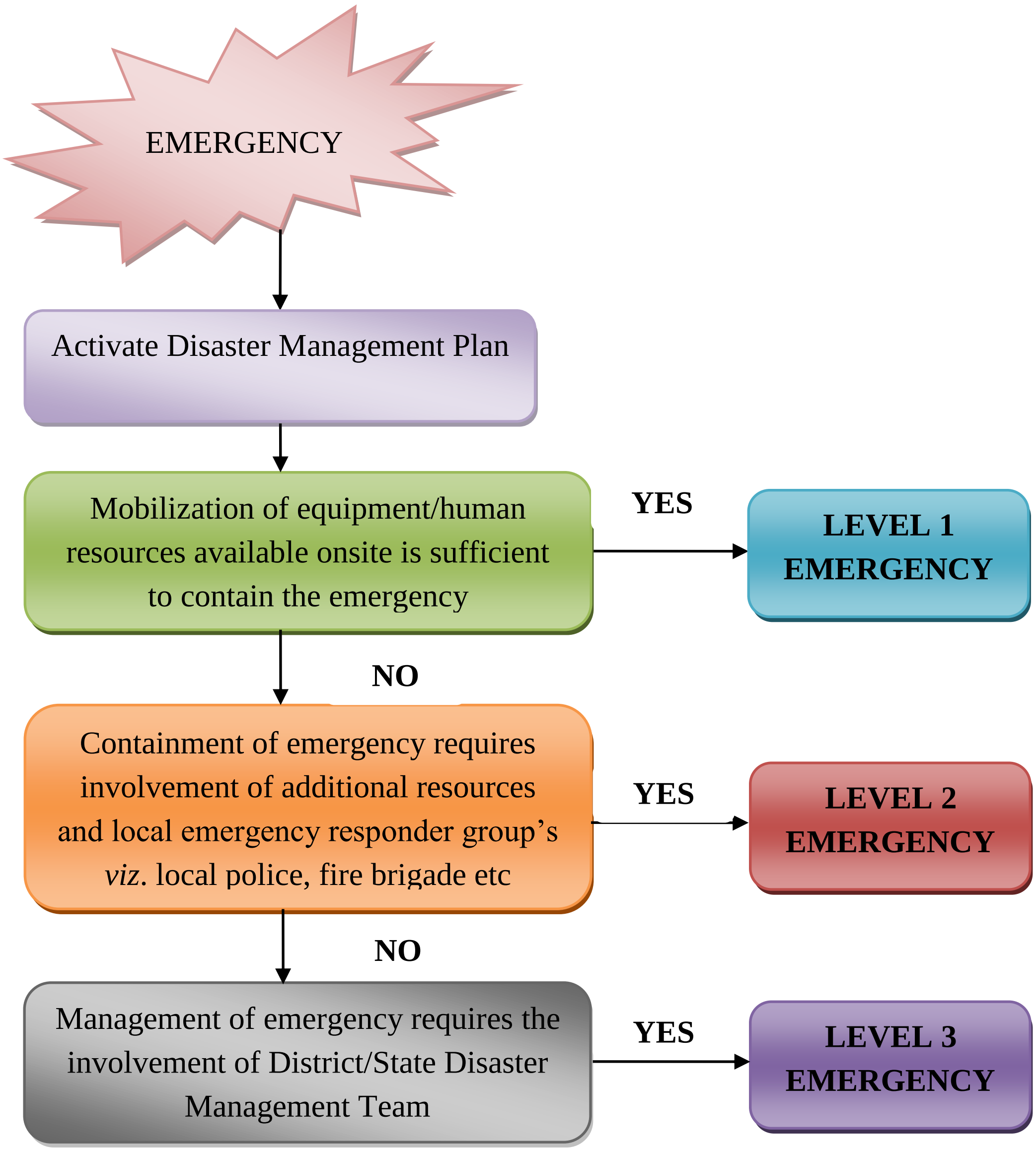
The purpose of the DMP is to effectively manage and control the emergencies occurring during project operations. This DMP ensures,

