RISK ASSESSMENT & DISASTER MANAGEMENT PLAN

7.1 INTRODUCTION

Environmental Risk Assessment is a scientific analysis for identification of credible risk and thereafter estimating the safe distances from any hazardous installations/processes in the eventuality of an accident. Estimation of near accurate safe distances is absolutely necessary to protect the public, property and environment.

Development drilling and testing operations of hydrocarbon, EPS & Pipeline within Charaideo block under Charaideo Nahophabi PML are considered hazardous in nature, which can pose risk to life and property in an unlikely event of sudden and violent release of hydrocarbon fluid and hydrogen sulfide (H_2S) gas due to other unsafe acts/conditions and from fuel HSD storage. Therefore, detailed hazard identification, risk assessment have been carried out and disaster management plan has been prepared for prompt response in the event of an emergency.

7.1.1 OBJECTIVE

The objectives of the study are to provide:

- Preliminary identification of hazards and hazardous scenarios that could produce an undesirable consequence arising from the proposed developmental drilling of wells, EPS & Pipeline within Charaideo block.
- Assessment of consequences of hazards from developmental drilling of wells, EPS & Pipeline within the facility in terms of ignition, thermal radiation, blowout etc.
- Determination of the magnitude of all major accidents arising due to the proposed developmental drilling of wells, EPS & Pipeline within Charaideo block that have the potential to cause damage to life, property and environment including:
  - ✓ Effects are as where personnel may be located within the proposed developmental drilling of wells, EPS & Pipeline within Charaideo block
  - ✓ Effects on are as external to the development drilling, EPS & Pipeline
- Estimation of frequency of occurrence of the hazards.
- Review of safety features (organizational systems & safety equipment)
- Recommendations for prevention, control and mitigation measures for any identified risk

The overall aim of the study is to provide a degree of predictability on the risk of the operation as a result of the proposed developmental drilling of wells, EPS & Pipeline within Charaideo block.

7.1.2 METHODOLOGY & APPROACH EMPLOYED

Risk analysis consists of hazard identification studies to provide an effective means to identify different types of hazard during the operation of the facility. This is followed by an assessment of the impacts of these hazards.

Hazard is present in any system, plant or unit that handles or stores flammable materials. The mere existence of hazards, however, does not automatically imply the existence of risk. Screening & ranking methodologies based on Preliminary Hazard Analysis (PHA) techniques have to be adopted for risk to be evaluated.

The approach and methodology by ABC Techno Labs followed for the Risk Assessment study are described hereunder:

❑ **Identification of Hazards Analysis**

Various possible hazards will be identified during developmental drilling of wells, EPS & Pipeline within Charaideo block. The release sources and potential accidents scenarios associated with each hazards will be listed. For each selected release sources, several scenarios may be possible depending upon the failure mode causing loss of containment. The criteria used for selection of scenarios for the consequence analysis will be the Maximum Credible Accidental (MCA) scenarios.

- **Effects & Consequence Estimation**

Effects & consequence distance estimation performed to determine the potential for damage or injury from the selected scenarios. The incident outcomes analyzed using release rates, dispersion, combustion, thermal radiation from fire and spill. Damage distance computation based on jet fire, flash fire scenarios, as applicable.

- **Failure Frequency Analysis**

Failure frequency analysis done for Blowout & well release, Structural failure etc. Standard international database referred for estimation of probabilities.

Failure rate data is essentially derived from internationally well known generic databases. The generic failure data base selected for calculating the failure frequencies and the values in the database are used to reflect the mechanical and process design of the development drilling operations, EPS & Pipeline.

- **Risk Summation**

Risk quantification and summation is based on probabilities from standard international database. The risk to personnel will be expressed in terms of Individual Risk (IR) represented by Iso Risk Contours and Group Risk/Societal risk represented by F-N Curves based on risk tolerability criteria.

- **Risk Mitigation Measures**

Based on consequence analysis and risk summation findings, risk mitigation measures will be suggested in view of applicable standards, guidelines and best practices to reduce risk and enhance safety at the proposed developmental drilling of wells, EPS & Pipeline within Charaideo block.

7.2 RISK ASSESSMENT AND HAZARD IDENTIFICATION

Developmental operations and testing operations, EPS & Pipeline are generally hazardous in nature by virtue of intrinsic chemical properties of hydrocarbons or their temperature or pressure of operation or a combination of these factors. Fire, explosion due to hazardous release of crude oil, gas, H_2S or a combination of these are the hazards associated with hydrocarbon developmental and testing operations. These have resulted in the development of more comprehensive, systematic and sophisticated methods of safety engineering, such as, hazard identification and risk assessment to improve upon the integrity, reliability and safety of hydrocarbon operations.

The primary emphasis in safety engineering is to reduce risk to human life and environment. The broad tools attempt to minimize the chances of accidents occurring. Yet, there always exists, no matter how remote, that small probability of a major accident occurring. If the accident involves hydrocarbon in sufficient large quantities, the consequences may be serious to the project site, to surrounding area and the population therein.

Derrick floor is the center stage of all the development drilling operations and it is most susceptible to accidents. Safety precaution with utmost care is required to be taken during drilling as per the prevailing regulations and practices so that accidents can be avoided. Due to advancement in technology, numbers of equipment have been developed over a period to cater the need of smooth operation on derrick floor. Various standards are required to be referred to cover the variety of equipments used for safe operation in drilling and it is desirable to use a properly prepared manual for occupational safety while working or drilling over rig.

The following are the main hazards envisaged during developmental drilling of well.

