ANNEXURE- IV

RAPID RISK ANALYSIS STUDY

RISK ASSESSMENT STUDY

Bharat Petroleum

BHARAT PETROLEUM CORPORATION LTD RASAYANI

Submitted by:

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Rev No	Date	Purpose	Prepared By	Reviewed By	Approved By
0	09/07/2019	Issued As Final	MG	DK	DK

PREFACE

M/s Bharat Petroleum Corporation Limited (BPCL) has awarded the job of carrying out Environmental Impact Analysis and Risk Analysis of Polypropylene Unit (PPU) to M/s Engineers India Limited (EIL).

Risk Assessment study identifies the hazards associated with the facility, analyses the consequences, draws suitable conclusions and provides necessary recommendations to mitigate the hazard/ risk.

This Risk Assessment study is based on the information made available at the time of this study and EIL's own data source for similar plants. EIL has exercised all reasonable skill, care and diligence in carrying out the study. However, this report is not deemed to be any undertaking, warrantee or certificate.

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1 EXECUTIVE SUMMARY

1.1 INTRODUCTION

Mumbai Refinery (MR) of Bharat Petroleum Corporation Limited (BPCL), is located at Mahul, Mumbai, Maharashtra, India. The refinery was commissioned in 1955 with a crude oil processing capacity of 2.2 MMTPA in a plot area of 450 acres. The refining capacity has subsequently been augmented through progressive revamps, addition of various process units and incorporating advanced refining technologies.

BPCL intends to diversify into Petrochemical products with major focus on Ethylene/ Propylene based petrochemical products to further improve refinery profitability. BPCL has recently carried out a Bottoms upgrading Study which recommended the setting up of a Petrochemical Resid FCC (PRFCC) complex with the intent of maximizing Polymer Grade Propylene production which will feed a Polypropylene complex being planned at Rasayani, 50 km from MR.

The 450 KTPA Polypropylene Unit (PPU) will include the following sections:

- Feed Purification
- Catalyst & Co-Catalyst Handling, Storage and Metering
- Reaction Section
- Polymer Degassing and Monomer Recovery Section
- Powder Conveying
- Extrusion and Additivation
- Pellet Conveying and Blending
- Bagging and Dispatch
- Auxiliary Facilities

This executive summary covers major findings arising out of the Risk Assessment study and recommendations for the safe operation.

1.2 APPROACH METHODOLOGY

Risk analysis study evaluates the consequences of potential failure scenarios, assess extent of damages, based on damage criteria's and suggest suitable measures for mitigating the Hazard.

Risk Analysis involves identification of various potential hazards & credible failure scenarios for various units and other facilities including off-site storages & pumping, etc., based on their frequency of occurrence & resulting consequence. Basically two types of scenarios are identified spanning across various process facilities; Cases with high chance of occurrence but having low consequence, e.g., Instrument Tapping Failure (20mm) or Flange Leakage (10mm) or Seal Failure (6mm) and cases with low chance of occurrence but having high consequence, e.g., Catastrophic Rupture of Pressure Vessels or large hole. Effect zones for various outcomes of failure scenarios (Flash Fire, Jet Fire, Pool Fire, Blast overpressure, etc.) are studied and identified in terms of distances on plot plan. Based on effect zones, measures for mitigation of the hazard/risk are suggested.

1.3 MAJOR FINDINGS AND RECOMMENDATIONS

The detailed consequence analysis of release of hydrocarbon in case of major credible scenarios are modeled in terms of release rate, dispersion, flammability and toxic characteristics, which have been discussed in detail in the report. The major findings and recommendations arising out of the Risk Assessment study are summarized below (*directions based on plant north*):

1. **Instrument Tapping Failure at Propylene Feed Pump Discharge in PPU** (Figures 1.1): A 20 mm leak scenario corresponding to instrument tapping failure is analyzed under this case. This results in a flash fire zone which covers a portion of the road on the western side of the unit. Jet fire thermal radiation intensity of 37.5 kW/m^2 covers a portion of the pipe rack on the western side of the unit.

   It is recommended to

   - *Restrict vehicle movements on the road on the western side of the unit through suitable means. Only emergency vehicles or authorized vehicles shall be allowed on this road.*
   - *Review the fire proofing requirement on the pipe rack on the western side of the unit based on the location of Propylene Feed Pump finalized during detail engineering.*

2. **Instrument Tapping Failure at C3 Splitter Reflux Pump Discharge in PRU** (Figures 2.2): A 20 mm leak scenario corresponding to instrument tapping failure is analyzed under this case. This results in a flash fire zone which is restricted around the pump. Jet fire thermal radiation intensity of 37.5 kW/m^2 covers the pipe rack on the western side of the unit.

   It is recommended to

   - *Review the fire proofing requirement on the pipe rack on the western side of the unit based on the location of C3 Splitter Reflux Pump finalized during detail engineering.*

<u>General Recommendations</u>

✓ Quantitative Risk analysis needs to be carried out for entire facility for overall risk assessment.

