7.2 Risk Assessment

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.

'Risk Assessment' also known as 'Hazard Analysis' and 'Vulnerability Assessment' is a procedure for identifying hazards and determining their possible effects on a community and environment. Risk or hazard by itself is not an event - it is the potential for an event.

7.2.1 Approach to the Study

Risk involves the occurrence or potential occurrence of various type accidents consisting of an event or sequence of events. The main objectives of the risk assessment of the proposed onshore exploratory drilling are illustrated schematically in **Figure-7.4**.

Standard industry practices of risk assessment are considered in the project. Maximum Credible Accident analysis is carried out to arrive at the hazard distance for the worst case scenario.

7.2.2 Maximum Credible Accident Analysis (MCAA)

Maximum Credible Accident (MCA) is a probable accident with maximum damage distance. In practice, the selection of accident scenarios for MCAA is carried out on the basis of engineering judgement and past accident analysis. MCAA does not include quantification of the probability of occurrence of an accident.

Risk involves the potential occurrence of some accident consisting of an event or sequence of events. Accidental release of oil and gas to the atmosphere from well or processing equipment is studied by visualising scenarios on the basis of their properties and the impacts are computed in terms of damage distances. A disastrous situation is the outcome of fire or explosion of the released gas in addition to other natural causes, which eventually leads to loss of life, damage to property and/or ecological imbalance.

Depending on the effective hazardous attributes and their impacts, the maximum effect to the surroundings could be assessed.

The steps of MCA analysis along with data requirement are shown in **Figure-7.5**.

- *Past Accident Data Analysis*

The data required for MCA analysis has either to be generated by monitoring and/or collected from the records of the past occurrences. This data, when analysed, helps in formulation of the steps towards mitigation of hazards faced commonly. Trends in safety of various activities can be evaluated and actions can be planned accordingly, to improve the safety.

Data analysis helps in correlating the causal factors and the corrective steps to be taken for controlling the accidents. It is, therefore, of vital importance to collect the data methodically, based on potential incidents, sections involved, causes of failure and the preventive measures taken. This helps to face future eventualities with more preparedness.

- *Hazard Identification*

A major hazard is defined as an event, which may have the potential to cause one or more fatalities and also the potential to affect the integrity of the facility as a whole. The aim of this step is to create a complete tabulation of identified hazards.

Hazards are identified in terms of safety and/or environmental impact. The hazard in terms of blowout has been identified from well pad in the present exploratory drilling project. It is noted that some hazards are incorporated within other hazards.

Identification of hazards in the proposed drilling campaign is of primary significance in the analysis, quantification and cost effective control of accidents involving chemicals and process. Hence, all the components of a system /process need to be thoroughly examined to assess their potential for initiating or propagating an unplanned event/sequence of events, which can be termed as an accident.

Typical schemes of predictive hazard evaluation and quantitative risk analysis suggest that hazard identification step plays a key role. The hazard in terms of blowout has been identified from well pad in the present exploratory drilling project.

Major accident hazards considered are:

- Hydrocarbon escapes due to high geological pressures lead to possibility of fire, explosion, gas ingress to sensitive areas, contamination or toxic hazards arising from wells, test equipment fuel supply systems, storage, pipe work systems, etc.;
- Structural or foundation failure, including effects of corrosion, fatigue, extreme weather, overloading, seismic effects, abuse or accidental loading;
- Possibility of H_2S release while drilling; and
- Fire, including fires in accommodation, electrical fires, hot work, oxygen enrichment

The complete list of hazards and Occupational Hazards applicable to onshore drilling are presented in **Table-7.3** and **Table-7.4**.

TABLE-7.3
LIST OF MAJOR HAZARDS

Sr. No.	Hazard Source/Reason	Description	Impacts
1	Fire and Explosion	Occurrence of Blow Out	Topsides blow out
		Non hydrocarbon fires	Electrical fire in control room
			Fire in accommodation
2	Impacts and Collisions	Objects dropped from a crane/ derrick	Fatal accidents
			Loss of materials and equipment
3	Loss of station/ stability	Loss of stability	Structural failure Tug failure (during towing)
4	Extreme Weather Conditions	Extreme winds	Loss of lives and material
			Temporary withdrawal of well operations
5	Earthquakes	Sudden ground movement	Strong vibrations, failure
6	War, Crisis	Crisis situation	-