- emergency response group is effective & adequate;
- clear roles and responsibilities of key personnel & support groups;
- availability and adequacy of emergency infrastructure & resources; and
- efficient emergency communication

Emergency Classification

Due consideration is given to the severity of potential emergency situation that may arise as a result of storage tank as discussed in the **Quantitative Risk Analysis (QRA**) 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 Oil India Emergency/Crisis Management 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 1.3.**

FIGURE 1-3: EMERGENCY CLASSIFICATION "DECISION TREE"



Level 1 - Emergency

An event that can be dealt with by on-site/location personnel and resources; the event does not have any effect outside the site and external agencies are unlikely to be involved. There is unlikely to be danger to life, to the environment, or to Company assets or reputation. The Disaster Management Plan and relevant procedures are activated; the Site Head is notified.

Level 2 - Emergency

It is an event which may be dealt by the OIL Emergency/Crisis Management Team but requires involvement of wider Company support and external services. The initial event may be "on-site", having some effects outside the site or be "off-site", and external emergency services will be involved. There is likely to be a danger to life, the environment, or company assets or reputation. The Disaster Management Plan and relevant procedures are activated;

local administrative bodies and Emergency Response Groups including Oil India Corporate are notified.

Level 3 - Emergency

It is a major event which requires the involvement of District or State Crisis Management Group. For Company this may result from insufficient local resources and/or because the incident has broader implications such as reputation, legal prosecution, financial loss etc. Under such circumstances, the Disaster Management Plan is activated; Oil India Corporate, District/State Administrative Authorities and other Emergency Response Groups are notified.

The criterion for classification of various levels of emergencies and associated response has been presented in the **Figure 1.4** below.

FIGURE 1-4: EMERGENCY RESPONSE LEVELS

Level	Type	Criteria for Classification
Level 1	Small	• Minor medical or injury case requiring no external support • Equipment damage without any significant impact on operation • Minor fire without any personnel injury or plant damage • Net negative financial impact of <1 crores. • Small operational spills • No potential impact on flora and fauna of identified eco-sensitive areas. • Local stakeholder concern and public attention
Level 2	Medium	• Fire and explosion which requires external assistance • Requires evacuation of injured personnel and locals through assistance from local emergency groups. • Loss of corporate image and reputation • Adverse impact on environmental sensitivities (if any) within a radius of 1km. • Medium sized spills • Net negative financial impact of 1 - 5crore
Level 3	Large	• Incident leading to multiples injuries or fatalities • Requires assistance from District/State emergency responding groups. • Adverse impact on environmental sensitivities (if any) within a radius of >1km. • Major oil spills • State/nationwide media coverage • Net negative financial loss of >5crore

OIL Emergency Response/Crisis Management Team

OIL has in place an Emergency Response/Crisis Management Team (ERT) to respond to fire, blow-out, spills, accidents and technical emergencies. These teams will be made up from operations personnel, who can be called upon 24 hours a day, supported by senior management field personnel as and when required. The emergency response teams will receive specific training for their roles and exercise on a regular basis. Specific roles and responsibilities of the OIL ERT headed by the Chief Coordinator have been outlined below with the organizational structure being presented in **Figure 1.5**.

Chief Coordinator

- Declares Crisis/Emergency situations.
- Communicates with CMD/Ministry. State Govt. high officials and releases information's to Press / Mass communications Media.
- Directs main Coordinators as deemed necessary arising out of Crisis situations.

Services Coordinator

- Coordinates for implementation of fire control measures.
- Provision of emergency communication.
- Maintenance and supply of essential services like Water, Electricity, Gas, Transport.
- Ensures provision of material, repair facilities at workshop.
- Provision of temporary accommodation, repair / Restore roads & Bridges, removal of debris etc.

Production Coordinator

- Assesses damages to production systems.
- Arranges for Isolation, Salvaging of the affected installation.
- Arranges for repairs and restoration of Crude Oil, Natural Gas, LPG production and supply.

