Onshore Oil & Gas development drilling and production in Tengakhat-Kathaloni-Dikom area in Dibrugarh district

Dibrugarh and Tinsukia District, Assam

Risk Assessment

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Risk Assessment

1.1 Risk Assessment

This section on Risk Assessment)RA(aims to provide a systematic analysis of the major risks that may arise 167 nos. of onshore drilling wells, 07 nos. of production installations and laying of oil and gas pipelines. The RA 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 RA 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 RA will also help in assessing risks arising from potential emergency situations like a blow out and develop a structured Emergency Response Plan)ERP(to restrict damage to personnel, infrastructure and the environment.

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

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.

1.2 Objectives of the RA Study

The overall objective of this RA 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 exploration and development drilling activities, following specific objectives need to be achieved.

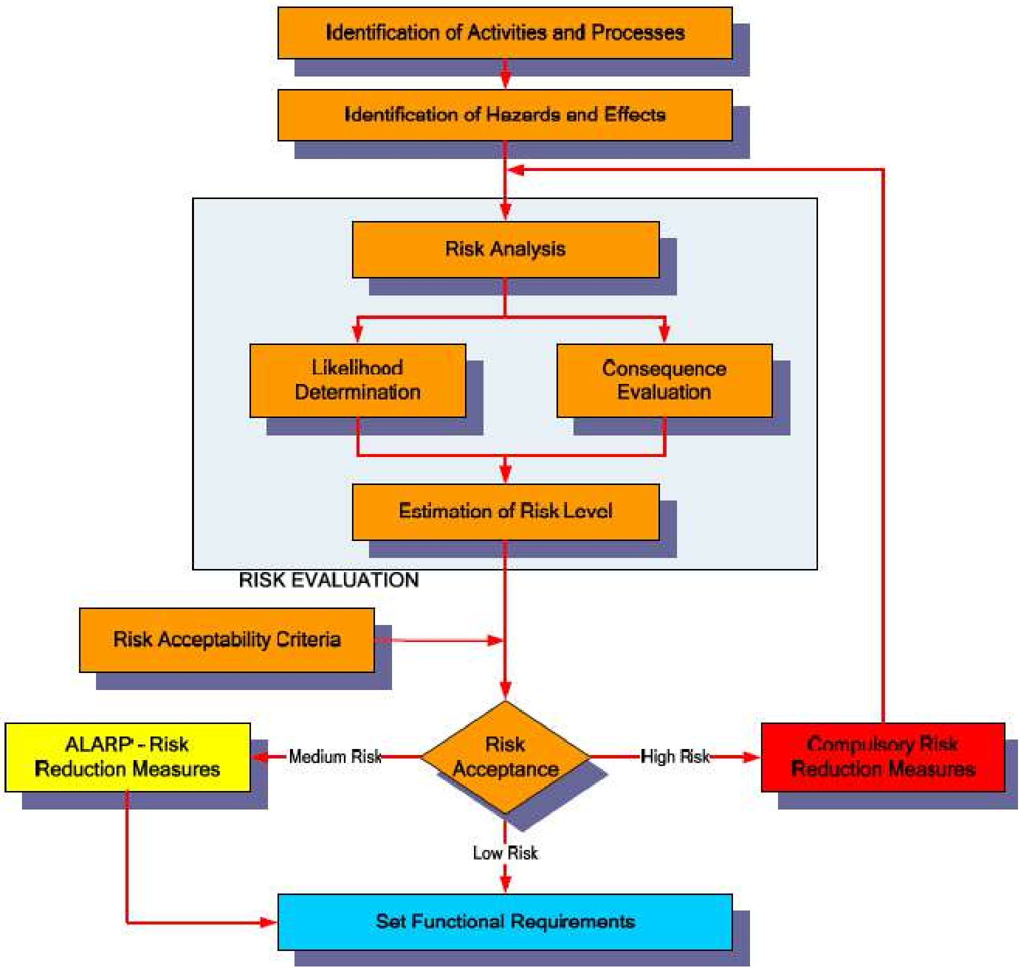
- Identify potential risk scenarios that may arise out of proposed development well drilling, operation of oil and gas pipelines and associated equipment's, mud chemicals storage and handling etc.
- Analyse the possible likelihood and frequency of such risk scenarios by reviewing historical accident related data for onshore oil and gas industries.
- Predict the consequences of such potential risk scenarios and if consequences are high, establish the same by through application of quantitative simulations.
- Recommend feasible preventive and risk mitigation measures as well as provide inputs for drawing up of Emergency Management Plan)EMP(for the Project.

1.2.1 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, non-process fires etc. have been assessed and evaluated through a risk matrix generated to combine the risk severity and likelihood factor. Risk associated with the well exploration and development activities have been determined semi-quantitatively as the product of likelihood/probability and severity/consequence by using order of magnitude data)risk ranking = severity/consequence factor X likelihood/probability factor(. Significance of such project related risks was then established through their classification as high, medium, low, very low depending upon risk ranking.

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

Figure 1.1 Risk Assessment Methodology



1.2.1.1 Hazard Identification

Hazard identification for the purposes of this RA 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 development drilling operations to be undertaken in the identified well locations, there are three major categories of hazards that can be associated with proposed Project which has been dealt with in detail. This includes:

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

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

1.2.1.2 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 risks1.

For RA 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 operations2, 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 RA 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.

1It 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.
2Although 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 well development activities, following criteria for likelihood rankings have been drawn up as presented in the **Table 1.1**.

Table 1.1 Frequency Categories and Criteria

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

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

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

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

Table 1.2 Severity Categories and Criteria

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

1.2.1.4 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 1.3** assigns risk significance criteria in four regions that identify the limit of risk acceptability. Depending on the position of intersection of a column with a row in the risk matrix, hazard prone activities have been classified as low, medium and high thereby qualifying a set of risk reduction / mitigation strategies.

Table 1.3 Risk Matrix

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

Table 1.4 Risk Criteria and Action Requirements

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

1.2.2 Risk Assessment of Identified Project Hazards

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

1.2.2.1 Blow Outs/Loss of Well Control

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

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

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

Box 1.1 Primary Causes of Blow Outs

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

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

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

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

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

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

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

For better understanding, causes of blow outs have been systematically defined in terms of loss of pressure control)failure of primary barrier(, uncontrolled flow of fluid or failure of secondary barrier)BOP(. The blow out incidents resulting from primary and secondary failures for proposed operations as obtained through comprehensive root cause analysis of the Gulf Coast)Texas, OCS and US Gulf of Mexico(Blow Outs1 during 1960-1996 have been presented in the **Table 1.5** below.

Table 1.5 Blow Out Cause Distribution for Failures - Drilling Operations

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

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

Blowout Frequency Analysis

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

The blowout frequencies presented in this report are extracted from the latest revision of the Scandpower2 report and are presented in **Table 1.6** below. The 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.

1 “Trends extracted from 1200 Gulf Coast blowouts during 1960-1996” – Pal Skalle and A.L Podio
2 “Blowout and Well Release Frequencies” - Based on SINTEF Offshore Blowout Database 2010, Report, Scandpower Risk Management. Report no. 19.101.001-3009/2011/R3, 05.04.2011.

Table 1.6 Blow Out Frequencies Recommended per Drilled Well

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

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

No of wells to be drilled per year = 25)A(

Blow out frequency for drilling)oil(= 2.62 X 10-5 per well drilled)B(

Blow out frequency for drilling)gas(= 2.16 X 10-5 per well drilled)C(

Frequency of blow out occurrence for)oil(=)A X B(= 25 X 2.62 X 10-5
= 6.55 X 10-4 per well drilled

Frequency of blow out occurrence for development)gas(=)A X C(= 25 X 2.16 X 10-5
= 5.40 X 10-4 per well drilled

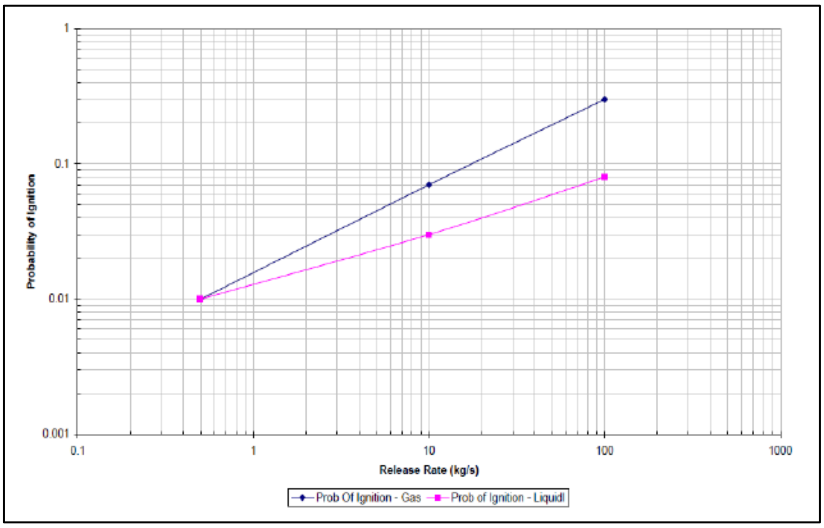
Thus, the blow out frequency for the proposed project for development oil and gas wells have been identified to be as “Not Likely”.

Blowout Ignition Probability

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

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

Figure 1.2 Ignition Probability Vs Release Rate



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

No of wells to be drilled per year = 25)A(Blow out frequency for drilling)oil(= 2.62 X 10-5 per well drilled)B(Blow out frequency for drilling)gas(= 2.16 X 10-5 per well drilled)C(Blow out ignition probability = 0.09)D(Probability of Blow out ignition for drilling)oil(=)A X B X D(= 25 X 2.62 X 10-5 X 0.09 = 5.89 X 10-5= ~ 0.0021% Probability of Blow out ignition for drilling)gas(=)A X C X D(= 25 X 2.16 X 10-5 X 0.09 = 4.86 X 10-5= ~ 0.0017%

Hence based on the aforesaid calculation the probability of ignition of blow out releases of hydrocarbons for the proposed development project for both oil and gas is found to range within ~0.0021% and 0.0017% and therefore can be considered to be as negligible.