- ✓ It is recommended to follow and implement licensor's safety guidelines for handling and storage of chemicals such as TEA, silane, peroxide, additives etc. in Polypropylene Unit.
- ✓ To enable rapid detection of leak/ fire, flammable gas detector shall be located in strategic location in the facility.
- ✓ For positively pressurized building, both Hydrocarbon & Toxic detectors need to be placed at suction duct of HVAC. HVAC to be tripped automatically in event of the detection of any Hydrocarbon / toxic material by detector.
- ✓ Proper checking of contract people for Smoking or Inflammable materials to be ensured at entry gates to avoid presence of any unidentified source of ignition.
- ✓ It shall be ensured that all the vehicles entering the plant shall be provided with spark arrestors at the exhaust.
- ✓ Employees and Truck drivers must be well trained and must be aware of the hazards involved in the loading operation.
- ✓ The critical operating steps shall be displayed on the board near the location where applicable.
- ✓ Loading operations shall be immediately suspended in the event of leak, a fire in the vicinity, lightning and thunder storm.
- ✓ Clearly marked escape routes shall be provided in the gantry for ease of escape.
- ✓ Mock drills to be organized at organization level to ensure preparation of the personnel's working in premises for handling any hazardous situation.
- ✓ Active fire protection system shall be provided throughout the plant for preventing escalation of fire.
- ✓ Recommended to use portable HC detector during sampling and maintenance etc.

(A) <u>Mitigating Measures</u>

Mitigating measures are those measures in place to minimize the loss of containment event and hazards arising out of Loss of containment. These include:

- ✓ Early detection of an undesirable event (HC/ toxic leak, Flame etc.) and development of subsequent quick isolation mechanism.
- ✓ Measures for controlling / minimization of Ignition sources inside the operating area.
- ✓ Active and Passive Fire Protection for critical equipment's and major structures
- ✓ Effective Emergency Response plans to be in place

(B) <u>Ignition Control</u>

- ✓ Ignition control will reduce the likelihood of fire events. This is the key for reducing the risk within facilities processing flammable materials. As part of mitigation measure it is strongly recommended to consider minimization of the traffic movement in the vicinity of operating area.

(C) Escape Routes

- ✓ Ensure sufficient escape routes from the site are available to allow redundancy in escape from all areas.
- ✓ Ensure sufficient number of windsocks throughout the site to ensure visibility from all locations. This will enable people to escape upwind or crosswind from flammable / toxic releases.
- ✓ Provide sign boards marking emergency/safe roads to be taken during any exigencies.

(D) Preventive Maintenance for Critical Equipment's

- ✓ In order to reduce the failure frequency of critical equipment's, the following are recommended:

  a. High head pumps and Compressors, which are in flammable/ toxic services, are needed to be identified.
     i. Their seals, instruments and accessories are to be monitored closely
     ii. A detailed preventive maintenance plan to be prepared and followed.

  b. High inventory vessels whose rupture may lead to massive consequences are needed to be identified and following to be ensured:
     i. Monitoring of vessel internals during shut down.
     ii. A detailed preventive maintenance plan to be prepared and followed.
     iii. Emergency inventory isolation valves shall be provided for vessel/column having large inventory and containing flammable/ toxic compound.

2 INTRODUCTION

2.1 STUDY AIMS AND OBJECTIVE

The objective of the Risk Assessment study is to identify and quantify all potential failure modes that may lead to hazardous consequences and extent. Typical hazardous consequences include fire, explosion and toxic releases.

The Risk Assessment study will also identify potential hazardous consequences having impacts on population and property in the vicinity of the facilities, and provides information necessary in developing strategies to prevent accidents and formulate the Disaster Management Plan.

The Risk Assessment study includes the following steps:

a) Identification of failure cases within the process and off-site facilities

b) Evaluate process hazards emanating from the identified potential accident scenarios.

c) Analyze the damage effects to surroundings due to such incidents.

d) Suggest mitigating measures to reduce the hazard / risk.

The Risk analysis study has been carried out using the risk assessment software program 'PHAST ver. 8.0' developed by DNV Technica.