Administrative & Welfare Coordinator

- Coordinates for provision and maintenance of security arrangements.
- Liaises with Police and District Civic authorities.
- Coordinates with HEAD (MS) & GM(ER) for Rescue, Shelter and Medical relief operations.
- Informs voluntary organizations to assist for rescue and relief operations.
- Maintains public relations.

Medical Relief Coordinator

- Arranges for first-aid at the site of incidence
- Arranges for Ambulance and Medical Services
- Organized Medical relief camp in Oil Hospital and arranges for extended services under Mutual Aid Scheme with the Neighboring Industries and Civil Hospitals.

Employee Relations & Welfare Coordinator

- To participate in rescue and relief operations.

- To contact relatives of affected persons and provide Food/ Beverage etc. at relief camp.
- Contacts to Union Officials.

Safety & Environment Coordinator

- To liaise between the main Coordinators.
- To liaise with statutory Safety & Environment authorities i.e. Mines Safety Directorate, Petroleum & Explosive Safety Organisation, State/ Central Pollution Control Board, OISD etc.
- To liaise with members of mutual aid scheme i.e. BVFCL- Namup, IOC, (AOD) Digboi, AGCL- Duliajan, APL- Namrup, NEEPCO- Kathalguri, CIL Margherita, NTPS- Namrup.