Blowout Consequence Analysis

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

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

Pool fire

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

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

Table 1.7 Pool Fire Modelling Scenario

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

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

$D = \sqrt{4Q/\pi b}$
Where D = pool diameter)m(
Q = release rate)kg/s(
b = burning rate)kg/m^2s(
The mass burning rate for crude oil has been considered to be 0.05 kg/m^2s

Based on above equation, the pool fire diameter and the steady study burning areas computed for various release types have been presented in the **Table 1.8** below.

Table 1.8 Pool Fire Diameter & Steady State Burning Scenario

Scenario	Release Rate (kg/s)	Release Type	Pool fire diameter (m)	Steady State Burning Area (m2)
Scenario - I	1	Small	5.05	6.37
Scenario - II	10	Medium	15.96	63.69
Scenario - III	50	Large	35.69	318.47

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

Table 1.9 Thermal Radiation Intensity Threshold Values Impact Criterion

Threshold Radiation Intensity	Threat Zone	Impact Criterion
5.0 kW/m2	Green	Escape actions within one minute. Cause second degree burns within 60 sec.

12.5 kW/m2	Blue	Escape actions lasting for few seconds. Cause second degree burns within 40 sec.
37.5 kW/m2	Red	Results in immediate fatality. Pain threshold is instantaneous leading to second degree burns within 8 sec.

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

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

Where:

X = distance to the heat radiation level)m(
HC = heat of combustion of the flammable liquid)joules/kg(
HV = heat of vaporization of the flammable liquid)joules/kg(
A = pool area)m2(
CP = liquid heat capacity)joules/kg-ºK(
TB = boiling temperature of the liquid)ºK(
TA = ambient temperature)ºK(

For crude oil HC = 42600000 joules/kg; HV = 957144 joules/kg; CP = 1892 joules/kg-ºK; TB = 633 ºK and TA = 300 ºK. The following input parameter along with pool area)m2(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** below

Table 1.10 Distance to Thermal Radiation Threshold Levels

Release Type	Pool fire diameter (m)	Pool fire area (m2)	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” 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)CH4(as a flammable component, but it also contains heavier gaseous hydrocarbons such as ethane)C2H6(, propane)C3H8(and butane)C4H10(. Other gases such as CO2, nitrogen and hydrogen sulfide)H2S(are also often present. Methane is typically 90 percent, ethane 5-15 percent, propane and butane, up to 5 percent. Thus, considering higher percentage of methane in natural gas, the thermo-chemical properties of the same has been utilized in the jet fire blow out consequence modelling. The following risk scenarios (Table 1.11) have been considered for nature gas release consequence modelling:

Table 1.11 Natural Gas Release Modelling Scenario

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

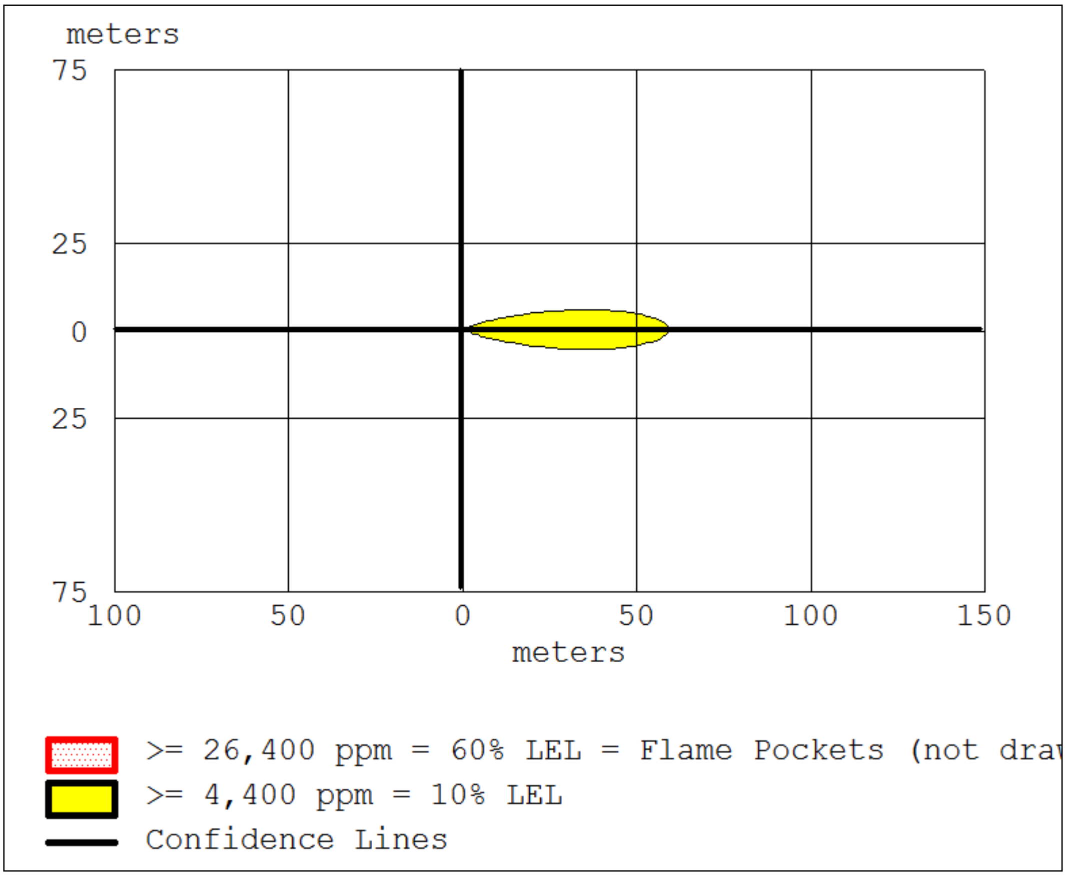
The modelling of nature gas releases has been carried out using ALOHA. A Flammable Level of Concern approach has been utilized for assessing safety risk associated with the release of flammable gases)here methane(from well blow outs. In ALOHA, a flammable Level of Concern)LOC(is a threshold concentration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

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

When a flammable vapor cloud is dispersing, the concentration of fuel in the air is not uniform; there will be areas where the concentration is higher than the average and areas where the concentration is lower than the average. This is called concentration patchiness. Because of concentration patchiness, there will be areas)called pockets(where the chemical is in the flammable range even though the average concentration has fallen below the LEL. Because of this, ALOHA's default flammable LOCs are each a fraction of the LEL, rather than the LEL itself. ALOHA uses 60% of the LEL as the default LOC for the red threat zone, because some experiments have shown that flame pockets can occur in places where the average concentration is above that level. Another common threat level used by responders is 10% of the LEL, which is ALOHA's default LOC for the yellow threat zone. The flammable LOC threat zones for methane release are as follows:
Red : 26,400 ppm = 60% LEL = Flame Pockets
Yellow: 4,400 ppm = 10% LEL