2.2 SCOPE OF WORK

The study addresses the hazards that can be realized due to operations associated with the proposed facilities. It covers the following facilities:

- Polypropylene Unit (PPU)
- Offsites

3 SITE CONDITION

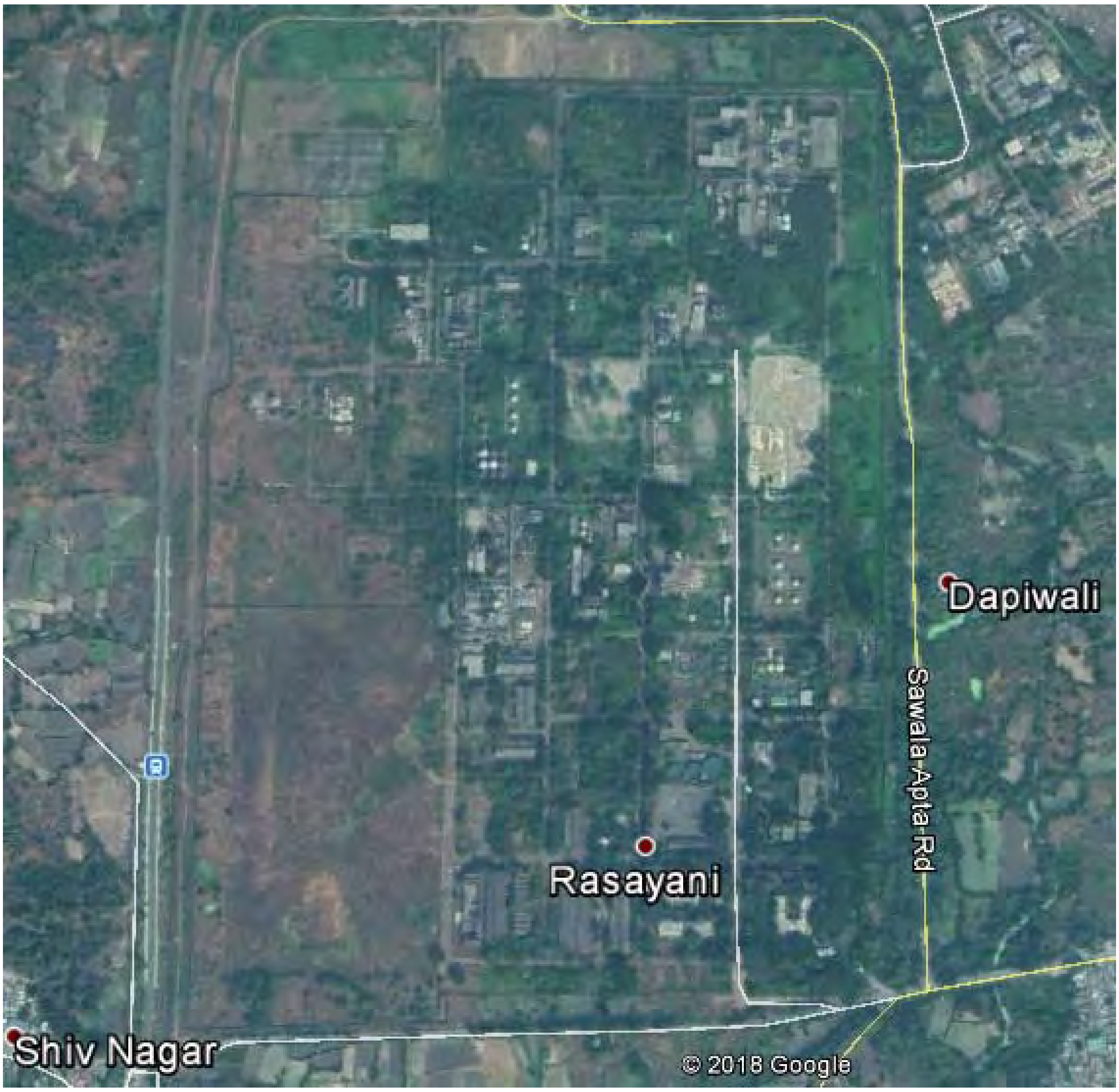
3.1 GENERAL

This chapter describes the location of BPCL Rasayani and meteorological data, which have been used for the Risk Assessment study.

3.2 SITE, LOCATION AND VICINITY

The proposed PPU shall be set up located at Rasayani in Mumbai (Maharashtra).

Figure 1: Rasayani



3.3 METEOROLOGICAL CONDITIONS

The consequences of released toxic or flammable material are largely dependent on the prevailing weather conditions. For the assessment of major scenarios involving release of toxic or flammable materials, the most important meteorological parameters are those that affect the atmospheric dispersion of the escaping material. The crucial variables are wind direction, wind speed, atmospheric stability and temperature. Rainfall does not have any direct bearing on the results of the risk analysis; however, it can have beneficial effects by absorption / washout of released materials. Actual behavior of any release would largely depend on prevailing weather condition at the time of release.

For the Risk Analysis study, Meteorological data of Mumbai has been taken from the Climatological Tables of Observatories in India (1981-2010) published by Indian Meteorological Department, Pune.

Atmospheric Parameters

The Climatological data which have been used for the Risk Analysis study is summarized below:

Table 1: Atmospheric Parameter

Sl. No.	Parameter	Average Value
1.	Ambient Temperature (^{O}C)	27.6
2.	Atmospheric Pressure (mm Hg)	756
3.	Relative Humidity (%)	68
4.	Solar Radiation flux (kW/m^2)	0.39

Wind Speed and Wind Direction

The meteorological data considered for the study is based on the location Mumbai from the IMD Table. The mean wind speed as per the Meteorological data provided in IMD table is given below.