7.2.1 Minor Oil Spill

During development drilling and testing operations, EPS & Pipeline details of classification of possible oil spill scenario(s) and respective activities are as follows:

Table 7.1: Classification of Oil spill during Developmental Drilling, EPS & Pipeline

Classification of spill	Extent of spill	Impact	Scenarios	Preventive Measures
Tier 1 ***Response can be adequately addressed using equipment and materials available at the site.***	Spill contained on site.	Minor equipment damage. Brief disruption to operations.	• Diesel fuel refueling (i.e. drill rig hose leaks, overfilling or connection/disconnection incidents). • Drilling fluid (i.e. leaks from tanks, pumps or other associated equipment within the closed loop circuit system). • Drilling fluid chemicals (i.e. chemicals used during drilling; note that the volumes are limited by the storage containers used i.e. 200 L drums etc.). • Hydraulic oil (i.e. leaks from a split hydraulic hose or failed connector; moderate pressure, low volume lines).	One of the following preventive systems or its equivalent shall be used as a minimum for onshore facilities: • Dykes, berms or retaining walls sufficiently impervious to contain spilled oil
Tier 2 ***Response requires additional oversight expertise, equipment, and materials available***	Localized spill with potential for escaping the site or that has escaped the site but is of limited extent	Moderate to major equipment damage/loss. Partial or short-term shutdown of operations.	• Transportation incidents associated with the delivery of diesel fuel to the drill-site (i.e. third party supplier's truck rollover or collision). • Complete failure of an on-site storage tank (e.g. diesel fuel for generators).	
Tier 3 ***Response requires oversight, expertise, equipment, and materials available***	Major incident or a spill that has extended beyond the site.	Extensive equipment damage/loss. Long-term shutdown of operations.	• Uncontrolled fluid flow (blowout) from a well during development drilling in case oil is part of fluid.	

Source: ABC Techno Labs India Pvt. Ltd.

Spill response strategies for combating incidents include:

- **Prevent or reduce further spillage:** One of the first response actions, if safe to do so, is the isolation of the source and prevention of further discharge.
- **Monitoring and evaluation:** Monitoring and evaluation are used to: Determine the location and movement (if any) of the spill, its appearance, its size and quantity, changes in the appearance and distribution of the spill over time and potential threat to the environment and the resources required to combat the spill (i.e. a more effective and coordinated response).
- **Mechanical containment and recovery:** restriction of spill movement through the use of physical barriers (e.g. bunds, booms, diversion swales). Containment would be followed by the physical removal of the spilled material. This may be accomplished using sorbent pads, vacuum trucks, skimmers or other mechanical means appropriate to the material spilled.
- **Protection of sensitive areas:** Bunds or booms will be used to prevent spills from migrating down a watercourse or stream.
- **Clean-up:** This involves earthmoving equipment used to recover the absorbed spill and affected soil. Such operations may involve the collection of significantly greater volumes of material than was originally released.
- Combinations of the above strategies.

Affected area due to oil spill will be isolated. Spilled oil will be recovered and stored. Contaminated earth will be collected and disposed in consultation with Assam Pollution Control Board. Oil contaminated area will be reclaimed using bioremediation technique through oil zapper or other appropriate methods.

7.2.2 Blowout

If the hydrostatic head exerted by the column of drilling fluid is allowed to drop below the formation pressure then formation fluids will enter the well bore (this is known as a kick) and a potential blowout situation has developed. Blowout means uncontrolled violent escape of hydrocarbon fluids from a well. Blowout followed by ignition, is a major hazard. Major contributors to blowout are:

Primary

- Failure to keep the hole full;
- Too low mud weight;
- Swabbing during trips;
- Lost circulation; and
- Failure of differential fill-up equipment.

Secondary

- Failure to detect and control a kick as quickly as possible;
- Mechanical failure of Blow Out Preventer (BOP);
- Failure to test BOP equipment properly;
- Damage to or failure of wellhead equipment;
- Failure of casing; and
- Failure of formation or cement bond around casing.
- Fast and efficient action by operating personnel in recognizing the above situations and taking precautionary measure can avert a blowout.

❑ *Presence of Sour Gas (Hydrogen Sulphide-H_2S)*

Presence of Sour Gas (H_2S) in hydrocarbon during blowout of well can pose immediate dangers to life and health at and around the rig area. On ignition, H_2S is converted to sulfur dioxide (SO_2) which is also highly toxic. Therefore, a safety system should be in place to monitor H_2S.

Hydrogen Sulphide gas (H_2S) is extremely toxic and even very low concentrations can be lethal depending upon the duration of exposure. Additionally it is corrosive and can lead to failure of the drill string or other tubular components.

Important characteristics of H_2S gas are briefed below:

1. H_2S is a toxic colourless gas heavier than air.
2. In concentrations greater than 100 ppm, it causes loss of senses in 3 to 15 minutes and death within 48 hours.
3. The safe concentration for a normal working period without protection is 10 ppm.
4. It has an odour of rotten eggs.
5. In concentration greater than 10 ppm, the olfactory sense to smell the gas is lost, hence need for detectors is apparent.
6. It dissolves in the blood and attacks through the nervous system.
7. It is very irritating for the eyes as it forms sulphurous acid together with water.
8. It attacks the body through the respiratory organs.
9. The Occupational Safety and Health Act (OSHA) sets a 10 ppm ceiling for an (eight) hour continuous exposure (TWA limit), a limit of 15 ppm for short term exposure limit for 15 minutes (STEL) and a peak exposure concentration of 50 ppm for 10 minutes.
10. The best protection is breathing apparatus, with mask covering the whole face and a bottle containing breathing air.
11. H_2S burns with a blue flame to sulphur dioxide which is also dangerous
12. It forms an explosive mixture with air at concentrations from 4% to 46%.
13. Short exposure of high tensile steel to as little as 1 ppm in aqueous solution can cause failures.
14. Concentrations greater than 15 ppm can cause failure to steel harder than Rockwell C-22. High stress levels and corrosive environments accelerate failures.
15. When pH is above 9 and solubility is relatively high, it is readily soluble in mud and especially in oil mud.
16. A 30% hydrogen peroxide solution will neutralize H_2S gas in the mud or 20 gallons of H_2O_2 per 100 barrels of mud.It occurs together with natural gas in all oil provinces of the world.
17. Coughing, eye burning and pain, throat irritation, and sleepiness are observed from exposure to low concentrations of H_2S.
18. Exposure to high concentrations of H produces systems such as panting, pallor, cramps, paralysis of the pupil and loss of speech. This is generally followed by immediate loss of consciousness. Death may occur quickly from respiratory and cardiac paralysis.