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

Figure 1.3 Scenario I: Risk Contour Map



THREAT ZONE:
Threat Modelled: Flammable Area of Vapor Cloud

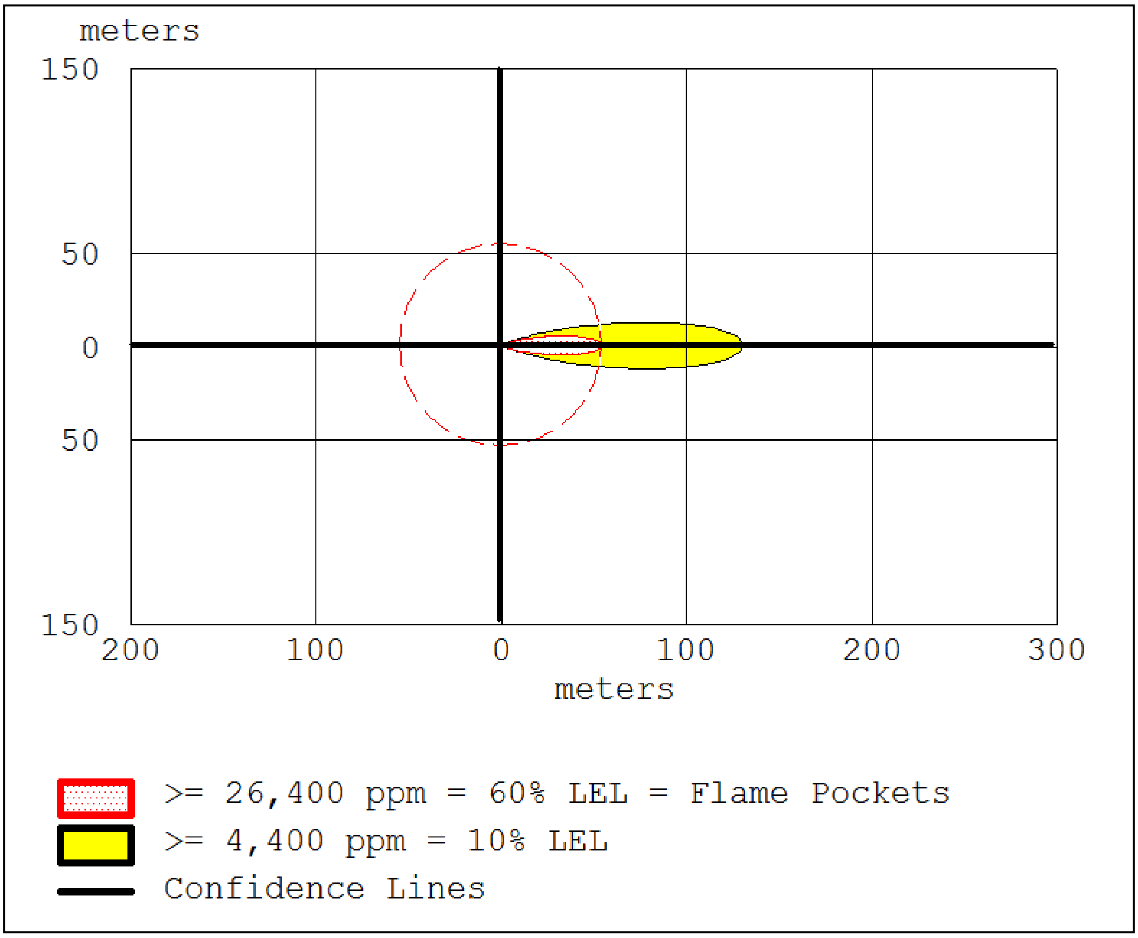
Model Run: Gaussian

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

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

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

Figure 1.4 Scenario II: Risk Contour Map



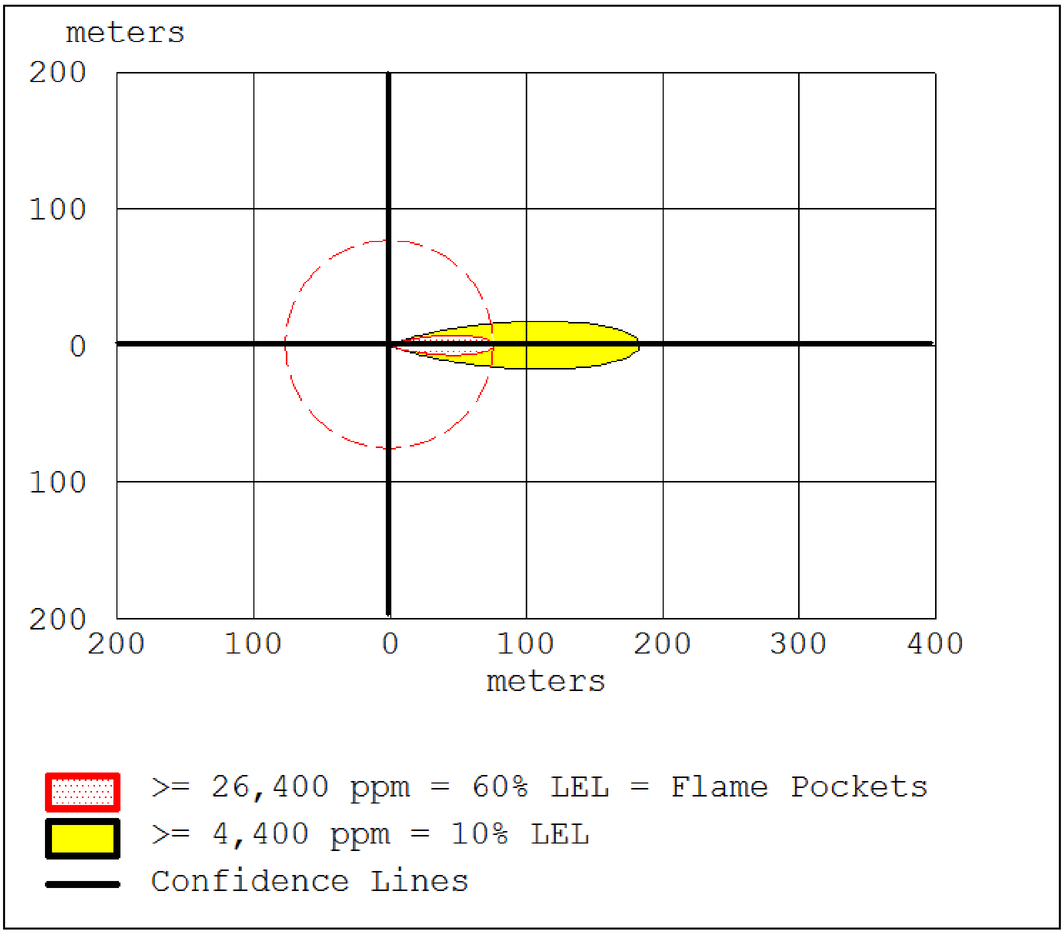
THREAT ZONE:
Threat Modeled: Flammable Area of Vapor Cloud