TABLE-7.4
OCCUPATIONAL HAZARDS

Sr. No.	Hazard	Description	Specific Hazard
1	Working at heights	Fall	Fall
			Man overboard
2	Disease/ Illness	Illness	Medical evacuation
3	Storage of chemicals	Release of chemicals	Exposure to chemicals, inhalation, ingestion, body contact etc

- *Consequence Analysis*

Quantification of the damage can be done by means of various models, which can then be translated in terms of injuries and damage to the exposed population and buildings. Oil and gas may be released and result into jet fire & less likely unconfined vapour cloud explosion causing possible damage to the surrounding areas. Extent of the damage depends upon the nature of release. The release of flammable material and subsequent ignition results in heat radiation, pressure wave or vapour cloud depending upon the flammability and its physical state.

An insight into physical effects resulting from the release of hazardous substances can be had by means of various models. The results of consequence analysis are useful for getting information about all known and unknown effects that are of importance when some failure scenario occurs and also to get information as how to deal with the possible catastrophic events.

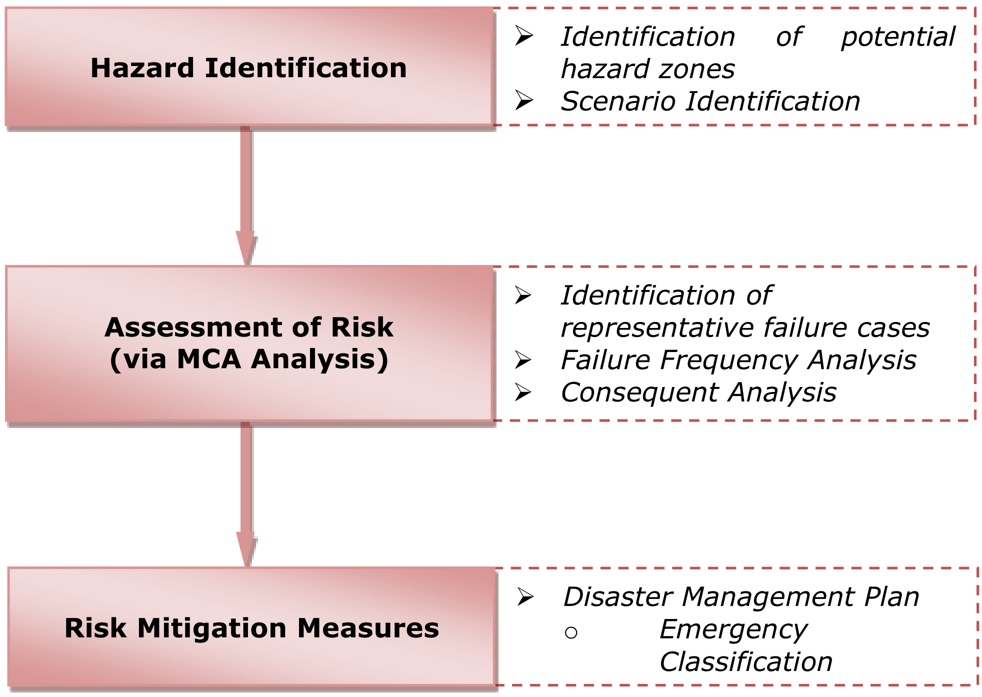

FIGURE-7.4
OBJECTIVES OF RISK ASSESSMENT

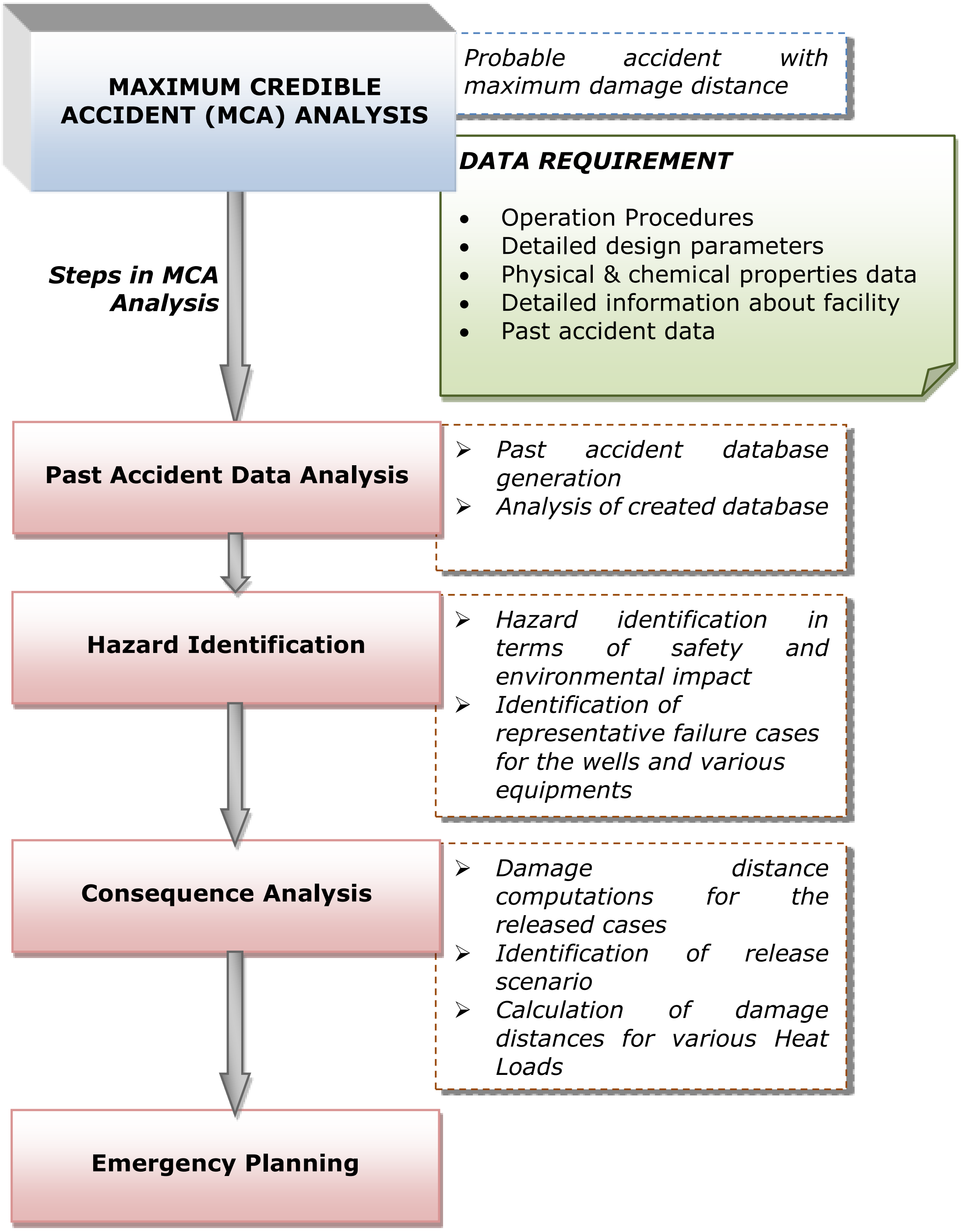

FIGURE-7.5
METHODOLOGY OF MCA ANALYSIS

7.2.3 Damage Effects of Various Heat Loads

Damage effects of various peak over pressures and incident radiation intensities are detailed in **Table-7.5** and **Table-7.6** respectively.

TABLE-7.5
DAMAGE DUE TO PEAK OVER PRESSURE

Human Injury		Structural Damage	
Peak Over Pressure - bar	**Type of Damage**	**Peak Over Pressure- bar**	**Type of Damage**
5 - 8	100% lethality	0.3	Heavy (90% damage)
3.5 - 5	50% lethality	0.1	Repairable (10% damage)
2 - 3	Threshold lethality	0.03	Damage of Glass
1.33 - 2	Severe lung damage	0.01	Crack of Windows
1 - $1^{1/3}$	50% Eardrum rupture	-	-

Source: Marshall, V.C. (1977) 'How lethal are explosives and toxic escapes'