Concentrations	Symptoms/ Effects
100 ppm	Coughing, eye irritation, loss of smell after 2-15 minutes (olfactory fatigue).

Concentrations	Symptoms/ Effects
	Altered breathing, drowsiness after 15-30 minutes. Throat irritation after 1 hour. Gradual increase in severity of symptoms over several hours. Death may occur after 48 hours.
Greater than 100 ppm	Loss of smell (olfactory fatigue or paralysis).
500-700 ppm	Staggering, collapse in 5 minutes. Serious damage to the eyes in 30 minutes. Death after 30-60 minutes.
700-1000 ppm	Rapid unconsciousness, "knockdown" or immediate collapse within 1 to 2 breaths, breathing stops, death within minutes.
1000-2000 ppm	Nearly Instant Death

As per available data, there is no chance of presence of H_2S in the hydrocarbon present within block, however, as a hypothetical case, scenario of presence of 3% H_2S has been considered for consequence analysis.

7.2.3 Other Hazards during Drilling Rig Operations

7.2.3.1 Hazards During Preparation for Setting Up the Substructure

Equipment(s) are unloaded and positioned at or near the exact location of drilling point. The substructure is assembled, pinned together, leveled, and made ready for other rig components on the floor. Equipping the cellar begins but can be done throughout the rigging up process. This includes welding on a drilling nipple to the conductor pipe and attaching a flow line.

Potential Hazards:

- Being struck by the crane, load, truck.
- Pinched fingers when assembling equipment.
- Burns from cutting and welding on the drilling nipple.
- Temporary eye irritation from welding light flash.
- Falling from heights.

7.2.3.2 Hazards during Setting Up the Rig Floor and Mast or Derrick

Once the substructure is set in place, the process of setting up the rig floor begins by installing stairways and guardrails to allow access to the rig floor. Then, the draw works is set in place and secured to the substructure. On mechanical rigs, the engines are set in place and the compound and associated equipment connected to the draw works. On electric rigs, the electric cables (lines) are strung to the draw works.

The bottom of the mast is raised to the rig floor and pinned in place. The crown section is then raised into place on the derrick stand. The "A-legs" are raised and pinned into place. The monkey board is pinned in place on the mast and all lines and cables are laid out to prevent tangling when the mast is raised. A thorough inspection of the mast should be made before raising the mast/derrick. The mast is now ready to be raised. The engines are started, and the drilling line is spooled onto the draw works drum. Once the mast has been raised and pinned, the remaining floor equipment can be set into place. If the rig has safety guy lines, they must be attached to the anchors and properly tensioned prior to continuing the rigging up process. A derrick emergency escape device is installed on the mast.

Potential Hazards:

- Falling or tripping during rigging up;
- Falling from rig floor;
- Being struck by swinging equipment;
- Being struck by falling tools;
- Being crushed or struck by equipment due to failure or overloading of hoisting equipment;
- Getting entangled in lines during rising of the derrick or mast;
- Failure to properly install derrick emergency escape device; etc

7.2.3.3 HAZARD IN RIGGING UP THE CIRCULATING SYSTEM

While one crew finishes preparing the rig floor, another crew might be rigging up the circulating system. The mud tanks and mud pumps are set into the predetermined location. The mud lines are then connected and electric cords are strung.

Potential Hazards:

- Being struck by or crushed by equipment being set into place;
- Getting caught in pinch points;
- Being struck by crane, load, truck or forklift tipping;
- Being struck by hammer when connecting mud line unions; etc

7.2.3.4 HAZARDS DURING INSTALLING THE AUXILIARY EQUIPMENT

All remaining drilling and auxiliary equipment must be set into place and installed where needed. The catwalk and pipe racks are positioned and the pipe and drill collars are set on the racks.

Potential Hazards:

- Getting struck or pinched by, or caught in between, tubulars being loaded onto racks.
- Having feet pinched or crushed when setting up the pipe racks and catwalk.

7.3 CONSEQUENCE ANALYSIS

The risk presented by a blowout (hydrocarbons release event) is determined by the frequency and consequence of its possible outcomes. The consequence of igniting a hydrocarbon release during blowout depends on the type of material released, the mass release rate, the timing of the ignition, and the environment into which the hydrocarbon is released. Briefly, typical outcomes are:

- **Jet fires:** produced by an ignited jet of gas or liquid spray released under pressure;
- **Pool fires:** produced by ignition of a liquid release that accumulates on the surface and ignites;
- **Flash fires:** produced by igniting a gas cloud so that a fire propagates through the gas cloud (without generating a significant overpressure);
- **Explosions:** produced by igniting a gas cloud in conditions where the resultant accelerating flame front produces a significant overpressure.

Jet fire emanating from the release source may follow a flash fire or explosion.

1. **Early Ignition**

In the consequence analysis, gas and two-phase events that ignite early are modeled as jet fires. Liquid releases that ignite early are modeled as pool fires.

Briefly, jet fires are modeled as follows:

- Mass release rate is determined (for each representative hole size) based on the operating temperature and pressure at the point of release.
- From the mass release rate, the jet flame length and associated fatality area.

2. Late Ignition

In the event of two-phase releases that ignite late are modeled as explosions.

Delayed ignition is not assumed to occur for oil releases. The consequential effect of a hydrocarbon gas explosion on personnel is determined by a variety of factors, including:

- Direct effects of blast overpressure;
- Whole body translation due to the blast wave;
- Thermal effects on personnel inside the burning gas cloud.

It is assumed that all personnel caught inside the burning gas cloud are likely to be fatally injured due to thermal radiation effects and inhalation of burning gases. Outside the gas cloud, personnel may still suffer from the effects of flash fire.