Model Run: Gaussian

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

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

Figure 1.5 Scenario III: Risk Contour Map



THREAT ZONE:
Threat Modelled: Flammable Area of Vapor Cloud

Model Run: Gaussian

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

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

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

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

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

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

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

Figure 1.6 Scenario III)Worst Case(– Overpressure Risk Modelling

```
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 development drilling has been presented below. For calculating the risk significance, the likelihood ranking is considered to be "2" as the frequency analysis for blow outs incidents is computed at "~ 10-5" 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	2	Consequence ranking	4
Risk Ranking & Significance = 8 i.e. "Low" i.e. Risk is Acceptable and can be managed through use of existing controls and evaluation of additional controls.			

1.2.2.2 OCS Tank Failure

This section assesses the risks resulting from the storage of crude oil at the OCS in two production tanks of 795 KL capacity each.

Frequency Analysis

The most credible scenario of a storage tank will be pool fire. In order to determine the probability of a pool fire occurring, the failure rate needs to be modified by the probability of the material finding an ignition source. The probability of a pool fire occurring in the event of a release is therefore equal to the product of the failure rate and the probability of ignition. The frequency of the release scenarios identified in the earlier section is represented in **Table 1.13** below. The ignition probability is dependent on a number of factors including the type of site, the release rate and the type of material released.

Table 1.13 Tank Failure Frequency

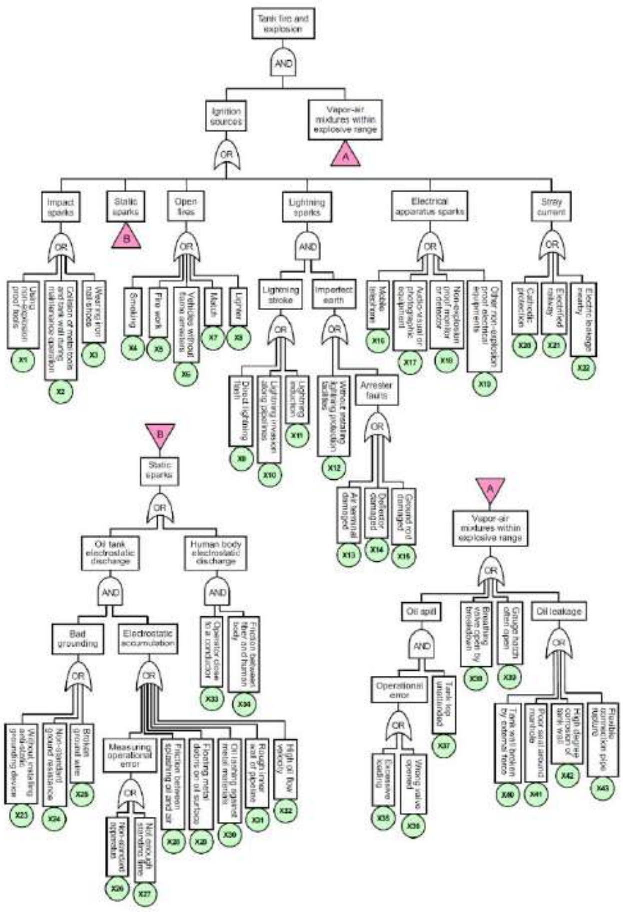
Sl. No	Type of Release	Failure Rate)per vessel per year(	Frequency
1	Catastrophic tanks failure	5.0 x 10-6	Remote
2	Small bund fire	9.0 x 10-5	Remote
3	Large bund fire	6.0 x 10-5	Remote

Source: OGP Risk Assessment Data Directory Report No 434 – 3, March 2010, Section 2 – Summary of Recommended Data

Event Tree Analysis

Event tree analysis)ETA(is used to model the evolution of an event from the initial release through to the final outcome such as jet fire, fireball, flash fire etc. This may depend on factors such as whether immediate or delayed ignition occurs, or whether there is sufficient congestion to cause a vapour cloud explosion. The event tree for fire and explosion for an oil storage tank is shown in **Figure 1.7**.

Figure 1.7 Scenario III: Risk Contour Map



Source: Fuzzy Fault Tree Analysis for Fire and Explosion in Crude Oil Tanks – Daqing Wang, Peng Zhang and Liqiong Chen, Journal of Loss Prevention in the Process Industries

Consequence Analysis – Tankages

The main hazards associated with the storage and handlings of crude oil are pool fires resulting from the ignition of released material as well as explosions and Flash fires resulting from the ignition of a flammable cloud formed in the event of tank overfilling. The hazards may be realised following tank overfilling and leaks/failures in the storage tank and ancillary equipment such as transfer pumps, metering equipment, etc. all of which can release significant quantities of flammable material on failure.

Bulk Storage Tank Scenarios

In addition to overfill, the scenarios considered for the crude oil storage tanks were partial/local failures and cold catastrophic failures. Factors that have been identified as having an effect on the integrity of tanks are related to design, inspection, maintenance, and corrosion1. The following representative scenarios for the tanks were considered (Table 1.14).

Table 1.14 OCS Storage Tank – Risk Modelling Scenarios

Scenario	Tank	Tank Diameter)m(	Tank Height)m(	Tank Volume)KL(	Accident Scenario
1	OCS Storage Tank	10.0	10.0	795	50mm leak
2		10.0	10.0	795	100mm leak
3		10.0	10.0	795	300mm leak)worst case(

The OCS storage tank failure risk scenarios have been modeled using ALOHA for n-decane which best represent the properties of crude oil and interpreted in terms of Thermal Radiation Level of Concern)LOC(encompassing the following threshold values)measured in kilowatts per square meter(to create the default threat zones:

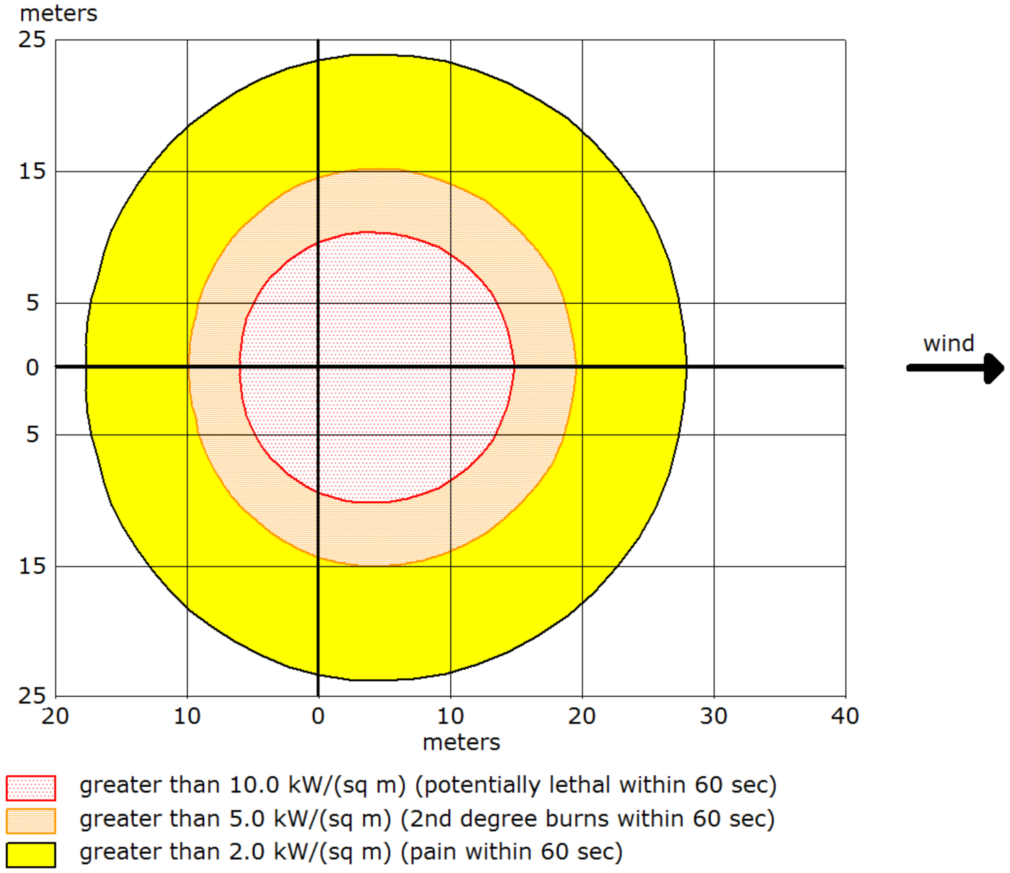
Red: 10 kW/)sq. m(-- potentially lethal within 60 sec;
Orange: 5 kW/)sq. m(-- second-degree burns within 60 sec; and
Yellow: 2 kW/)sq. m(-- pain within 60 sec

1 AEA Technology, HSE Guidance Document

Scenario 1: OCS Storage Tank Leak (50mm dia.)

The pool fire threat zone plot for release and ignition of crude oil from a storage tank leak of 50mm dia is represented in **Figure 1.8** below.

Figure 1.8 Threat Zone Plot – OCS Storage Tank Leak)50mm dia(



Source: ALOHA

THREAT ZONE:

Threat Modeled: Thermal radiation from pool fire