TABLE-7.6
DAMAGE DUE TO INCIDENT RADIATION INTENSITIES

Sr. No.	Incident Radiation (kW/m^2)	Type of Damage Intensity	
		Damage to Equipment	**Damage to People**
1	37.5	Damage to process equipment	100% lethality in 1 min. 1% lethality in 10 sec.
2	25.0	Minimum energy required to ignite wood at indefinitely long exposure without a flame	50% Lethality in 1 min. Significant injury in 10 sec.
3	19.0	Maximum thermal radiation intensity allowed on thermally unprotected adjoining equipment	--
4	12.5	Minimum energy to ignite with a flame; melts plastic tubing	1% lethality in 1 min.
5	4.5	--	Causes pain if duration is longer than 20 sec, however blistering is un-likely (First degree burns)
6	1.6	--	Causes no discomfort on long exposures

Source: Techniques for Assessing Industrial Hazards by World Bank

7.2.4 Scenario Identification

Emergency scenario is identified based on past experiences and historical evidences. A flowchart that can be followed to evaluate the consequences of the release of a flammable or toxic chemical is given in **Figure-7.6**.

Historical evidence demonstrates that although unlikely, the most significant hazard arises from the thermal radiation produced by an ignited liquid or gas release. Releases from the wells could arise in the form of blowouts. This may lead to release of gas into the atmosphere. An availability of ignition source can lead to jet fire.

- *Model for the Calculation of Heat Loads and Shock Waves*

If a flammable gas or liquid is released, damage resulting from heat radiation or explosion may occur on ignition. Humidity of the air (water vapour) has a relatively high heat-absorbing capacity. The orientation (horizontal / vertical) of the object irradiated with respect to the fire is an important factor to be considered. If a jetted release of the oil & gas mixture is ignited, a stable diffusion torch or jet fire may be produced. For the flammable gas, in this model, an ellipse is assumed for the shape of a torch. The volume of the (torch) flare in this model is related to the outflow. In order to calculate the thermal load, the centre of the flare is regarded as a point source. This centre is taken as being half a flare-length from the point of outflow.

A flash fire is the non-explosive combustion of vapour cloud resulting from release of a flammable material in the atmosphere, which after mixing with air, ignites. A flash fire results from the ignition of a released flammable cloud, in which there is essentially no increase in combustion rate. The ignition source could be electric spark, a hot surface, and friction between moving parts of a machine or an open fire.

Part of the reason for flash fire is that flammable fuels have a vapour temperature less than ambient temperature. Hence as a result of spill, they are dispersed initially by the negative buoyancy of the cold vapours and subsequently by atmospheric turbulence. After the release and dispersion of a flammable fuel, the resulting vapour cloud is ignited and when the fuel vapour is not mixed with sufficient air prior to ignition, it results in the diffusion fire burning. Therefore, the rate at which the fuel vapour and air are mixed together during combustion determines the rate of burning in the flash fire.

The main dangers of flash fires are radiation and direct flame contact. The size of the flammable cloud determines the area of possible direct flame contact effects. Radiation effects on a target depend on several factors including its distance from the flames, flame height, flame emissive power, local atmospheric transitivity and cloud size. Most of the time, flash combustion of a flash lasts for no more than a few seconds.

7.2.5 Input Data for Consequence Analysis

The data used for the consequence analysis is depicted in **Table-7.7**.

TABLE-7.7
INPUT DATA FOR CONSEQUENCE ANALYSIS

Parameter	Case
Ambient Temperature	35^0C
Atmospheric stability	A & D
Relative humidity	70%
Wind speed	2 m/s for stability class A 5 m/s for stability class D