❑ **Thermal Radiation**

Thermal radiation from a hydrocarbon fire is a significant hazard to personnel. The degree of injury caused by thermal radiation is related to the intensity of the thermal radiation and the exposure time.

Thermal radiation effect modeling to estimate the likely injury or damage to people and objects due to thermal radiations resulting from incident outcomes is the straightest forward of the three types of physical exposure modeling referred to above. The consequence caused by exposure to heat radiation is a function of:

- The radiation energy onto the human body [kW/m^2];
- The exposure duration [sec];
- The protection of the skin tissue (clothed or naked body).

The following damage distances for thermal radiation have been used for modeling:

37.5 kW/m^2	:	*Damage to process equipment. 100% fatality in 1min. 1% fatality in 10sec.*
12.5 kW/m^2	:	*First degree burn for 10 sec exposure*
4.0 kW/m^2	:	*First degree burn for 30 sec exposure*

❑ **Ignition of Blowout**

Surprisingly, few surface blowouts ever ignite. Less than 10 blowouts per year ever catch on fire, worldwide. Typically, large formation water flows lifted by the hydrocarbon flow make ignition difficult if not impossible. Water comes into the blowout zone, drawn in by low flowing bottom hole pressure; or adjacent wet zones are exposed to the flow path.

Highly flammable blowouts may never ignite if no ignition source is present and flow is quickly dispersed. Thus, knowledgeable and experienced blowout specialists always restrict blowout access and carefully inspect the area around blowouts for ignition sources, particularly areas within an explosive vapor cloud.

7.3.1 Model Used For Consequence Analysis

PHAST (Version 6.53.1) software of DNV has been used to perform the consequence calculations. PHAST is a consequence and risk assessment software for calculation of physical effects (fire, explosion, atmospheric dispersion) of the escape of hazardous materials. PHAST software allows detailed modeling and quantitative assessment of release of pure and mixtures of liquid and gaseous chemicals.

7.3.2 Scenarios wise Findings of Consequence Analysis

Subsequent to the accidental release of hydrocarbon, the consequence depends on various factors e.g. type and quantity, presence and location of an ignition source, meteorological conditions, etc. The consequence analysis for the selected accident scenarios for hydrocarbon releases have been carried out to estimate the impacted distances and outcomes of same have been described in subsequent sections.

- **Release of HSD leak from 40KL storage tank (25 mm)**

A. Jet Fire

In the event of leak on HSD storage Tank of 25mm dia , computed thermal radiation distances resulting from jet fire are as per given hereunder:

Radiation Level	Distances(m)			
	1 m/s-B	3 m/s-D	3 m/s-E	2 m/s –F
4kW/m^2	0.978	Not Reached	Not Reached	Not Reached
12.5kW/m^2	0.951	Not Reached	Not Reached	Not Reached
37.5kW/m^2	0.913	Not Reached	Not Reached	Not Reached

B. Poolfire

Computed thermal radiation distances resulting from Pool fire are as per given hereunder:

Early pool fire due to leak in HSD storage tank				
Radiation Level	Distances(m)			
	1 m/s-B	3 m/s-D	3 m/s-E	2 m/s –F
4kW/m^2	0.978	0.951	0.913	09.10
12.5kW/ m^2	Not Reached	Not Reached	Not Reached	Not Reached
37.5kW/ m^2	Not Reached	Not Reached	Not Reached	Not Reached
Late pool fire due to leak in HSD storage tank				
Radiation Level	**Distances(m)**			
	1 m/s-B	**3 m/s-D**	**3 m/s-E**	**2 m/s –F**
4kW/ m^2	23.23	23.10	22.63	22.92
12.5kW/ m^2	16.51	16.32	14.99	15.56
37.5kW/ m^2	8.74	8.12	6.98	7.02
Late pool fire due to catastrophic rupture of HSD storage tank				
Radiation Level	**Distances (m)**			
	1 m/s-B	**3 m/s-D**	**3 m/s-E**	**2 m/s –F**
4kW/ m^2	59.62	52.62	58.95	56.64
12.5kW/ m^2	21.21	29.26	26.12	27.98
37.5kW/ m^2	19.65	18.32	16.99	17.23

Level Indicators, earthing, flame arrestor are the control equipments are proposed for the site.

- **Blowout during Drilling of Well**

Formation pressure in hydrocarbon wells is typically may be high, thus conventional BOP stack is used at drilling rig.

Release of Hydrocarbon through 150 mm hole containing 3 % H_2S gas due to Blowout

1. IDLH Concentration of 3 % H_2S

In the event of vertical release of hydrocarbon, IDLH concentration of hydrogen sulphide (H_2S) will not reach to the ground. Therefore, no hazard is anticipated.

IDLH Concentration	IDLH Concentration Distances (m)			
	3 m/s - B	3 m/s - D	2 m/s – E	1 m/s - F
100 ppm	No Hazard	No Hazard	No Hazard	No Hazard

2. UFL and LFL Concentration Distances

In the event of release of hydrocarbon during blow-out, hydrocarbon /fluid gas cloud will be formed, if it is not getting source of ignition. Computed hydrocarbon gas concentrations between UFL and LFL are as per given below:

Concentration	UFL and LFL Concentration Distances (m)			
	1 m/s - B	3 m/s - D	3 m/s - E	2 m/s – F
UFL	0.4206	0.4399	0.29607	0.1518
LFL	4.4010	3.9030	3.7254	3.0290
LFL Fraction (50%)	10.9116	11.8302	11.9041	9.8477

Heights (m) for above distances are given below:

Concentration	Height of cloud (m)			
	1 m/s - B	3 m/s - D	3 m/s - E	2 m/s – F
UFL	14.0123	14.9357	15.9621	16.2453
LFL	39.2846	40.6116	46.8858	54.2279
LFL Fraction (50%)	57.0586	58.7686	59.376	55.4106