Table 2: Mean Wind Speed (m/s)

Jan	Feb	Mar	April	May	June	July	Aug	Sep	Oct	Nov	Dec
1.6	1.8	2.0	2.2	2.6	3.0	3.4	3.1	1.9	1.5	1.4	1.4

Weather Category

One of the most important characteristics of atmosphere is its stability. Stability of atmosphere is its tendency to resist vertical motion or to suppress existing turbulence. This tendency directly influences the ability of atmosphere to disperse pollutants emitted into it from the facilities. In most dispersion scenarios, the relevant atmospheric layer is that nearest to the ground, varying in thickness from a few meters to a few thousand meters. Turbulence induced by buoyancy forces in the atmosphere is closely related to the vertical temperature gradient.

Temperature normally decreases with increasing height in the atmosphere. The rate at which the temperature of air decreases with height is called Environmental Lapse Rate (ELR). It will vary from time to time and from place to place. The atmosphere is said to be stable, neutral or unstable according to ELR is less than, equal to or greater than Dry Adiabatic Lapse Rate (DALR), which is a constant value of 0.98°C/100 meters.

Pasquill stability parameter, based on Pasquill – Gifford categorization, is such a meteorological parameter, which decreases the stability of atmosphere, i.e., the degree of convective turbulence. Pasquill has defined six stability classes ranging from `A' (extremely unstable) to `F' (stable). Wind speeds, intensity of solar radiation (daytime insulation) and nighttime sky cover have been identified as prime factors defining these stability categories. Below Table indicates the various Pasquill stability classes.

Table 3: Pasquill Stability Classes

Surface Wind Speed (meter/s)	Day time solar radiation			Night time cloud cover		
	Strong	Medium	Slight	Thin < 3/8	Medium 3/8	Overcast >4/5
< 2	A	A – B	B	-	-	D
2 – 3	A – B	B	C	E	F	D
3 – 5	B	B – C	C	D	E	D
5 – 6	C	C – D	D	D	D	D
> 6	C	D	D	D	D	D

Legend: A = Very unstable, B = Unstable, C = moderately unstable, D = Neutral, E = moderately stable, F = stable

When the atmosphere is unstable and wind speeds are moderate or high or gusty, rapid dispersion of pollutants will occur. Under these conditions, pollutant concentrations in air will be moderate or low and the material will be dispersed rapidly. When the atmosphere is stable and wind speed is low, dispersion of material will be limited and pollutant concentration in air will be high. In general worst dispersion conditions (i.e. contributing to greater hazard distances) occur during low wind speed and very stable weather conditions, such as that at 1F weather condition (i.e. 1 m/s wind speed and Pasquill Stability F).

Stability category for the present study is identified based on the cloud amount and wind speed. For risk analysis the representative average annual weather conditions are assessed based on the following:

Average Wind speeds are unevenly distributed around 1.5, 2.5 and 3.5 m/s throughout the year. Based on weather analysis, predominant weather stability of “F, “B” & “D” was selected with wind speed 1.5 m/s, 1.5 m/s & 3.5 m/s for consequence analysis, respectively.

The consequence results are reported in tabular form for all the weather conditions and are represented graphically for worst weather condition.

Table 4: Weather Conditions

Wind Speed	Pasquill Stability
1.5	B
1.5	F
3.5	D

Note: Proposed Petrochemical Plant Layout (Doc. No.: B143-00-17-44-0001 Rev. E) of BPCL Rasayani has been used for Study.

4 HAZARDS ASSOCIATED WITH THE FACILITIES

This chapter describes in brief the hazards associated with the materials being handled in the Plant.

4.1 HAZARDS ASSOCIATED WITH LIGHTER HYDROCARBONS

Hydrocarbons are highly hazardous due to their high flammability. The hydrocarbon vapors can even be ignited at a distance from the electrostatic charges generated especially during filling, draining, processing or leakages. They even allow the buildup of electrostatic sparks especially during flow, agitation, filling, draining etc.

The lighter hydrocarbons like ethylene, propylene, butadiene, methane and butene are normally stored under pressurized conditions therefore on their release from storage vessel, drums or spheres, a substantial fraction of it flashes into vapor almost instantaneously. This rapid evaporation causes liquid entrainment of the condensed liquid. Consequently, a release from pressure containment is assumed to convert immediately and completely to vapor/aerosol cloud. A considerable amount of mixing with air occurs during evaporation, depending upon precise circumstances the flames can be very intense near the fire but falls off rapidly beyond 3-5 pool diameters. Such fires are very destructive within plant area at a near source of generation but usually do not cause much damage in well laid-out plant beyond its boundaries.