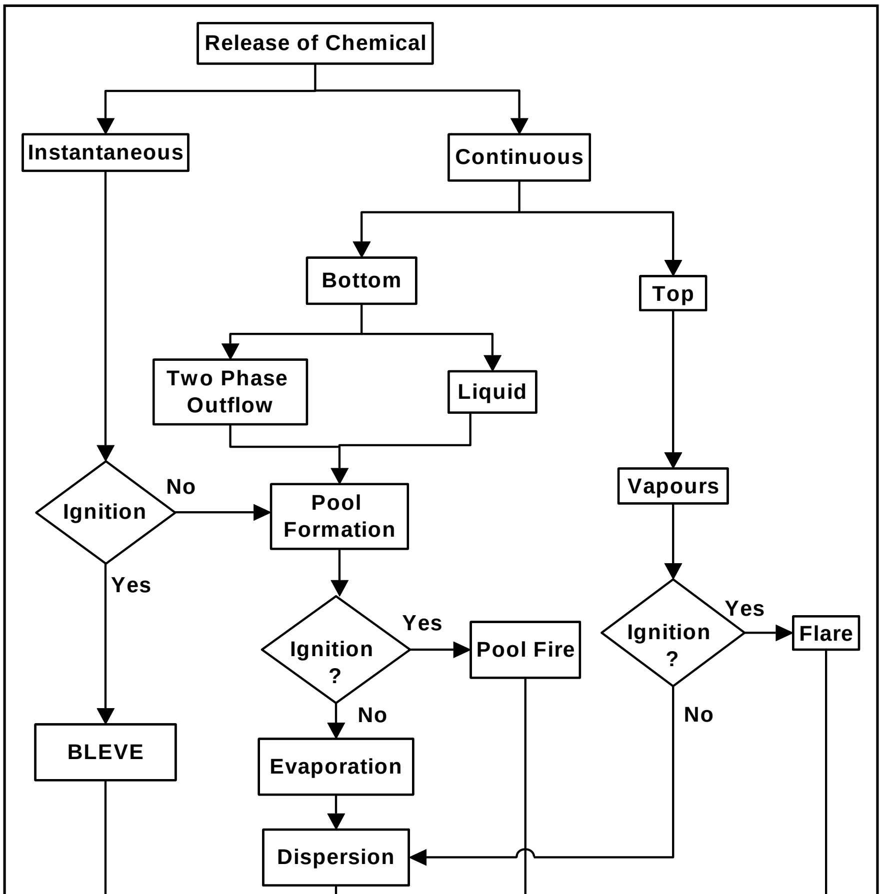

FIGURE-7.6
FLOWCHART FOR EVALUATION OF CONSEQUENCES DURING THE RELEASE OF FLAMMABLE OR TOXIC CHEMICAL

7.2.6 Results and Discussions

Jet Fire from Well (Oil) Blowout is visualised for carrying out the consequence analysis. A well blow out can lead to uncontrolled release of oil into the atmosphere. A subsequent jet fire could result on availability of an immediate ignition source. Heat load generated by the flame depends upon the mass flow rate of the released material. Damage distances are computed for the operating pressure of 290 psi and temperature of 70°C. Weather conditions 2A and 5D are considered while computing the damage distances. The damage distance of 95.7m is obtained for the heat load of 4 kW/m^2 in case of well blow out for 5D conditions. Results are shown in **Table-7.8**. The calculations of Pool Fire is given in **Annexure-X.**

TABLE-7.8
SUMMARY OF CONSEQUENCE ANALYSIS FOR JET FIRE SCENARIO AT WELL

Pressure (psi) / Temp (°C)	Scenario	Mass Flow Rate (kg/s)	Weather	Damage Distance (m) for various Heat loads		
				4.0 kW/m^2	12.5 kW/m^2	37.5 kW/m^2
290 / 70	Blow out	16	2A	82.5	-	-
			5D	95.7	-	-

7.2.7 Failure Frequency Analysis

A blowout is defined as an uncontrolled release of fluid, viz., hydrocarbon (oil and/or gas), but drilling mud, completion fluid or water from a well. It is most hazardous when the fluid is hydrocarbon. Blowouts are important because they have the potential to release large amounts of hydrocarbons and are very difficult to control.

A well control incident is one in which a high potential release which may result in blowouts either does not occur or is quickly stopped. They typically involve formation fluid accidentally entering the wellbore, but controlled by the available barriers such as the blowout preventer (BOP). These incidents usually have relatively minor consequences, and are not well reported.

For some events, it is unclear whether they should be counted as a full blowout or as a well control incident. Different databases categorise events in different ways, and some analyses use the term "blowout" to refer to all well control incidents.

7.2.8 Historical Data Sources

The main compilations of secondary data on blowouts are:

- **SINTEF blowout database** - An internal SINTEF compilation sponsored by 6 operators and 2 consultants (Holand 1995), including 319 blowouts for the period 1970-94, of which 128 occurred in the US GoM OCS or North Sea during 1980-94. It is an update of the Marintek blowout database, for which the full list (SINTEF 1983) and an analysis (NSFI 1985) were published. Detailed analyses have been published for the period 1980-93 (Holand 1996, 1997). Scandpower (1995) analysed the data for the period 1980-92, and included a full list of the events.
- **E&P Forum database** - Frequencies from BLOWOUT for the period 1970-85 were published by OCB / Technica (1988) and E&P Forum (1992).