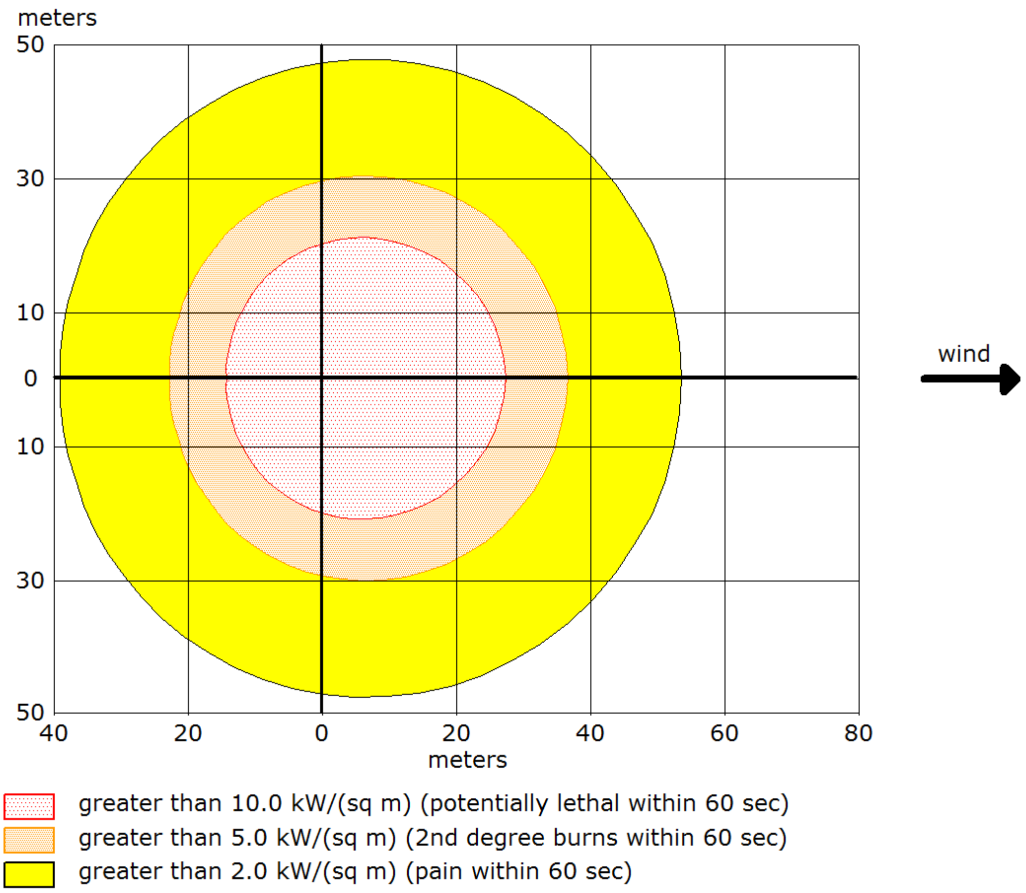
Red : 15 meters ---)10.0 kW/)sq. m(= potentially lethal within 60 sec(
Orange: 20 meters ---)5.0 kW/)sq. m(= 2nd degree burns within 60 sec(
Yellow: 28 meters ---)2.0 kW/)sq. m(= pain within 60 sec(

The worst hazard for release and ignition of crude oil from storage tank leak)50mm(will be experienced to a maximum radial distance of 15m from the source with potential lethal effects within 1 minute.

Scenario 2: OCS Storage Tank Leak (100mm dia)

The pool fire threat zone plot for release and ignition of crude oil from a storage tank leak of 100mm dia is represented in **Figure 1.9** below.

Figure 1.9 Threat Zone Plot – Diesel Storage Tank Leak)100mm dia(



Source: ALOHA

THREAT ZONE:

Threat Modeled: Thermal radiation from pool fire

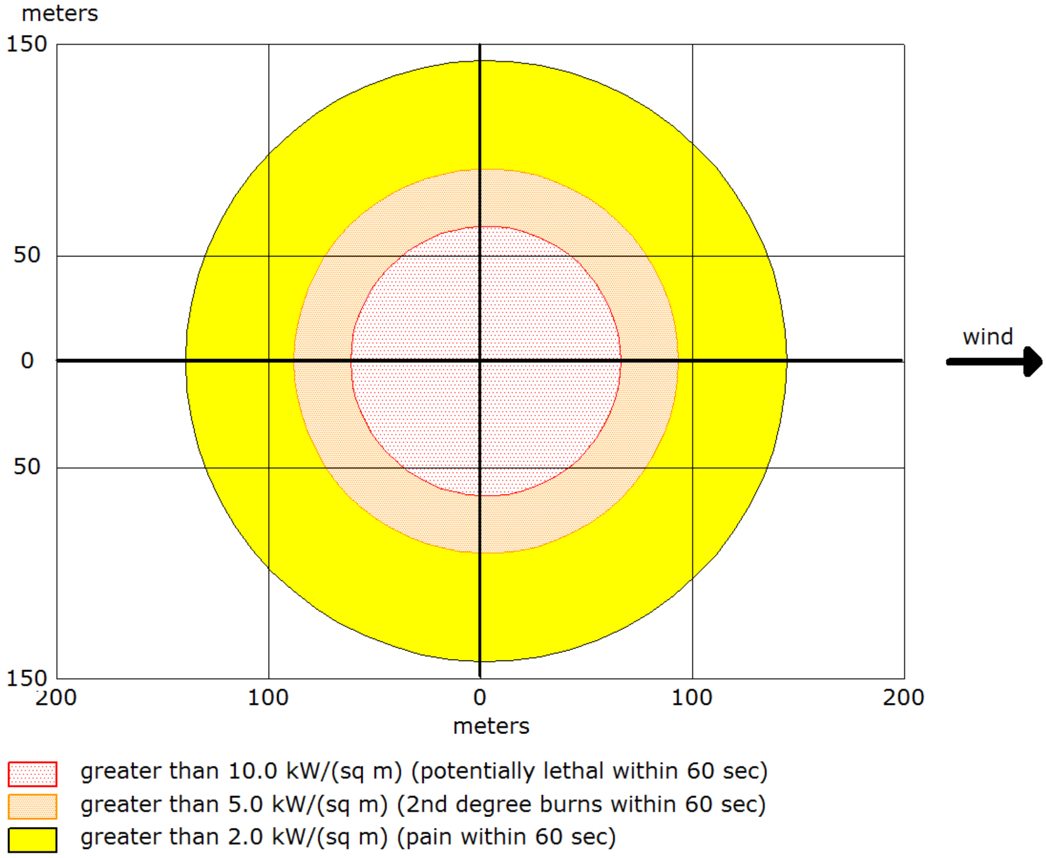
Red : 26 meters ---)10.0 kW/)sq. m(= potentially lethal within 60 sec(
Orange: 38 meters ---)5.0 kW/)sq. m(= 2nd degree burns within 60 sec(
Yellow: 54 meters ---)2.0 kW/)sq. m(= pain within 60 sec(

The worst hazard for release and ignition of crude oil from OCS storage tank leak)100mm(will be experienced to a maximum radial distance of 26m from the source with potential lethal effects within 1 minute.

Scenario 3: OCS Storage Tank Leak (300mm dia)

The pool fire threat zone plot for release and ignition of crude oil from a storage tank leak of 300mm dia)worst case(is represented in figure below.

Figure 1.10 Threat Zone Plot – OCS Storage Tank Leak)300mm dia(



Source: ALOHA

THREAT ZONE:

Threat Modeled: Thermal radiation from pool fire

Red : 67 meters ---)10.0 kW/)sq. m(= potentially lethal within 60 sec(
Orange: 93 meters ---)5.0 kW/)sq. m(= 2nd degree burns within 60 sec(
Yellow: 145 meters ---)2.0 kW/)sq. m(= pain within 60 sec(

The worst hazard for release and ignition of crude oil from storage tank leak)300mm(will be experienced to a maximum radial distance of 67m from the source with potential lethal effects within 1 minute.

For calculating the risk significance of crude oil storage failure, the likelihood ranking is considered to be “2” as the failure probability for such failure is computed to be ~5 x10-6 per year. With respect to consequence ranking, for the aforesaid incident it has been identified to be as “4” given for a worst case scenario lethal effects is likely to be experienced within a maximum radial zone ~67 meters. However, considering that isolated crude oil storages will be equipped appropriate state of the art process and fire safety controls in consistent with OISD-117 requirements, the risk is likely to be less significant.

Risk Ranking – OCS Tank Failure)Worst Case Scenario(

Likelihood ranking	2	Consequence ranking	4
Risk Ranking & Significance =8 i.e. “Low” i.e. Risk is Acceptable and can be managed through use of existing controls with the option for installation of additional controls, if necessary.			

1.2.2.3 Hazardous Material Releases or Mishaps

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

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

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

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

1.2.2.5 Interconnecting Hydrocarbon Pipeline Network

As discussed in the project description section, the project involves laying of 100 km long assorted oil & gas flow lines/ delivery lines in TKD Area under Dibrugarh district of Assam. Some of the key hazard likely to be associated with same has been presented below

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

Each of these hazards has been described below.

Jet Fire

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

Flash Fire

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

Where ignition of a release does not occur immediately, a vapour cloud is formed and moves away from the point of origin under the action of the wind. This drifting cloud may undergo delayed ignition if an ignition source is reached, resulting in a flash fire if the cloud ignites in an unconfined area or vapour cloud explosion)VCE(if within confined area.

Vapour Cloud Explosion

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

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

1.2.2.6 Pipeline Frequency Analysis

An effort has also been made to understand the primary failure frequencies of pressurised gas/oil to be transported through the interconnecting pipeline network. Based on the European Gas Pipeline Incident Data Group)EGIG(database the evolution of the primary failure frequencies over the entire period and for the last five years has been provided in **Table 1.15** below.

Table 1.15 Primary Gas Pipeline Failure Frequency

Period	No. of Incidents	Total System Exposure)km.yr(	Primary failure frequency)1000 km.yr(
1970-2007	1173	3.15.106	0.372
1970-2010	1249	3.55.106	0.351
1970-2013	1309	3.98.106	0.329
1974-2013	1179	3.84.106	0.307
1984-2013	805	3.24.106	0.249
1994-2013	426	2.40.106	0.177
2004-2013	209	1.33.106	0.157
2009-2013	110	0.70.106	0.158

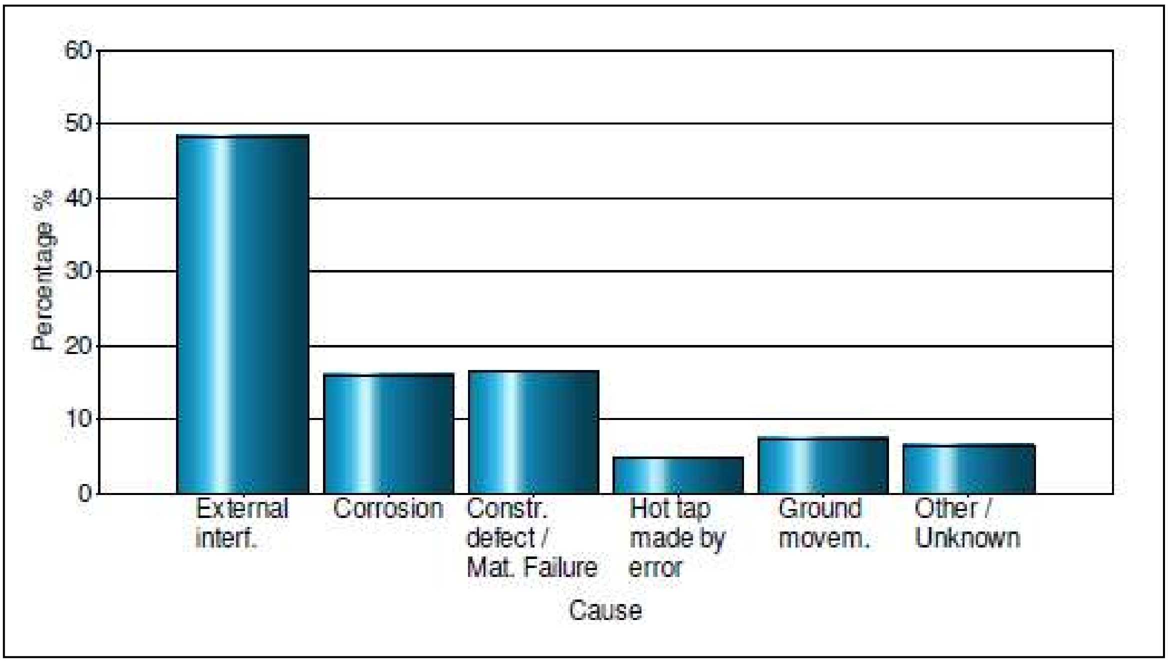
Source: *9th EGIG Report*

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

Incident Causes