Clouds of vapor may burn as "Fire Ball". This is roughly spherical cloud of flammable material burning with much turbulence and rising, as it mixes with surrounding air; combustion is complete within seconds. The radiation from such a fireball is very intense and can cause a great deal of damage. The risk of occurrence of a fireball is particularly serious where there is immediate ignition of a large mass of fuel getting released rapidly. (E.g. due to catastrophic failure of a pressurized storage exposed to fire). Such an event is often referred to as a BLEVE (Boiling Liquid Expanding Vapor Explosion).

Clouds of vapor mixed with air may sustain propagating flames when ignited. In certain cases, flame may spread rapidly through the cloud from the point of ignition and complete combustion may take place within seconds. Radiation intensity is severe, similar to fire ball. If flame travels fast enough, overpressure or "blast" effects will be created which can cause damage at considerable distances from the release point. Many of most severe industrial accidents have been associated with such unconfined explosions. If the released hydrocarbons remain unignited, they cause very little damage. There is some possibility of asphyxiation at very high concentrations in the immediate vicinity of release, but this is such a small probability in comparison with the flammable risks that it has not been considered.

The flammable clouds formed by escaping pressurized gas are denser than air except that of methane and generally form a thin layer on the ground under gravity. These could also flow in to depressions along trenches and can, in this way travel considerable distance. Even very small wind current, prevailing in the area of spill moves the cloud downwind while it gets diluted gradually and attains such dilution level, with air that mixture is no longer inflammable. However, a very large release may have to travel a long distance to get it safely diluted. Released pressurized gas may ignite in the vicinity of spillage or at any time during travel of flammable mixture downwind.

The table 5 lists the hazardous properties of Propylene.

Table 5: Hazardous Properties of Propylene

Sl. No.	Properties	Values
1.	LFL (%v/v)	2
2.	UFL (%v/v)	11.1
3.	Auto ignition temperature (°C)	455
4.	Heat of combustion (Kcal/Kg)	-10940
5.	Normal Boiling point (°C)	-47.7

5 HAZARD IDENTIFICATION

5.1 GENERAL

A classical definition of hazard states that hazard is in fact the characteristic of system/plant/process that presents potential for an accident. Hence all the components of a system/plant/process need to be thoroughly examined in order to assess their potential for initiating or propagating an unplanned event/sequence of events, which can be termed as an accident.

In Risk Analysis terminology a hazard is something with the potential to cause harm. Hence the Hazard Identification step is an exercise that seeks to identify what can go wrong at the major hazard installation or process in such a way that people may be harmed. The output of this step is a list of events that need to be passed on to later steps for further analysis.

The potential hazards posed by the facility were identified based on the past accidents, lessons learnt and a checklist. This list includes the following elements.

- Catastrophic Rupture of Pressure vessel
- Large hole on outlet of process vessel
- “Guillotine-Breakage” of pipe-work
- Small hole, cracks or small bore failure (i.e. instrument tapping failure, drains/vents failure etc.) in piping and vessels.
- Flange leaks.
- Storage Tank on fire
- Leaks from pump glands and similar seals.

5.2 MODES OF FAILURE

There are various potential sources of large leakage, which may release hazardous chemicals and hydrocarbon materials into the atmosphere. These could be in form of gasket failure in flanged joints, bleeder valve left open inadvertently, an instrument tubing giving way, pump seal failure, guillotine failure of equipment/ pipeline or any other source of leakage. Operating experience can identify lots of these sources and their modes of failure. A list of general equipment and pipeline failure mechanisms is as follows:

Material/Construction Defects

- Incorrect selection or supply of materials of construction
- Incorrect use of design codes
- Weld failures
- Failure of inadequate pipeline supports

Pre-Operational Failures

- Failure induced during delivery at site
- Failure induced during installation
- Pressure and temperature effects

- Overpressure
- Temperature expansion/contraction (improper stress analysis and support design)
- Low temperature brittle fracture (if metallurgy is incorrect)
- Fatigue loading (cycling and mechanical vibration)

Corrosion Failures

- Internal corrosion (e.g. ingress of moisture)
- External corrosion
- Cladding/insulation failure (e.g. ingress of moisture)
- Cathodic protection failure, if provided

Failures due to Operational Errors

- Human error
- Failure to inspect regularly and identify any defects

External Impact Induced Failures

- Dropped objects
- Impact from transport such as construction traffic
- Vandalism
- Subsidence
- Strong winds

Failure due to Fire

- External fire impinging on pipeline or equipment
- Rapid vaporization of cold liquid in contact with hot surfaces

5.3 SELECTED FAILURE CASES

A list of selected failure cases was prepared based on process knowledge, engineering judgment, experience, past incidents associated with such facilities and considering the general mechanisms for loss of containment. A list of cases has been identified for the consequence analysis study based on the following.