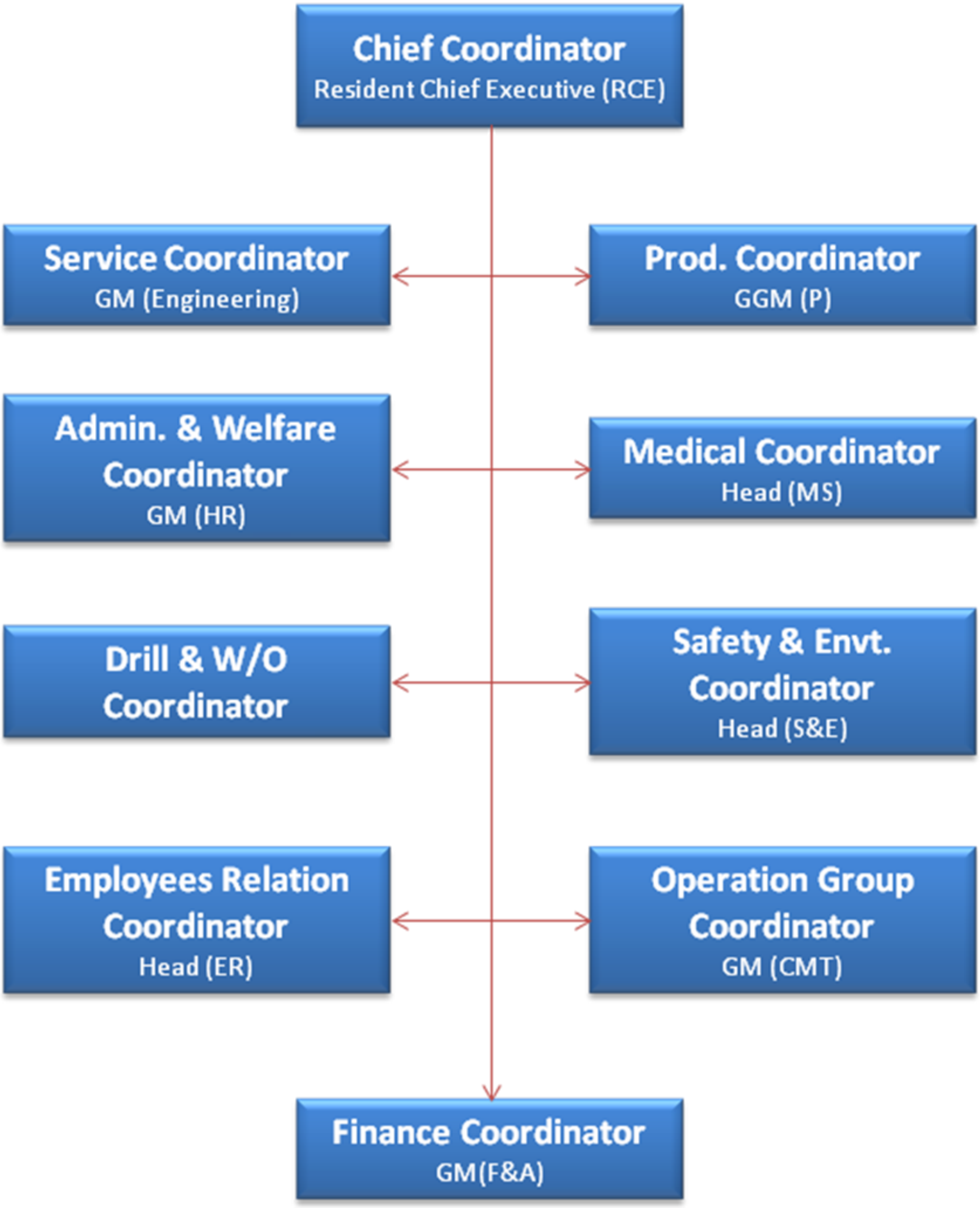
Finance Coordinator

- To give financial support for all activities arranged by Main Coordinators.

Operation Group Coordinator

- To co-ordinate activities of Well control measures in case of impending blowout or blowout with or without fire.
- Coordinate with Oil and Natural Gas Corporation Limited for emergency support.
- To liaise with Services Coordinator for fire control measures and emergency standby duty.

FIGURE 1-5: ORGANIZATIONAL STRUCTURE – OIL INDIA EMERGENCY RESPONSE TEAM



Interface with Other Plans

The Disaster Management Plan for the proposed project will be interfaced with the Tinsukia and Dibrugarh Disaster Management Plan prepared by the relevant District Disaster Management Authority (DDMA). The District Disaster Management Authority (DDMA) is an apex planning body and plays a major role in preparedness and mitigation. The district level response is coordinated under the guidance of the Deputy Commissioner, who acts as a District Disaster Manager. The District Disaster Management Authority (DDMA) for Tinsukia District has been formed to deal with any exigencies like natural calamity or man-made structural disturbances *viz*. fire, explosion etc. A Disaster Management Committee also exists to assist the Deputy Commissioner in reviewing the threat of disasters, vulnerability of the district to such disasters and evaluating the preparedness.

The District Disaster Response & Information Centre (Control Room), under the control of the Deputy Commissioner, will act as the Emergency Response Centre. It has been set up to monitor, co-ordinate and implement the action for disaster management. It works throughout the year and orders the various departments to work as per the directions during the disaster.

Communication Mechanism – District Level Emergencies/Disasters

On the basis of reports from possible disaster/emergency site that involves a Level-3 response, or on the warning from the agencies competent to issue such a warning, or on the receipt of warning or alert from Emergency Operations Centre, the Deputy Commissioner will exercise powers and responsibilities of the District Disaster Manager. The information dissemination at times of emergency for Tinsukia District has been laid down as under:

- The Deputy Commissioner will be the nodal officer for this who will apprise the Addl. Deputy Commissioner, Project Officer (DM) and persons concerned, Circle Officers, Water Resource Dept., PWD (Roads) Dept. IWT Dept., Medical & Health Dept. through SMS and phone.
- Deputy Commissioner will give direction to BSNL of Tinsukia District to immediate arrangement for alternative phone connectivity in the control room of Deputy Commissioner's Office.
- For any early warning reports received from North-East Space application Centre (NESAC), Umiam, Meghalaya, the same should be intimated to Executive Engineer, Water Resource, PWD State Roads / Rural Roads and Superintendant of Police, Addl. SP, SDO Civil Sadiya and Margherita and all Circle Officers.

Circle officers will have village vulnerability map with them so that they can pass message to respective Gaon Buras / LR Staff and PRI members without fail. Superintendent of Police will accordingly inform Officers-in-Charge of Police Stations and In-Charge of Out Posts. Circle Officers will also keep contact with the representative members of vulnerable villages.