3. Flash Fire Envelope

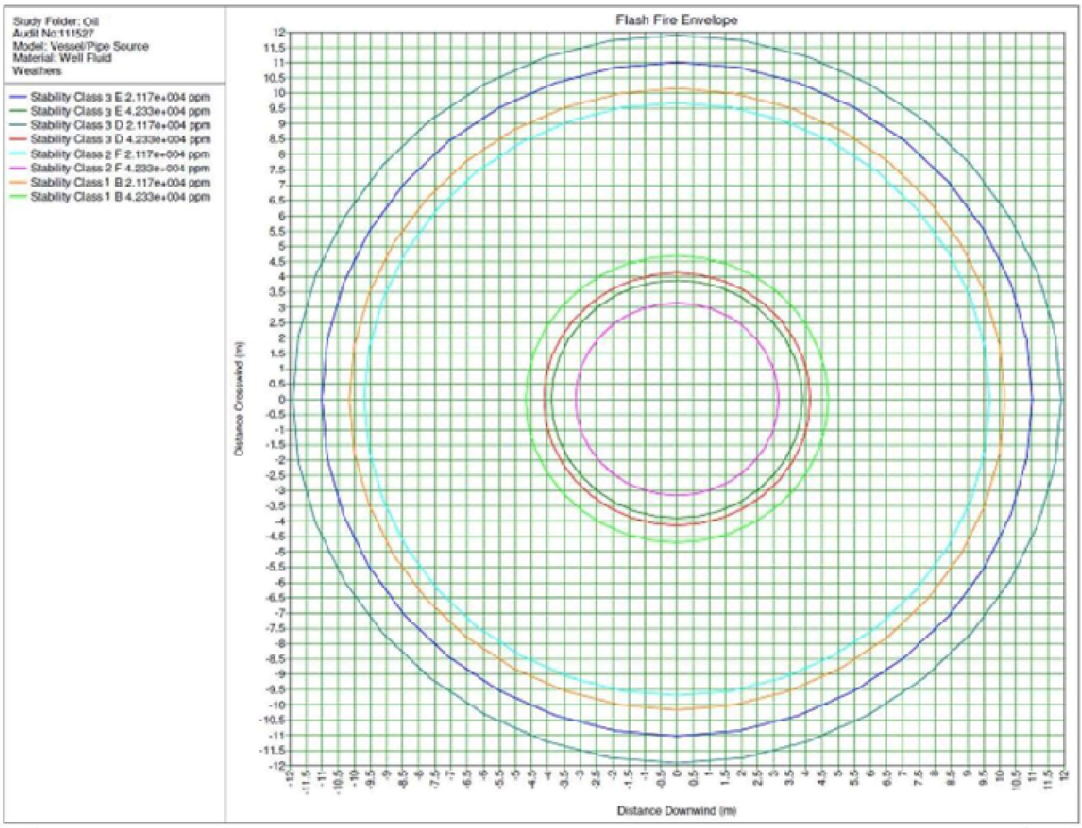
On ignition of Hydrocarbon gas, flash fire envelope will be formed as per details given below:

Concentration	Distances Fire covered by Flash Envelope (m)			
	1 m/s - B	3 m/s - D	3 m/s - E	2 m/s – F
Furthest	4.40103	3.90301	3.72547	3.02901
Furthest (50%)	10.9116	11.8302	11.9041	9.8477

Heights (m) for flash fire envelope are given below:

Concentration	Height of Flash Fire Envelope (m)			
	1 m/s - B	3 m/s - D	3 m/s - E	2 m/s – F
Furthest	39.2846	40.6116	46.8858	54.2279
Furthest (50%)	57.0586	58.7686	59.3760	55.4106

Flash fire envelope distances are depicted in Figure 7.1.



Source: ABC Techno Labs India Pvt. Ltd.

Figure 7.1: Flash Fire Envelope

4. Jet Fire on Immediate Ignition

In the event of ignition of blow out, computed thermal radiation distances resulting from jet fire are as per given hereunder:

Radiation Level	Thermal Radiation Level Distances (m)			
	1 m/s - B	3 m/s - D	3 m/s - E	2 m/s – F
4 kW/ m^2	71.6135	70.1652	67.7123	59.3962
12.5 kW/ m^2	11.1	Not Reached	Not Reached	Not Reached
37.5 kW/ m^2	Not Reached	Not Reached	Not Reached	Not Reached

Thermal radiation distances and intensity radii from jet fire are depicted in Figure 7.2.

7.4 FAILURE FREQUENCY ANALYSIS

The failure frequency analysis aims at estimation of the “probability” of the incident. Failure frequencies may be classified as generic and synthesised for a particular situation, especially for more complex systems. Generic failure frequencies are preferred wherever available, as these reduce variances arising out of analyst judgement in the failure frequency estimation.

The standard method of calculating the failure rate of an isolated section of equipment or a chosen set of equipment items is to count the different items and associated line lengths.

The failure rate for a certain item is then broken down into the correct proportions for required release rate bands.

7.4.1 Blowout and Well Release Frequencies

The study *(Source: White Rose oilfield development on the Grand Banks, offshore New foundland by Husky Oil Operations Limited)* estimates that there have been 51,000 development wells drilled in that period of 1955 to 1988 giving a frequency of 4/51,000 =7.8E-05 blowouts per well drilled.
The frequency of well blowout and well release is discussed in The International Association of Oil & Gas Producers Risk Assessment Data Directory. Table 7.2 shows the expected frequency of such events based on historical data from recent years,

Table 7.2: OGP Blowout and Well Release Frequencies

Operation	Frequency			
Category	Average	Gas	Oil	Unit
Blowout	6.0E-05	7.0E-05	4.8E-05	Per drilled well
Well Release	4.0E-04	5.7E-04	3.9E-04	Per drilled well

Source: OGP - Oil & Gas Producers

Additional correction factors could also be considered based on the likelihood that the wind is blowing in the direction of populated areas. Also for smaller releases it is believed that the well release could be isolated by mechanical means reducing the event duration.
The above estimate is, however, still very conservative for a number of reasons. The data on which the above frequency is based cover several decades.
In past years, drilling technology has improved significantly since that time and the risk of a development drilling blowout will inevitably be lower than the above frequency suggests. Finally, the drilling rig will operate in accordance with stringent operating procedures and these will be in line with the best practice of well drilling operation worldwide.