- Cases with high chance of occurrence but having low consequence: Example of such failure cases includes two-bolt gasket leak for flanges, seal failure for pumps, instrument tapping failure, etc. The consequence results will provide enough data for planning routine safety exercises. This will emphasize the area where operator's vigilance is essential.
- Cases with low chance of occurrence but having high consequence (The example includes Large hole on the outlet of pressure vessels, Catastrophic Rupture of Pressure Vessels, etc.)

  This approach ensures at least one representative case of all possible types of accidental failure events, is considered for the consequence analysis. Moreover, the list below includes at least one accidental case comprising of release of different sorts of highly hazardous materials handled in the facility. Although the list does not give complete failure incidents considering all equipment's, units, but the consequence of a similar incident considered in the list below could be used to foresee the consequence of that particular accident.

6 CONSEQUENCE ANALYSIS

6.1 GENERAL

Consequence analysis involves the application of the mathematical, analytical and computer models for calculation of the effects and damages subsequent to a hydrocarbon / toxic release accident.

Computer models are used to predict the physical behavior of hazardous incidents. The model uses below mentioned techniques to assess the consequences of identified scenarios:

- Modeling of discharge rates when holes develop in process equipment/pipe work
- Modeling of the size & shape of the flammable/toxic gas clouds from releases in the atmosphere
- Modeling of the flame and radiation field of the releases that are ignited and burn as jet fire, pool fire and flash fire
- Modeling of the explosion fields of releases which are ignited away from the point of release

The different consequences (Flash fire, pool fire, jet fire and Explosion effects) of loss of containment accidents depend on the sequence of events & properties of material released leading to the either toxic vapor dispersion, fire or explosion or both.

6.2 CONSEQUENCE ANALYSIS MODELLING

6.2.1 DISCHARGE RATE

The initial rate of release through a leak depends mainly on the pressure inside the equipment, size of the hole and phase of the release (liquid, gas or two-phase). The release rate decreases with time as the equipment depressurizes. This reduction depends mainly on the inventory and the action taken to isolate the leak and blow-down the equipment.

6.2.2 DISPERSION

Releases of gas into the open air form clouds whose dispersion is governed by the wind, by turbulence around the site, the density of the gas and initial momentum of the release. In case of flammable materials the sizes of these gas clouds above their Lower Flammable Limit (LFL) are important in determining whether the release will ignite. In this study, the results of dispersion modeling for flammable materials are presented LFL quantity.

6.2.3 FLASH FIRE

A flash fire occurs when a cloud of vapors/gas burns without generating any significant overpressure. The cloud is typically ignited on its edge, remote from- the leak source. The combustion zone moves through the cloud away from the ignition point. The duration of the flash fire is relatively short but it may stabilize as a continuous jet fire from the leak source. For flash fires, an approximate estimate for the extent of the total effect zone is the area over which the cloud is above the LFL.

6.2.4 JET FIRE

Jet fires are burning jets of gas or atomized liquid whose shape is dominated by the momentum of the release. The jet flame stabilizes on or close to the point of release and continues until the release is stopped. Jet fire can be realized, if the leakage is immediately ignited. The effect of jet flame impingement is severe as it may cut through equipment, pipeline or structure. The damage effect of thermal radiation is depended on both the level of thermal radiation and duration of exposure.

6.2.5 POOL FIRE

A cylindrical shape of the pool fire is presumed. Pool-fire calculations are then carried out as part of an accidental scenario, e.g. in case a hydrocarbon liquid leak from a vessel leads to the formation of an ignitable liquid pool. First no ignition is assumed, and pool evaporation and dispersion calculations are being carried out. Subsequently late pool fires (ignition following spreading of liquid pool) are considered. If the release is bunded, the diameter is given by the size of the bund. If there is no bund, then the diameter is that which corresponds with a minimum pool thickness, set by the type of surface on which the pool is spreading.

6.2.6 VAPOR CLOUD EXPLOSION

A vapor cloud explosion (VCE) occurs if a cloud of flammable gas burns sufficiently quickly to generate high overpressures (i.e. pressures in excess of ambient). The overpressure resulting from an explosion of hydrocarbon gases is estimated considering the explosive mass available to be mass of hydrocarbon vapor between its lower & upper explosive limits.

6.2.7 TOXIC RELEASE

The aim of the toxic risk study is to determine whether the operators in the plant, people occupied buildings and the public are likely to be affected by toxic substances. Toxic gas cloud e.g. H_2S, chlorine, Benzene etc. was undertaken to the Immediately Dangerous to Life and Health concentration (IDLH) limit to determine the extent of the toxic hazard Created as the result of loss of containment of a toxic substance.

6.3 SIZE AND DURATION OF RELEASE

Leak size considered for selected failure cases are listed below[1].

Table 6: Size of Release

Failure Description	Leak Size
Flange gasket failure	10 mm hole size
Instrument tapping failure	20 mm hole size
Large Hole	50 mm, complete rupture of 2” drain line
Catastrophic Rupture	Complete Rupture of the Pressure Vessels

[1] Refer to Guideline for Quantitative Risk assessment ‘Purple Book’.