The secondary data on Failure Rate Frequency is given in **Annexure-XI**.

7.2.9 Probability of Immediate Ignition and Individual Risk Assessment Criteria

The information available on probability of ignition is mostly in the form of expert estimates. The details of immediate ignition probabilities used in this analysis are given in **Table-7.9**. This data has been obtained from E&P Forum. Similarly, the ADNOC individual risk assessment criteria are given in **Table-7.10**.

TABLE-7.9
PROBABILITY OF IGNITION FOR LEAKS OF FLAMMABLE FLUIDS

Leak Rate	Probability of Ignition	
	Gas	Liquid
Minor (< 1kg/s)	0.01	0.01
Major (1 to 50 kg/s)	0.07	0.03
Massive (>50 kg/s)	0.30	0.08

Source: E&P Forum

TABLE-7.10
THE ADNOC INDIVIDUAL RISK ASSESSMENT CRITERIA

ADNOC Acceptability Criteria	Maximum Individual Risk Criteria for Workers		Maximum Individual Risk Criteria for Public
	Existing Installation	New Installation	
Benchmark	IR < 2×10^{-4}	IR < 2×10^{-5}	IR < 1×10^{-5}
Unacceptable	IR > 1×10^{-3}	IR > 1×10^{-3}	IR > 1×10^{-4}
Acceptable	IR < 1×10^{-5}	IR < 1×10^{-5}	IR < 1×10^{-6}

Source: E&P Forum

7.2.10 Individual Risk Assessment

The Individual risk due to well blowout is calculated with the help of SAFETI Software. 20 persons were considered as a population present within the well pad in a shift and frequency of well blowout. The individual risk due to well blowout varies from $1E^{-06}$ to $1E^{-09}$ and it is concluded that the risk due to well blowout is acceptable for workers as well as for the public as per **Table-7.10**.

7.2.11 Geo-hazards

Geo-hazards include land slides, flooding, land subsidence and earth quakes. The major geo-hazard associated with oil production is land subsidence. Land subsidence is termed as the sudden sinking or gradual downward settling of land with little or no horizontal motion, caused by a loss of subsurface support which may result from a number of natural and human caused occurrences including subsurface mining or the pumping of oil or ground water. Land subsidence events, depending on where they occur, can pose significant risks to health and safety or interruption to transportation and other services. Land subsidence is effected by characteristic of the reservoir rocks, pressure of overburden, relationship between compaction and pressure gradient in the reservoir, pressure decline dynamic and its influence on the compaction rate and the surface subsidence.

Drilling activities do not involve any extraction of hydrocarbon and thus in this case, any possibility of subsidence is ruled out. In the event of a successful discovery leading to production activities, geo-technical investigations, geological impacts assessment will be carried out and appropriate measures will be undertaken.

7.3 Recommendations to Mitigate Risk/Hazards

The recommendations to mitigate risk at the well site during the drilling operation are given in **Table-7.11.**

TABLE-7.11
RECOMMENDATIONS TO MITIGATE BLOW OUT RISK/HAZARDS

Sr. No.	Mitigative Measures	Remarks
1	Maintenance of mud weight	• Drilling Mud Engineer should check the ingoing & outcoming 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 & furthermore, a well blow out.
2	Monitoring of active mud tank level	• Increase in active tank level indicates partial or total loss of fluid to the well bore, which can lead to well kick; • If any increase or decrease in tank level is detected, shift personnel should immediately inform the Shift Drilling Engineer & take necessary actions as directed by him.
3	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 which returns back to the pit when the string runs back; • Both the 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.
4	Monitoring of inflow	• The flow nipple during tripping or connection time should be monitored for any inflow from the well bore
5	Monitoring of Background / trip gas	• Increase in background gas or trip gas indicates insufficient mud weight against drilled formation. Such indications should be immediately brought to the notice of the Shift Drilling Engineer.
6	Team Coordination	• Each team member must religiously follow the safety aspects pertaining to respective operational area. • Drilling operation is a team effort and success of such an operation depends upon the sincerity, efficiency & motivation of all team members. • Safety in such operations is not the duty of a single person, but it is everyone's job. • The use of protective fireproof clothing and escape respirators will reduce the risk of being seriously burnt. • Adequate fire fighting facilities and first aid facilities

Sr. No.	Mitigative Measures	Remarks
		should be provided, in case of any emergency. • Risk reducing measures include kick simulation training for personnel, presence of well trained drillers and mud engineers, and strict adherence to safety management procedures and good well control procedures.