Gas pipeline failure incidents can be attributed to the following major causes viz. external interference, construction defects, corrosion)internal & external(, ground movement and hot tap. The distribution of incidents with cause has been presented in the
Figure **1.11** below.

Figure 1.11 Gas Pipeline Failure – Distribution of Incident & Causes



Source: *8th EGIG Report*

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

Review of the 9th EGIG report indicates that primary failure frequency varies with pipeline diameter, and the same has been presented in **Table 1.16** below.

Table 1.16 Primary Failure Frequency based on Diameter Class)1970-2013(

Nominal Diameter)inch(	Primary failure frequency)per km.yr(		
	Pinhole/Crack	Hole	Rupture
diameter < 5"	4.45 X 10-4	2.68 X 10-4	1.33 X 10-4
5" ≥ diameter < 11"	2.80 X 10-4	1.97 X 10-4	6.40 X 10-5
11" ≥ diameter < 17"	1.27 X 10-4	0.98 X 10-4	4.10 X 10-5

Nominal Diameter)inch(	Primary failure frequency)per km.yr(		
	Pinhole/Crack	Hole	Rupture
17" ≥ diameter < 23"	1.02 X 10-4	5.00 X 10-5	3.40 X 10-5
23" ≥ diameter < 29"	8.50 X 10-5	2.70 X 10-5	1.20 X 10-5
29" ≥ diameter < 35"	2.30 X 10-5	5.00 X 10-6	1.40 X 10-5
35" ≥ diameter < 41"	2.30 X 10-5	8.00 X 10-6	3.00 X 10-6
41" ≥ diameter < 47"	7.00 X 10-6	-	-
diameter ≤ 47"	6.00 X 10-6	6.00 X 10-6	6.00 X 10-6

Source: 9th EGIG Report

The pipeline failure frequency viz. leaks or rupture for the natural gas pipeline has been computed based on the aforesaid table. Considering the interconnecting gas pipeline to be laid is likely to have the following diameters - 50mm)1.96 inches(, 200mm)7.87 inches(to 300mm)11.81 inches(, the failure frequency has been presented in **Table 1.17** below.

Table 1.17 Interconnecting Pipeline - Failure Frequency

Sl. No	Pipeline Failure Case	EGIG Failure Frequency)per km.year(	Pipeline Dia)mm(	Avg. Pipeline Length)km(	Project Pipeline Failure Frequency)per year(	Frequency
1	Pipeline Rupture	1.33 x 10-4	50	10	1.33 x 10-3	Occasional/Rare
2	Pipeline Leak	4.45 x 10-4	50	10	4.45 x 10-3	Occasional/Rare
3	Pipeline Rupture	6.40 X 10-5	200	180	11.52 x 10-3	Occasional/Rare
4	Pipeline Leak	2.80 X 10-4	200	180	5.04 x 10-2	Occasional/Rare
5	Pipeline Rupture	4.10 X 10-5	300	10	4.10 x 10-4	Not Likely
6	Pipeline Leak	1.27 X 10-4	300	10	1.27 x 10-3	Occasional/Rare

Thus the probability of pipeline leak and rupture with respect to the interconnecting hydrocarbon pipeline network is identified to be as “Occasional/Rare”.
Pipeline Failure – Ignition Probability
The ignition probability of natural gas pipeline failure)rupture & leaks(with respect to the proposed expansion project is derived based on the following equations as provided in the IGEM/TD/2 standard

P ign = 0.0555 + 0.0137pd2; for 0≥pd2≥57
)For pipeline ruptures(
P ign = 0.81; for pd2>57

P ign = 0.0555 + 0.0137)0.5pd2(; for 0≥0.5pd2≥57
)For pipeline leaks(
P ign = 0.81; for 0.5pd2>57

Where:

P ign	=	Probability of ignition
p	=	Pipeline operating pressure)bar(
d	=	Pipeline diameter)m(

The ignition and jet fire probability of natural gas release from a leak/rupture of interconnected pipeline network is calculated based on the above equations and presented in **Table 1.18** below.

Table 1.18 Interconnecting Pipeline – Ignition & Jet Fire Probability

Sl. No	Pipeline Failure Case	Pipeline Dia)mm(	Project Pipeline Failure Frequency)per year(	Ignition Probability	Jet Fire Probability
1	Pipeline Rupture	50	1.33 x 10-3	0.056	7.46 x 10-5
2	Pipeline Leak	50	4.45 x 10-3	0.055	2.48 x 10-4
3	Pipeline Rupture	200	11.52 x 10-3	0.064	7.48 x 10-4
4	Pipeline Leak	200	5.04 x 10-2	0.060	3.03 x 10-3
5	Pipeline Rupture	300	4.10 x 10-4	0.076	3.14 x 10-5
6	Pipeline Leak	300	1.27 x 10-3	0.066	0.83 x 10-4

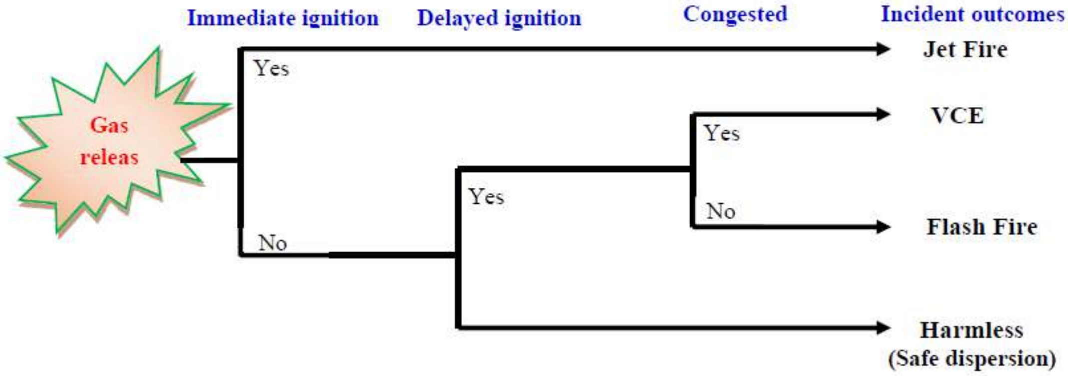
Hence from the above table it can be concluded that ignition probability of natural gas that may be released from the trunk and assorted pipelines due to any accidental event is mostly considered to be "Not likely".

1.2.2.7 Consequence Analysis – Pipelines & GCS

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

In case of pipe rupture containing highly flammable natural gas, an immediate ignition will cause a jet fire. Flash fires can result from the release of natural gas through the formation of a vapour cloud with delayed ignition and a fire burning through the cloud. A fire can then flash back to the source of the leak and result in a jet fire. Flash fires have the potential for offsite impact as the vapour clouds can travel considerable distances downwind of the source. Explosions can occur when a flammable gas cloud in a confined area is ignited; however where vapour cloud concentration of released material is lower than Lower Flammability Limit)LFL(, consequently the occurrence of a VCE is highly unlikely. VCE, if occurs may result in overpressure effects that become more significant as the degree of confinement increases)Refer
Figure 1.12(.Therefore, in the present study, only the risks of jet fires for the below scenarios have been modelled and calculated.

Figure 1.12 Natural Gas Release – Potential Consequences



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