The discharge duration is taken as 10 minutes for continuous release scenarios as it is considered that it would take plant personnel about 10 minutes to detect and isolate the leak[2]

6.4 DAMAGE CRITERIA

In order to appreciate the damage effect produced by various scenarios, physiological / physical effects of the blast wave, thermal radiation or toxic vapor exposition are discussed.

6.4.1 LFL OR FLASH FIRE

Hydrocarbon vapor released accidentally will spread out in the direction of wind. If a source of ignition finds an ignition source before being dispersed below lower flammability limit (LFL), a flash fire is likely to occur and the flame will travel back to the source of leak. Any person caught in the flash fire is likely to suffer fatal burn injury. Therefore, in consequence analysis, the distance of LFL value is usually taken to indicate the area, which may be affected by the flash fire.

Flash fire (LFL) events are considered to cause direct harm to the population present within the flammability range of the cloud. Fire escalation from flash fire such that process or storage equipment or building may be affected is considered unlikely.

6.4.2 THERMAL HAZARD DUE TO POOL FIRE, JET FIRE AND FIRE BALL

Thermal radiation due to pool fire, jet fire or fire ball may cause various degrees of burn on human body and process equipment. The damage effect due to thermal radiation intensity is tabulated below.

Table 7: Damage Due to Incident Thermal Radiation Intensity

Incident Radiation Intensity (kWm^2)	Type of Damage
37.5	Sufficient to cause damage to process equipment
32.0	Maximum flux level for thermally protected tanks containing flammable liquid
12.5	Minimum energy required for piloted ignition of wood, melting of plastic tubing etc.
8.0	Maximum heat flux for un-insulated tanks
4.0	Sufficient to cause pain to personnel if unable to reach cover within 20 seconds. However blistering of skin (1^{st}degree burns) is likely.

The hazard distances to the 37.5 kW/m^2, 12.5 kW/m^2 and 4 kW/m^2 radiation levels, selected based on their effect on population; buildings and equipment were modeled using PHAST.

[2] Release duration is based on Chemical Process Quantitative Risk Analysis, CCPS.

6.4.3 VAPOR CLOUD EXPLOSION

In the event of explosion taking place within the plant, the resultant blast wave will have damaging effects on equipment, structures, building and piping falling within the overpressure distances of the blast. Tanks, buildings, structures etc. can only tolerate low level of overpressure. Human body, by comparison, can withstand higher overpressure. But injury or fatality can be inflicted by collapse of building of structures. The damage effect of blast overpressure is tabulated below.

Table 8: Damage Effects of Blast Overpressure

Blast Overpressure (PSI)	Damage Level
5.0	Major structure damage
3.0	Oil storage tank failure
2.5	Eardrum rupture
2.0	Repairable damage, pressure vessels remain intact, light structures collapse
1.0	Window pane breakage possible, causing some injuries

The hazard distances to the 5 psi, 3 psi and 2 psi overpressure levels, selected based on their effects on population; buildings and equipment were modeled using PHAST.

6.4.4 TOXIC HAZARD

The inhalation of toxic gases can give rise to effects, which range in severity from mild irritation of the respiratory tract to death. Lethal effects of inhalation depend on the concentration of the gas to which people are exposed and on the duration of exposure. Mostly this dependence is nonlinear and as the concentration increases, the time required to produce a specific injury decreases rapidly.

The hazard distances to Immediately Dangerous to Life and Health concentration (IDLH) limit is selected to determine the extent of the toxic hazard Created as the result of loss of containment of a toxic substance.

6.5 CONSEQUENCE ANALYSIS FOR UNITS

This section discusses the consequences of selected failure scenarios for various units. The consequence distances are reported in tabular form for all weather conditions in Annexure-I and are represented graphically in Annexure-II for the all failure scenarios in a unit for worst weather conditions.

The various cases identified in PPU of BPCL-Rasayani and their consequences are described below. The directions mentioned are based on plant north indicated on plot plan.

6.5.1 CONSEQUENCE ANALYSIS FOR PPU

(Refer Figure from 1.1 to 1.5 in Annexure-II)

a. Instrument Tapping Failure at Propylene Feed Pump Discharge

A 20 mm leak scenario corresponding to instrument tapping failure is analyzed under this case. This results in a flash fire zone which covers a portion of the road on the western side of the unit. Jet fire thermal radiation intensity of 37.5 kW/m^2 covers a portion of the pipe rack on the western side of the unit. Blast over pressure effect of 2, 3 and 5 psi is mostly restricted within the unit and does not pose any significant risk on other units. However, local impact may damage the nearby equipment.