ANNEXURE-IX
POOL FIRE CALCULATION SHEET

A. Radiation Intensity (kW/m^2) **RI** - 37.5, 12.5, 4.5, 1.6

B. Rate of burning (m/s)

*y= (92.6e^(-0.0043TB)*Mol.wt/p)*(10^-7/6)*

where y = Burning velocity (m/s)
Mol.wt = Molecular weight (kg/kgmol)
p = liquid specific gravity
TB = Normal boiling point, deg.F

C. Pool Size (m)

1. Maximum diameter of pool (m)

D_{max} *=1.7892((V^2/y)*((g/Cd)^0.5)^(2/11)*

Where D_{max} = Maximum diameter of pool of a instantaneous release (m)
V = Volume of liquid (m^3)
y =Burning velocity (m/s)
g = Accelaration due to gravity (9.81 m/s^2)
Cd = Ground friction Co-efficient (0.5 for general use)

2. Pool Radius (m)

Rp $=D_{max}/2$

3. Time to reach maximum pool diameter for instantaneous release (Seconds)

t_{max} *= 0.5249*((V^3*Cd^2)/(g^2*y^7))^(1/11)*

D. Emissive Power of A flame (kW/m^2)

*Ep = '-0.313*TB+117*

Where
Ep = Effective emissive power (kW/m^2)
TB = Normal boiling point, deg.F

E. Heat received at a particular distance (m)

X = 1.079(Ep/Qi)^0.57*Rp*

Where
X = Distance (m)
Ep = Effective emissive power (kW/m^2)
Qi = Radiation intensity (kW/m^2)
Rp = Pool radius (m)

F. Radiation Intensities (kW/m^2)

Distance from the centre of the Pool (m) = =1.079(Ep/RI)^0.57*Rp*

ANNEXURE-XI
SECONDARY DATA FOR RISK ANALYSIS

1.0 Secondary Data Collected on Blowout Frequency and Failure Rate Analysis

1.1 Blowout Frequency

The analysis of the database for the US GoM OCS/North Sea for the period 1980-92 by Scandpower (1995) for the blowout frequency is given in **Table-1**. These are also presented by E&P Forum (1996).

TABLE-1
BLOWOUT FREQUENCIES BY PHASE OF OPERATION

Phase	Blowouts 1980-92	Exposure 1980-92	Blowout Frequency
Exploration drilling	43	5781 wells	7.5×10^{-3} per well drilled

Source: SCANDPOWER 1995

1.2 Blowout Frequencies Based on Fluid Released

Table-2 gives deep and shallow gas blowout frequencies from the analysis by Scandpower (1995) of the database. These are also presented by E&P Forum (1996).

TABLE-2
DRILLING BLOWOUT FREQUENCIES BY FLUID RELEASED

Phase	Fluid Type	Blowout Frequency (per well drilled)
Exploration drilling	Shallow gas	4.7×10^{-3}
	Deep	2.8×10^{-3}
	Total	7.5×10^{-3}

Source: SCANDPOWER 1995

1.3 Blowouts in Individual Drilling Operations

The contributions of the individual operations to the total blowout frequency for exploration and development drilling are given in **Table-3**.

TABLE-3
CONTRIBUTION OF INDIVIDUAL OPERATIONS TO BLOWOUT FREQUENCIES (SCANDPOWER 1995)

Operation	Exploration Drilling (%)	Development Drilling (%)
Before installing BOP		
Drilling	20.9	9.1
Tripping	14.0	24.2
Running casing	7.0	15.2
Other	20.9	9.1
After installing BOP		
Drilling	16.3	9.1
Tripping	7.0	15.2
Running casing	2.3	6.1
Other	11.6	12.1
TOTAL	100	100