7.4.2 Structural Failure Frequencies

Det Norske Veritas (DNV 1997) states that the total structural failure frequency is comprised of:

- ✓ ***Structural failure within design: 2.4E-05 per year;***
- ✓ ***Structural failure due to extreme weather: 1.2E-05 per year;***
- ✓ ***Structural failure due to ballast failures: 1.2E -05 per year;***

Therefore, the total structural failure frequency is 4.8E-05 per year, including failure in design, extreme weather and ballast failures.

7.4.2.1 Process Piping Failure Frequencies

Most data bases of pipe failure rates are not sufficiently detailed to allow a determination of the failure frequency as a function of the size of the release (i.e. size of the hole in the pipe). The data shows that well over 90% of all failure are less than a 1-inch (25 mm) diameter hole and 3% are greater than a 3 inch (75 mm) diameter hole. Since most full rupture of piping system are caused by outside forces, full rupture are expected to occur more frequently on small-diameter pipes.

7.5 Risk Reduction Measures

This section discusses the measures for risk reduction and enhancement of safety during development drilling operations.

7.5.1 Risk Mitigation Measures to Control Hazards

Occurrence of blowout and sour gas (H_2S) are the two major hazards. Occurrence of H_2S along with oil and gas is the major anticipated hazard during development drilling and production testing (The past experience and historical information available for drilling, developmental and production of hydrocarbons in the area revel that H_2S gas shall not be found in hydrocarbon reserves of the region. However, in the event of occurrence of H_2S during drilling operations, associated hazards and risk are considered for completeness of the study). Control measures for occurrence of blowout and release of H2S gas are discussed in following sub-sections:

7.5.1.1 Blowout

The risk mitigation measures used for blowout prevention are discussed below:

A. Blowout preventer assembly

- Blowout preventor assembly shall consist of:
  - ✓ One bag type of preventor for closing regardless whether drilling equipment is in the hole or not.
  - ✓ One blind ram preventor closing against an open hole.
  - ✓ One pipe ram preventor closing against drill pipe in use in the hole.
- In blow out preventor assembly, two seamless steel pipes at least 50 mm of diameter connected below each set of blow out preventor, (one for bleeding off pressure and the other for killing the well) shall be provided. These pipes shall be straight and lead directly into the well.
- Each pipeline shall consist of component having a working pressure equal to that of the blowout preventer.
- After the surface casing is set in a well, no drilling shall be carried out unless blowout preventor assembly is securely installed and maintained.

B. Blowout Preventer (BOP) Control Units: Location and Conditions

- BOP control units should be located at a distance of nearly 30 m from well center.
- Status of following should be checked and maintained in good condition:
  - ✓ Pressure gauges;
  - ✓ Pressure steel lines/fire resistant hoses;
  - ✓ Level of hydraulic oil;
  - ✓ Charging of unit; and
  - ✓ Availability of sufficient number of charged bottles.

C. Control System for Blowout Preventer

- All manual control for manually operated blowout preventer shall be located at least 0.60 meters outside the derrick substructures. Instructions for operating the controls shall be posted prominently near the control wheel;
- A control of power operated blowout preventer shall be located within easy reach of driller floor;
- A remote control panel for blowout preventer shall also be installed around floor level at a safe distance from the derrick floor;
- All control for blow out preventer shall be clearly identified with suitable markers; etc.

D. Other Preventive Measures

The following control equipments for drilling mud system should be installed and kept in use during drilling operations to prevent the blowout:

- A pit level indicator registering increase or reduction in the drilling mud volume and shall include a visual and audio –warning device near the driller stand;
- A device to accurately measure the volume of mud required to keep the well filled at all times;
- A gas detector or explosimeter at the primary shale shaker and connected to audible or visual alarm near the driller stand;
- A device to ensure filling of well with mud when the string is being pulled out;
- A control device near driller stand to close the mud pump when well kicks;
- Blowout prevention drill shall be carried out once every week near the well during drilling;
- Suitable control valves shall be kept available near the well which can be used in case of emergency to control the well;
- When running in or pulling out tubing, gate valve and tubing hanger shall be pre-assembled and kept readily available at the well; etc

E. Measures after Blowout

During controlling a blowout, the following precautions shall be taken:

- On appearance of any sign indicating the blowout of well, all persons, other than those whose presence is deemed necessary for controlling blowout, shall be withdrawn from the well and a competent person shall be present on the spot throughout;
- An area within the 500 meters of the well on the down wind direction shall be demarcated as danger zone;
- All electrical installations shall be de-energized;
- Approved safety lamps or torches shall only be used within the danger zone;
- No naked light or vehicular traffic shall be permitted within the danger zone;
- A competent person shall ascertain the condition of ventilation and presence of gases with an approved instrument as far as safety of persons is concerned;

- Two approved type of self containing breathing apparatus or any other breathing apparatus of approved type for use in an emergency shall be available at or near the place. Adequate firefighting equipment shall be kept readily available for immediate use; etc.

7.5.1.2 CONTROL MEASURES FOR H_2S DURING DRILLING

A. H_2S Detection System

A four channels H_2S gas detection system should be provided. Sensors should be positioned at optimum points for detection, actual locations being decided on site but likely to be at or near to:

- ✓ Well Nipple
- ✓ Rig Floor
- ✓ Shaker header tank
- ✓ Substructure cellar

The detection system should be connected to an audio visual (siren and lights) alarm system. This system should be set to be activated at a concentration of 15 ppm H_2S.