b. Instrument Tapping Failure at Propylene Reactor Outlet

A 20 mm leak scenario corresponding to instrument tapping failure is analyzed under this case. This results in a Jet fire thermal radiation intensity of 37.5 kW/m^2 which is restricted within the unit and does not pose any significant risk on other units. However, local impact may damage the nearby equipment. Blast over pressure effect of 2, 3 and 5 psi is restricted within the unit and does not pose any significant risk on other units. However, local impact may damage the nearby equipment.

c. Instrument Tapping Failure at Recycle Gas Compressor Discharge

An analysis of instrument tapping failure (20 mm) shows that the flash fire zone extends beyond the unit covering the road on the western and eastern side of the unit. The effect zone of Jet fire thermal radiation intensity of 37.5 kW/m^2 is restricted within the unit and does not pose any significant risk on other units. However, local impact may damage the nearby equipment. Blast over pressure effect of 2, 3 and 5 psi is restricted within the unit and does not pose any significant risk on other units. However, local impact may damage the nearby equipment.

d. Instrument Tapping Failure at Carrier Gas Compressor Discharge

A 20 mm leak scenario corresponding to instrument tapping failure is analyzed under this case. This results in a Jet fire thermal radiation intensity of 37.5 kW/m^2 which is restricted within the unit and does not pose any significant risk on other units. However, local impact may damage the nearby equipment. Blast over pressure effect of 2, 3 and 5 psi is restricted within the unit and does not pose any significant risk on other units. However, local impact may damage the nearby equipment.

e. Instrument Tapping Failure at Recycle Pump Discharge

An analysis of instrument tapping failure (20 mm) shows that the effect zone of Jet fire thermal radiation intensity of 37.5 kW/m^2 is restricted within the unit and does not pose any significant risk on other units. However, local impact may damage the nearby equipment.

6.5.2 CONSEQUENCE ANALYSIS FOR PROPYLENE RECOVERY UNIT (PRU)

(Refer Figure from 2.1 to 2.3 in Annexure-II)

a. Catastrophic Rupture of C3 Splitter Reflux Drum

An analysis of catastrophic rupture shows that the flash fire zone is restricted around the drum. The effect zone of Fireball thermal radiation intensity of 37.5 kW/m^2 extends beyond the unit. Pool fire thermal radiation intensity of 37.5 kW/m^2 is restricted within the unit and does not pose any significant risk on other units. However, local impact may damage the nearby equipment. Blast over pressure effects of 2, 3 and 5 psi extends beyond the unit.

b. Instrument Tapping Failure at C3 Splitter Reflux Pump Discharge

A 20 mm leak scenario corresponding to instrument tapping failure is analyzed under this case. This results in a flash fire zone which is restricted around the pump. Jet fire thermal radiation intensity of 37.5 kW/m^2 covers the pipe rack on the western side of the unit. Blast over pressure effect of 2, 3 and 5 psi is mostly restricted around the pump and does not pose any significant risk on other units. However, local impact may damage the nearby equipment.

c. Large Hole at C3 Splitter Bottom

A 50 mm leak scenario corresponding to large hole is analyzed under this case. This results in a jet fire thermal radiation intensity of 37.5 kW/m^2 which covers the pipe rack on the western side of the unit. Blast over pressure effect of 2, 3 and 5 psi is mostly restricted around the pump and does not pose any significant risk on other units. However, local impact may damage the nearby equipment.

6.5.3 CONSEQUENCE ANALYSIS FOR OFFSITES

(Refer Figure from 3.1 to 3.2 in Annexure-II)

a. Instrument Tapping Failure at Propylene Transfer Pump Discharge

An analysis of instrument tapping failure (20 mm) shows that the flash fire zone is restricted around the pump. The effect zone of Jet fire thermal radiation intensity of 37.5 kW/m^2 is restricted around the pump and does not pose any significant risk on other units. However, local impact may damage the nearby equipment. Blast over pressure effects of 2, 3 and 5 psi is restricted around the pump and does not pose any significant risk on other units. However, local impact may damage the nearby equipment.

b. Instrument Tapping Failure at Hydrogen Booster Compressor Discharge

A 20 mm leak scenario corresponding to instrument tapping failure is analyzed under this case. This results in a flash fire zone which is restricted within around the compressor. Jet fire thermal radiation intensity of 37.5 kW/m^2 is mostly restricted around the compressor and does not pose any significant risk on other units. However, local impact may damage the nearby equipment. Blast over pressure effect of 2, 3 and 5 psi is mostly restricted around the compressor and does not pose any significant risk on other units. However, local impact may damage the nearby equipment.

7 MAJOR FINDINGS & RECOMMENDATIONS

7.1 GENERAL

The detailed consequence analysis of release of hydrocarbon in case of major credible scenarios are modeled in terms of release rate, dispersion, flammability and toxic characteristics, which have been discussed in detail in the report. The major findings and recommendations arising out of the Risk Assessment study are summarized below.

7.2 CONCLUSIONS / RECOMMENDATIONS

Refer Executive Summary for Conclusions / Recommendations.