Based on the above discussion and frequency analysis as discussed in the earlier section, the following hypothetical risk scenarios)Refer **Table 1.19**(have been considered for consequence analysis of the interconnecting pipelines.

Table 1.19 Interconnecting Pipeline Risk Modelling Scenarios

Scenario	Source	Pipeline dia)mm(	Accident Scenario	Design Pressure)bar(	Temperature	Potential Risk
1	Pipeline	50	Complete rupture	17.23	24°C	Jet Fire
2	Pipeline	300	Leak of 75mm dia	17.23	24°C	Jet Fire
3	Pipeline	300	Complete rupture	17.23	24°C	Jet Fire
4	Pipeline	200	Leak of 50mm dia	17.23	24°C	Jet Fire
5	Pipeline	200	Complete Rupture	17.23	24°C	Jet Fire

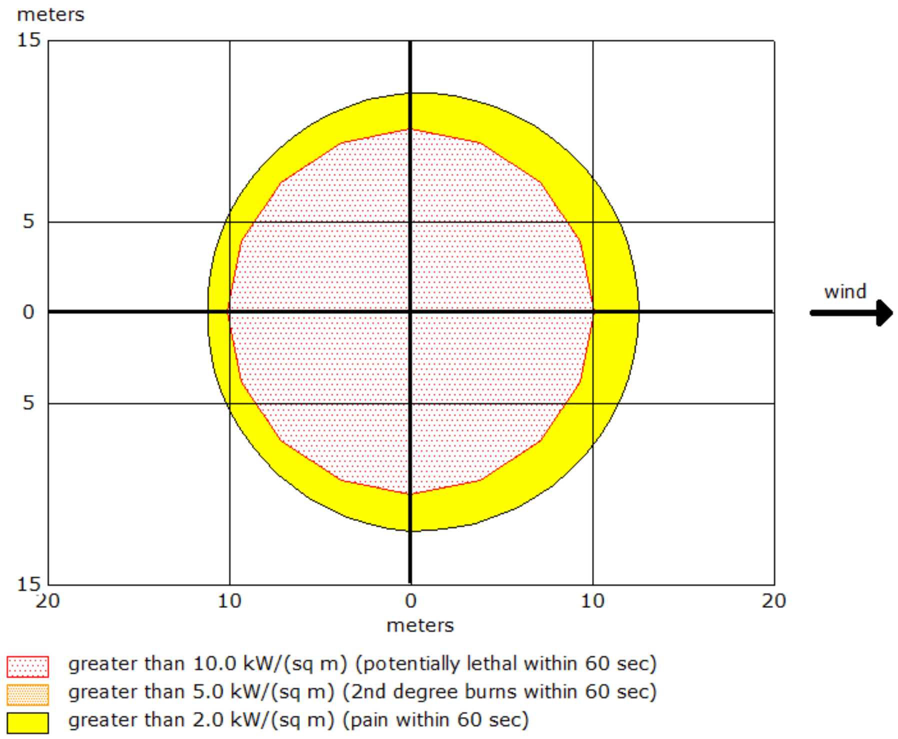
The pipeline failure risk scenarios have been modeled using ALOHA and interpreted in terms of Thermal Radiation Level of Concern)LOC(encompassing the following threshold values)measured in kilowatts per square meter(for natural gas)comprising of ~95% methane1(to create the default threat zones:
Red: 10 kW/)sq. m(-- potentially lethal within 60 sec;
Orange: 5 kW/)sq. m(-- second-degree burns within 60 sec; and
Yellow: 2 kW/)sq. m(-- pain within 60 sec.
For vapour cloud explosion, the following threshold level of concern has been interpreted in terms of blast overpressure as specified below:
Red: 8.0 psi – destruction of buildings;

1 https://www.naesb.org//pdf2/wgq_bps100605w2.pdf
http://www.google.co.in/url?sa=t&rct=j&q=&esrc=s&source=web&cd=18&ved=0ahUKEwjF7MiDttPRAhVCMI8KHd7aD6cQFghrMBE&url=http%3A%2F%2Fwww.springer.com%2Fcda%2Fcontent%2Fdocument%2Fcda_downloaddocument%2F9781848828711-c1.pdf%3FSGWID%3D0-0-45-862344-p173918930&usg=AFQjCNEaJklfYKl3fRUdi6xiRYeW-FJb2A

Orange: 3.5 psi – serious injury likely; and
Yellow: 1.0 psi – shatters glass
The risk scenarios modelled for pipeline failure has been presented below:

Scenario 1: 50mm dia Pipeline Complete Rupture
The jet fire threat zone plot for release and ignition of natural gas from 50 mm dia pipeline ruputre is represented in
Figure 1.13 below.

Figure 1.13 Threat Zone Plot – 50mm dia pipeline complete rupture



Source: ALOHA

THREAT ZONE:

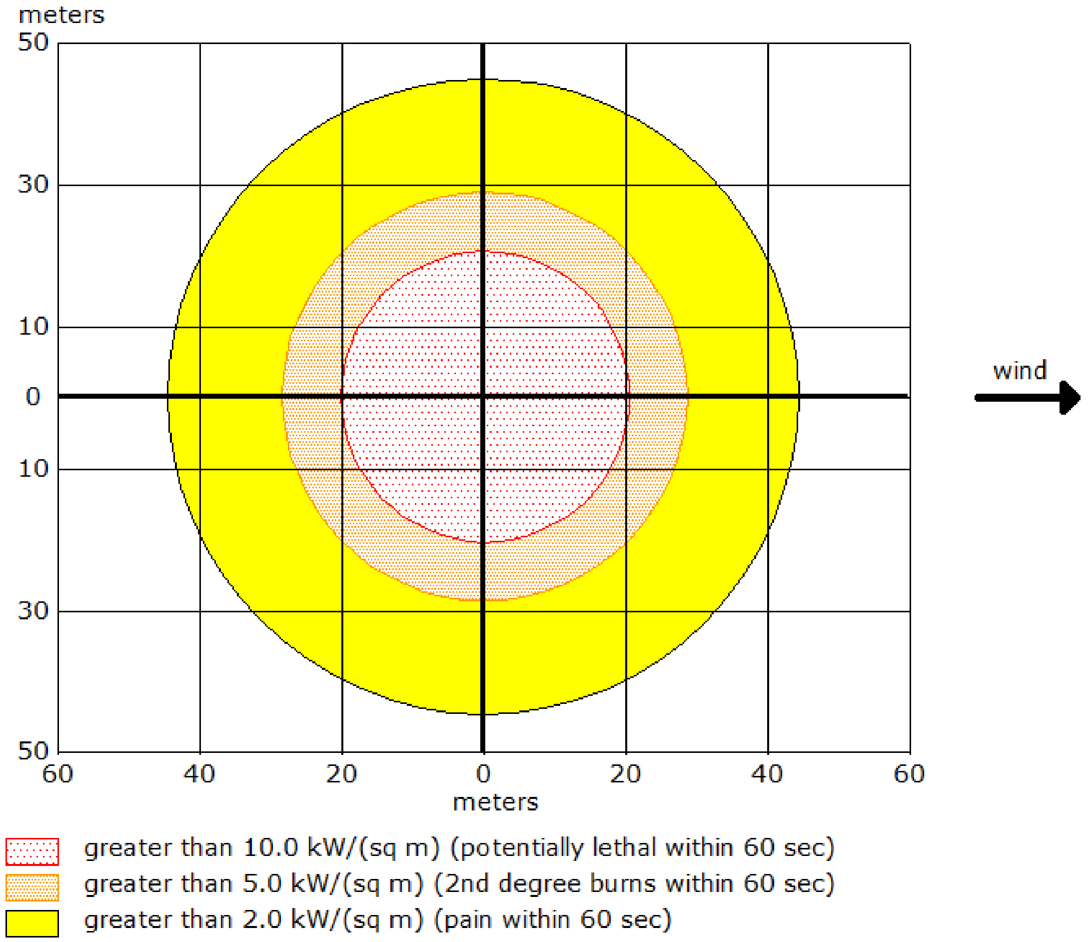
Threat Modeled: Thermal radiation from jet fire

Red : 10 meters ---)10.0 kW/)sq. m(= potentially lethal within 60 sec(
Orange: 10 meters ---)5.0 kW/)sq. m(= 2nd degree burns within 60 sec(
Yellow: 13 meters ---)2.0 kW/)sq. m(= pain within 60 sec(

The worst hazard for release and ignition of natural gas from the 50m dia pipeline rupture will be experienced to a maximum radial distance of 10m from the source with potential lethal effects within 1 minute.

Scenario 2: 300mm dia Pipeline Leak)75mm dia(
The jet fire threat zone plot for release and ignition of natural gas from 300mm dia pipeline leak of 75mm dia is represented in **Figure 1.14** below.

Figure 1.14 Threat Zone Plot – 300mm dia pipeline leak)75mm dia(



Source: ALOHA

THREAT ZONE:

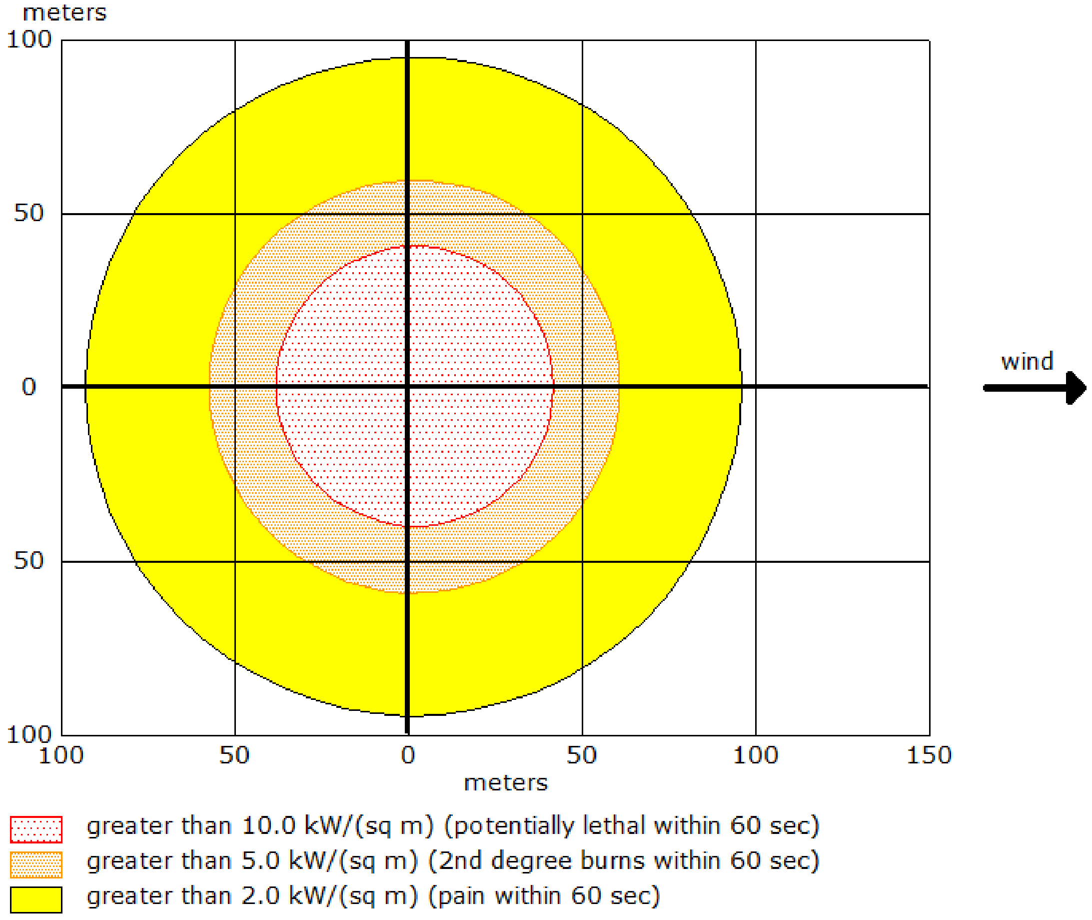
Threat Modeled: Thermal radiation from jet fire

Red : 21 meters ---)10.0 kW/)sq. m(= potentially lethal within 60 sec(
Orange: 29 meters ---)5.0 kW/)sq. m(= 2nd degree burns within 60 sec(
Yellow: 45 meters ---)2.0 kW/)sq. m(= pain within 60 sec(

The worst hazard for release and ignition of natural gas from 300m dia pipeline leak of 75mm dia will be experienced to a maximum radial distance of 21m from the source with potential lethal effects within 1 minute.

Scenario 3: 300mm dia Pipeline Rupture
The jet fire threat zone plot for release and ignition of natural gas from 300m dia pipeline rupture is represented in **Figure 1.15**.

Figure 1.15 Threat Zone Plot – 300mm dia pipeline rupture



Source: ALOHA

THREAT ZONE:

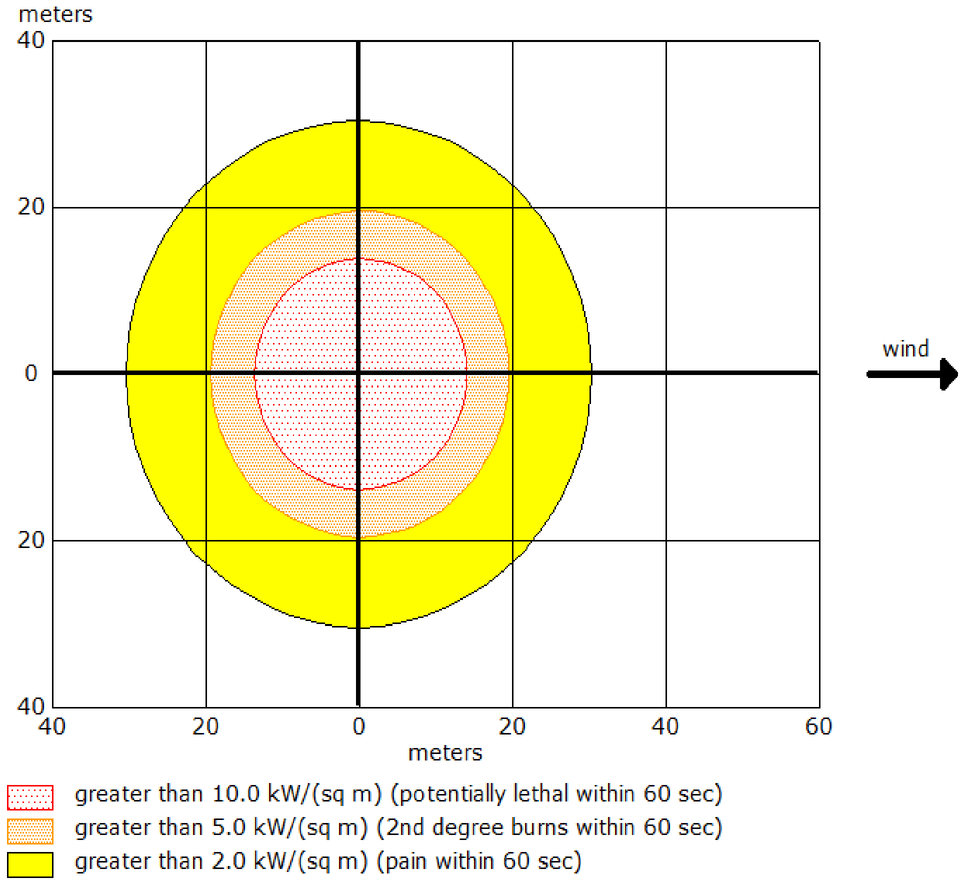
Threat Modeled: Thermal radiation from jet fire

Red : 41 meters ---)10.0 kW/)sq. m(= potentially lethal within 60 sec(
Orange: 61 meters ---)5.0 kW/)sq. m(= 2nd degree burns within 60 sec(
Yellow: 96 meters ---)2.0 kW/)sq. m(= pain within 60 sec(

The worst hazard for release and ignition of natural gas from 300mm dia pipeline rupture will be experienced to a maximum radial distance of 41m from the source with potential lethal effects within 1 minute.

Scenario 4: 200mm dia Pipeline Leak)50mm dia(
The jet fire threat zone plot for release and ignition of natural gas from 200mm dia pipeline leak of 50mm dia is represented in **Figure 1.16**.

Figure 1.16 Threat Zone Plot –200mm dia pipeline leak)50mm dia(



Source: ALOHA

THREAT ZONE:

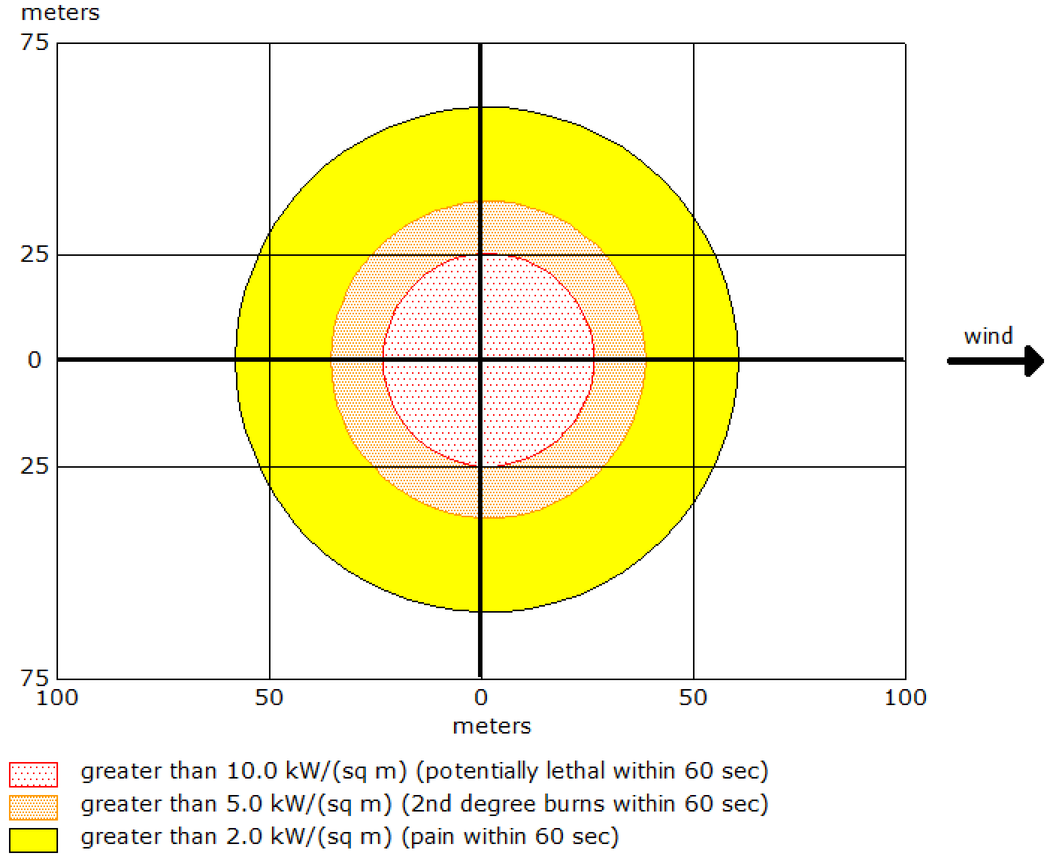
Threat Modeled: Thermal radiation from jet fire

Red : 15 meters ---)10.0 kW/)sq. m(= potentially lethal within 60 sec(
Orange: 21 meters ---)5.0 kW/)sq. m(= 2nd degree burns within 60 sec(
Yellow: 31 meters ---)2.0 kW/)sq. m(= pain within 60 sec(

The worst hazard for release and ignition of natural gas from 200mm dia pipeline leak of 50mm dia will be experienced to a maximum radial distance of 15m from the source with potential lethal effects within 1 minute.

Scenario 5: 200mm dia Pipeline Rupture
The jet fire threat zone plot for release and ignition of natural gas from 200mm dia pipeline rupture is represented in **Figure 1.17** below.

Figure 1.17 Threat Zone Plot –200mm dia pipeline rupture