The mud logging will have a completely independent detection system which is connected to an alarm in the cabin. This system will be adjusted to sound an alarm at a concentration level of 10 ppm H_2S as suggested in the Drilling and Production Safety Code for Onshore Operators issued by The Institute of Petroleum.

A stock of H_2S scavenger will be kept at drilling site for emergency use.

B. Small Levels of H_2S

Small levels of H_2S (less than 10 ppm) will not activate the well site alarms. Such levels do not create an immediate safety hazard but could be a first indication of high levels of H_2S to follow.

H_2S will cause a sudden drop of mud pH. The mud man will therefore organize and supervise continuous pH checks while drilling. Checks should be as frequent as required depending on ROP and always made following a formation change.

Following control measures will be taken in case of small level of detection:

- ✓ Add H_2S scavenger to mud.
- ✓ Check H_2S levels at regular intervals for possible increase.
- ✓ Inform all personnel of the rig about the presence of H_2S and current wind direction.
- ✓ Commence operations in pairs.
- ✓ Render sub base and cellar out-of-bounds without further checking levels in this area.

C. High Levels of H_2S

Higher levels of H_2S (greater than 10 ppm) do not necessarily cause an immediate safety hazard. However some risk does exist and, therefore, any levels greater than 10 ppm

should be treated in the same manner. Occurrence of 10 ppm or greater H_2S concentration will sound an alarm in the mud logging unit.
If higher levels of H_2S greater than 10 ppm are found, following steps will be taken:

- ✓ Driller to shut down rotary and pumps, pick-up the string so that drill pipe is in the BOP and chain down the break;
- ✓ One pre-assigned roughneck will go to the doghouse and put on the breathing apparatus. All other rig personnel will evacuate the rig and move up wind to designated muster points;
- ✓ Driller and roughneck will return to the rig floor and commence circulating H2S scavenger slowly and reciprocating the pipe string;
- ✓ The level of H_2S will be checked in all work areas. H_2S scavenger will be added to the mud and circulated. If H_2S levels drop, drilling will be continued with scavenger in the mud. Approximately 30 % of hydrogen peroxide (H_2O_2) solution will neutralize H_2S gas in the mud at 20 gallon of H_2O_2 per 100 barrels of mud; etc.

D. Control Measures for H_2S During Testing

H_2S scavenging chemicals (caustic soda solution, calcium hydroxide or iron oxide slurry) will be continuously injected in the recovered gas/oil/formation water after pressure reduction through choke before sending the same to separator.

7.5.2 Safety System For Drilling Rigs

Operational Safety is the foremost concern while working on drilling rig. Derrick floor is the center stage of all the operations and it is most susceptible to accidents. Safety precaution with utmost care is required to be taken as per the prevailing regulation and practice so that accidents can be avoided. Due to advancement in technology, number of equipment has been developed over a period to cater the need of smooth operation on derrick floor. Various standards are required to be referred to cover the variety of equipment used for safe operation in drilling and become cumbersome at times to refer standards for each equipment as per given hereunder;

- ✓ Twin stop safety device (crown-o-matic and floor-o-matic);
- ✓ Fall prevention device on mast ladder with safety belt;
- ✓ Emergency Escape device for top man;
- ✓ First aid box with Stretcher and Blanket;
- ✓ Fire bell /siren;
- ✓ Emergency vehicle;
- ✓ Fire extinguishers;
- ✓ Flame proof portable hand lamp /safety torch;
- ✓ Railling with toe board;
- ✓ Guards on all moving parts;
- ✓ Breathing apparatus (wherever required);

- ✓ Gas detector for hydrocarbon gas & H_2S gas (if required);
- ✓ Safety lines for power tongs;
- ✓ Rotary brake;
- ✓ Hoisting brake lever with safety chain;
- ✓ Emergency shutoff system for draw works;
- ✓ Safety chain for inclined ramp (to prevent fall of any person);
- ✓ Safety belt for top-man with lane yard;
- ✓ Railing on stair case at mud tank/walkways and derrick floor; etc.

7.5.3 Availability and Provisions Before Spudding of the well

To enhance the safety at the drilling rig during drilling operation following should be ensured:

- ✓ Geo-technical Order (GTO)/drilling program with shift in-charge;
- ✓ PPE for crew;
- ✓ First aid box ;
- ✓ Wash pipe should be greased after every 8 hours or as specified by the manufacturer;
- ✓ Kelly bushes to be greased after every 24 hours or as specified by the manufacturer;
- ✓ Lower & upper kelly cock (its operating lever should be kept at designated place at derrick floor);
- ✓ Kelly saver sub on Kelly;
- ✓ Mud check valve /full opening safety valve;
- ✓ BOP control panel on derrick floor;
- ✓ Before lowering casing, inspect all the instruments such as, weight indicator, pressure gauges, rotary torque, SPM counter, RPM counter mud volume totaliser, flow meter & trip tank;
- ✓ Required Number of drill collars and heavy weight D/Ps;
- ✓ Ensure availability of two mud pumps in good working condition;
- ✓ Rat hole and mouse hole be drilled;
- ✓ Twin stop safety device should be made in working order; etc.