Source: ALOHA

THREAT ZONE:

Threat Modeled: Thermal radiation from jet fire

Red : 28 meters ---)10.0 kW/)sq. m(= potentially lethal within 60 sec(
Orange: 38 meters ---)5.0 kW/)sq. m(= 2nd degree burns within 60 sec(
Yellow: 60 meters ---)2.0 kW/)sq. m(= pain within 60 sec(

The worst hazard for release and ignition of natural gas from 200mm dia pipeline rupture will be experienced to a maximum radial distance of 28m from the source with potential lethal effects within 1 minute.

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

THREAT ZONE:

Threat Modeled: Overpressure)blast force(from vapour cloud explosion
Type of Ignition: ignited by spark or flame
Level of Congestion: uncongested
Model Run: Heavy Gas

Red : LOC was never exceeded ---)8.0 psi = destruction of buildings(
Orange: LOC was never exceeded ---)3.5 psi = serious injury likely(

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

For calculating the risk significance of natural gas pipeline, the likelihood ranking is considered to be "3" as the probability of pipeline rupture is computed to be ~10-4 per year; whereas the consequence ranking has been identified to be as "3" as given for a worst case scenario)rupture(lethal effects is likely to be limited within a radial zone of ~41m. Further as discussed in the earlier section, adequate number of gas leak and fire detection system of appropriate design will be provided for the interconnecting pipeline network including GCS to prevent for any major risk at an early stage of the incident.

Risk Ranking – Pipeline Rupture)Worst Case Scenario(

Likelihood ranking	3	Consequence ranking	3
Risk Ranking & Significance =9 i.e. "Low" i.e. Risk is Acceptable and can be managed through use of existing controls with the option for installation of additional controls, if necessary.			

1.2.3 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.

1.2.4 Emergency Identified

Emergencies that may arise:

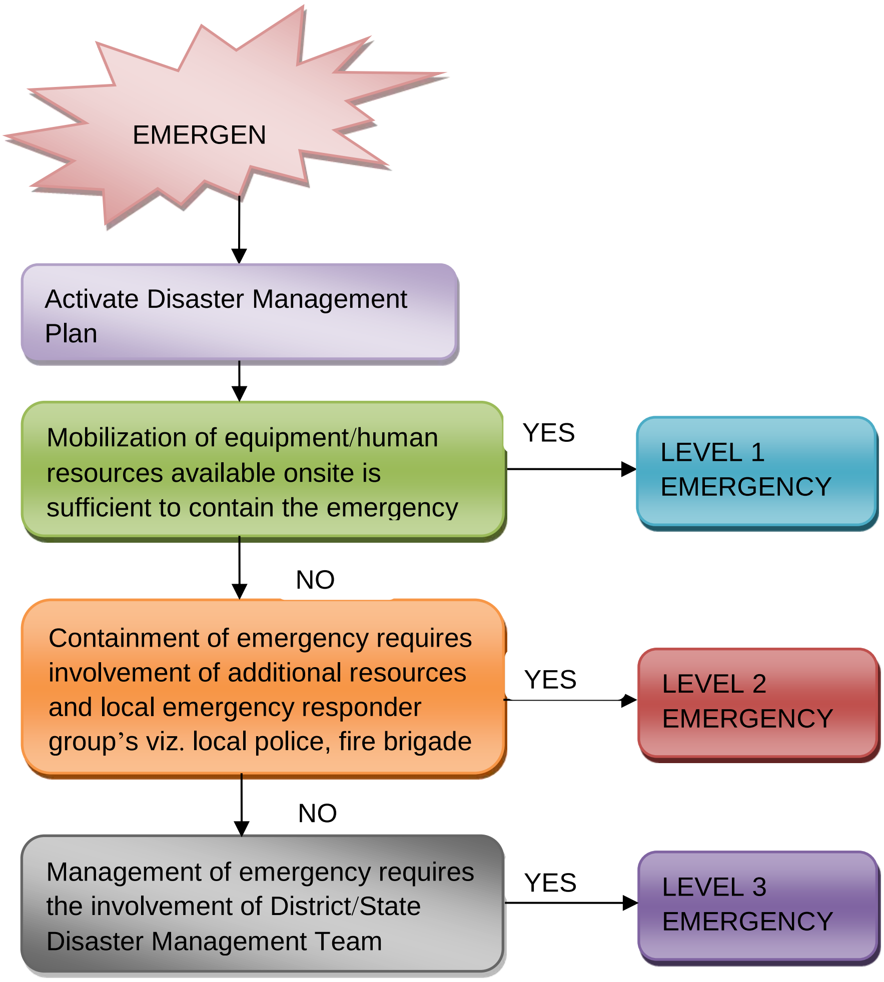
- Such an occurrence may result in on-site implications like :
    - Fire or explosion;
    - Leakage of natural gas; and
    - Oil spillage and subsequent fire.
- Incidents having off-site implications can be:
    - Natural calamities like earthquake, cyclone, lightening, etc.
- Other incidents, which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

- Sabotage.

1.2.5 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 1.18**.

Figure 1.18 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:

1.2.5.1 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.

1.2.5.2 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.

1.2.5.3 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 the concerned district)s(.

1.2.6 Preventive and Mitigation Measures for Blow Outs

In case of a blowout Fire service team from OIL and other Mutual Aid partners will report at site and will start spraying water continuously from all directions to disperse the formation of any explosive mixture in and around the well head area and keep the well head area cool to avoid any fire incident. The Disaster Control Room will be activated and information will be sent to all Disaster Management Coordinators of Mutual Aid partners. The Oil and Natural Gas Corporation Ltd. (ONGCL), Crisis Management Team (CMT) will be contacted for their expertise and support to control the situation. International Blowout control agencies will also be engaged for blowout control as necessary.

Proposed action plan control blowout of hydrocarbon prior to fire incident

- Creation of facilities for pumping water to the blowing well.
- Infrastructure arrangement for capping the well.
- Pumping of sufficient water through the well annulus to make the flowing gas wet, thereby reducing gas condensate spread to the nearby areas.
- Adequate water spraying through Fire Service pumps and nozzles/ monitors.
- Taking all adequate HSE measures.
- Continuous gas testing for LEL level around the well plinth area.
- To clear all equipment’s and debris from site.
- Arrange adequate drilling mud and pumping infrastructure
- To complete the fabrication of hydraulically operated mechanized structure (for moving/ placing Blow out Preventer (BOP)) at OIL’s workshop, incorporating all the points identified in the mock drill.
- Place fabricated mechanized structure 20-25 m from the wellhead
- Move BOP to well mouth hydraulically. Splash water continuously
- Cap the well by placing BOP on the wellhead
- Subdue the well by pumping drilling mud immediately.

Proposed action plan to extinguish the fire in case of blowout

- Heat shielding of the working areas by suitable means.
- To clear all debris and damaged rig package & equipment from site.
- Arrange water and pumping infrastructure.
- Arrange adequate drilling mud and pumping infrastructure.

- Special tools and equipment's used for controlling well under fire to be mobilized from various sources nationally and internationally.
- Arranging to cap the well by placing BOP with the help of special tools (Athey wagon) after creating a continuous water umbrella.
- Subdue the well by pumping drilling mud & kill the well immediately.
- Bring the well under control.