7.5.4 General Safe Practices during Drilling Operation

- ✓ Penetration rate shall be monitored. In case of any drilling break, stop rotary table, pull out the Kelly, stop mud pump and check for self flow;
- ✓ Different type of drill pipes should not be mixed up during making up the string;

- ✓ Protectors should be used on drill pipes while lifting and laying down the pipes on catwalk;
- ✓ Drill pipe rubber protector should be installed on drill pipes body while being used inside the casing;
- ✓ Before starting drilling, hole should be centered to avoid touching of kelly with casing / wellhead and ensure that no damage is done to well head and BOP;
- ✓ Continuous monitoring of the gain/loss of mud during;
- ✓ BOP mock drill should be carried during drilling / tripping and under mentioned operations;
- ✓ Safe Working Conditions and Practices to be Adopted During Drilling Operations; etc

7.5.5 EMERGENCY PREPAREDNESS

- ✓ BOP drills and trip drills should be done once a week;
- ✓ Deficiency observed in BOP drill should be recorded and corrective measures should be taken; etc

7.5.6 FIRE FIGHTING FACILITY FOR DRILLING RIG

For the drilling rigs following fire fighting system/equipments should be provided:

- ✓ Fire water system; and
- ✓ First aid fire fighting system

7.5.7 CONTROL OF HYDROCARBON RELEASE AND SUBSEQUENTLY FIRE & EXPLOSION DURING DRILLING AND TESTING

To detect the release of hydrocarbon during drilling and testing, hydrocarbon detectors should be placed, so that control measures may be taken to prevent fire and explosion.
Emergency control measures should also be adopted as per Mines Act 1952, Oil Mines Regulation 1984 and Oil Industry Safety Directorate Standard 2000.
As per Oil Industry Safety Directorate (OISD) Standard, for the drilling rigs and well testing following fire fighting system/equipments should be provided:

- ✓ Fire water system; and
- ✓ First aid fire fighting system.

A temporary closed grid hydrant system with monitors, hydrant points and fire hose boxes may be installed to cover well location, and oil and diesel fuel storage tanks. Portable fire extinguishers of DCP, mechanical foam and CO_2 types of sufficient capacity and in sufficient numbers along with sand buckets should also be placed at strategic locations. Electrical and manual siren systems should be provided at the Security Gate of the experimental production facility. Electrically operated siren of 500 m range along with push buttons at appropriate locations to operate the siren should be installed.
Adequate personal protective equipments including sufficient number of breathing apparatus must also be kept ready in proper working condition.

- ❑ **Fire Water System**

- ✓ One water tank/pit of minimum capacity of 40 Kl should be located at the approach of the drilling site.
- ✓ For experimental production testing, one additional tank/pit of 40 Kl should be provided.
- ✓ One diesel engine driven trailer fire pump of capacity 1800 lpm should be placed at the approach area of drilling site.
- ✓ One fire water distribution single line with minimum 4 " size pipe/casing should be installed at drilling site with a minimum distance of 15 m from the well.

❑ **First Aid Fire Fighting Equipments at Drilling Rig**

Portable fire extinguisher on the drilling rig will be installed in line with IS: 2190 and minimum number requirement is as per details given below:

Table 7.3: Details of Fire fighting equipments

Sl. No.	Type of Area	Portable Fire Extinguisher
1.	Derrick floor	2 nos. 10 kg DCP type extinguisher
2.	Main Engine Area	1 no. 10 kg DCP type extinguisher for each engine
3.	Electrical motor/pumps for water circulation for mud pump	1 no. 10 kg DCP type extinguisher
4.	Mud gunning pump	1 no.10 kg DCP type extinguisher
5.	Electrical Control Room	1 no. 6.8 kg CO2 type extinguisher for each unit
6.	Mud mixing tank area	1 no. 10 kg DCP type extinguisher
7.	Diesel storage area	1 no. 50 lit mechanical foam
		1 no. 50 kg DCP type extinguisher
		2 nos. 10 kg DCP type extinguisher
		2 nos. sand bucket or ½ sand drum with spade
8.	Lube Storage Area	1 no. 10 kg DCP type extinguisher
		1 no. sand bucket
9.	Air Compressor area	1 no. 10 kg DCP type extinguisher
10.	Fire pump area	1 no. 10 kg DCP type extinguisher
11.	Near Dill In-charge Office	One fire extinguisher/shed with 3 nos. 10 kg DCP type extinguisher and 2 sand buckets
12.	Fire bell near bunk house	1 no. 10 kg DCP type extinguisher

Source: Oilmax Energy Private Limited.

7.5.8 MEDICAL FACILITIES

First aids facilities should be made available at the core drilling site and a 24 hour standby vehicle (ambulance) should also be available at the well site for quick transfer of any injured personnel to the nearest hospital, in case an accident occurs and medical emergency arises. Prior arrangements should be made with the nearby hospitals to look after the injured persons in case of medical emergency during core hole drilling and experimental production testing operations.

7.6 RECOMMENDATIONS

Drilling Operations

A majority of accidents occur during drilling operation on the drill floor and may be associated with moving heavy tubular, which may strike or crush personnel. Being struck by objects, falling and crushing usually make up maximum occupational risk of fatality. Mechanical pipe handling, minimizing the requirement of personnel on the drill floor exposed to high level of risk, may be an effective way of reducing injuries and deaths. Good safety management, strict adherence to safety management procedures and competency assurance will reduce the risk. Some of the areas in drilling operations where safety practices are needed to carry out jobs safely and without causing any injury to self, colleagues and system are given below:

Maintenance of Mud Weight

It is very crucial for the safety of drilling well. Drilling Mud Engineer should check the in-going & out-coming mud weight at the drilling well, at regular intervals. If mud weight is found to be less, barytes should be added to the circulating mud, to raise it to the desired level. Failure to detect this decrease in level may lead to well kick and furthermore, a well blow out, which can cause loss of equipments and injury to or death of the operating personnel.

Monitoring of Active Mud Tank Level

Increase in active tank level indicates partial or total loss of fluid to the well bore. This can lead to well kick. If any increase or decrease in tank level is detected, shift personnel should immediately inform the Shift Drilling Engineer and take necessary actions as directed by him.

Monitoring of Hole Fill-up / return mud volume during tripping

During swabbing or pulling out of string from the well bore, the hole is filled with mud for metallic displacement. When this string runs back, the mud returns back to the pit. Both these hole fill up & return mud volumes should be monitored, as they indicate any mud loss or inflow from well bore, which may lead to well kick.

Monitoring of Inflow

Any inflow from the well bore during tripping or connection time may lead to well kick. So, it is needed to keep watch on the flow nipple during tripping or connection time.