RAPID RISK ANALYSIS STUDY
OF
PROPYLENE DERIVATIVE PETROCHEMICAL COMPLEX, KOCHI

BHARAT PETROLEUM CORPORATION LIMITED
PDPP COMPLEX, KOCHI REFINERY
PREFACE

Engineers India Limited (EIL), New Delhi, has been entrusted by M/s Bharat Petroleum Corporation Limited (BPCL) to carry out Rapid Risk Analysis study of the Propylene Derivative Petrochemical Complex, Kochi Refinery, Kerala.

As a part of the project execution, EIL is submitting RRA Report highlighting outcomes of risk analysis of Petrochemical Complex units, based on Overall Plot Plan available at the time of study.

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

This Risk Analysis study is based on the information made available at the time of this study. 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

M/s Bharat Petroleum Corporation limited (BPCL) has decided to conduct a Rapid Risk Analysis study of their Propylene Derivative Petrochemical Complex at Kochi in the state of Kerala, India. In this connection, M/s BPCL has entrusted M/s Engineers India Limited (EIL) for conducting the Rapid Risk Analysis for entire Petrochemical Complex.

As a part of the project execution, EIL is submitting RRA Report comprising of risk analysis of new proposed units under Petrochemical Project.

RRA study is an analytical tool for estimating the risk posed by an installation, to its working personnel and to the society. RRA study mainly consists of Consequence Assessment.

Consequence assessment 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 and Cases with low chance of occurrence but having high consequence, e.g. large holes. Effect zones for various outcomes of failure scenarios (Flash Fire, Jet Fire, Pool Fire, Blast overpressure, toxic release etc.) are studied and identified in terms of distances on plot plan.

This executive summary provides major findings and recommendations arising out of the Consequence assessment of the new proposed units under Propylene Derivative Petrochemical Complex of the BPCL-Kochi Refinery. This is based on the detailed analysis given in Section –7.
1.2 MAJOR FINDINGS AND RECOMMENDATIONS

The detailed consequence analysis of release of hydrocarbon in case of major credible scenarios has been modeled in terms of release rate, dispersion, flammability and toxic characteristics, which have been discussed in detail in the report.

Following are the major findings & recommendations for the respective units considering proposed location of the units:

**ACRYLIC ACID UNIT:** Various credible failure scenarios were modeled and studied for this unit.

**Toxic release case:**

On account of toxic dispersion modeling carried out for the units, it was observed that, Isopropyl Acetate IDLH concentration may reach up to a downwind distance of 241 m from the release source. Considering the fact that isopropyl acetate is much heavier than air with molecular mass 102 g/mol as compared to 29 g/mol for air, the vapor cloud may settle down gradually. Since the Plume Side View indicates that, the top of the plume rises 2 meters in the vertical direction from the source of release and then slumps. Therefore, the toxic effects can be restrained within the complex by providing boundary wall of adequate height around the plant.

In order to mitigate the risk, the following are recommended:

- **Relocation of acrylic acid unit may be considered as an option at the time of detail engineering of facilities so as to contain the toxic effects within the complex.**
- **It is recommended to provide adequate numbers of breathing apparatus within the plant at suitable locations.**

**Fire and explosion case:**

The hazard due to fire and explosion may cross the Battery Limit of Acrylic acid unit but shall be contained within the complex. It may affect the nearby tank farm area located inside PDPP complex depend upon the equipment location & prevalent weather conditions at the time of release.

In order to mitigate the risk, the following are recommended:

- **It is suggested to locate the Cyclohexane tank, Cyclohexane pump, Acrylic acid day tank and Acrylic acid pump in the south-east side of the unit away from the Tank farm-1 (Tank farm-1 is the tank farm on west side of Acrylic acid unit).**

**Note:** The acrylic acid pump being referred in the above point is the pump in the Acrylic acid unit which is different from acrylic acid pump that is located in offsite (approximately 40m south of southern battery limit of acrylic acid unit).

- **It is recommended that road along the unit should be classified and no normal vehicles should be allowed.**
It is recommended to consider blast resistant with positive pressurization construction for control room. The entries / exits to the control room shall face the least hazardous area.

**ACRYLATE UNIT:** Credible scenarios ranging from both high frequency & low consequence cases to low frequency & high consequence were modeled for this unit and analyzed.

**Toxic release case:**

Toxic dispersion modeling was carried out for the unit and it was observed that N-Butanol IDLH concentration was found to be contained within the complex.

In order to mitigate the risk, the following are recommended:

- It is recommended to provide adequate numbers of breathing apparatus within the plant at suitable locations.

**Fire and explosion case:**

Hazard on account of fire & explosion is contained within the PDPP complex. Although it is observed that hazard may extend beyond the Battery Limit of Acrylate Unit and affect the nearby facilities within the complex depending upon the equipment location & prevalent weather conditions at the time of release.

In order to mitigate the risk, the following are recommended:

- It is suggested to locate Esterification reactors and pump towards south-west side of the unit, away from Tank farms (Tank farm-1 is the tank farm on west side of Acrylic acid unit and tank farm-2 is on the west side of Acrylate unit).

**OXO ALCOHOL UNIT:** Various credible failure scenarios were modeled and studied for this unit.

**Toxic release case:**

It is observed that hazard due toxic release may get extended beyond the Battery Limit of Oxo alcohol unit and affect the nearby facilities within the complex depending upon the equipment location & prevalent weather conditions at the time of release. The N-Butanol IDLH concentration may get extended up to 121 m from source but limited within PDPP complex.

In order to mitigate the risk, the following are recommended:

- It is recommended to provide adequate numbers of breathing apparatus within the plant at suitable locations.

**Fire & explosion case:**

It is observed that hazard due to fire & explosion may get extended beyond the Battery Limit of Oxo alcohol unit but shall be contained within the complex. It may affect the nearby facilities within the complex depending upon the equipment location & prevalent weather conditions at the time of release.
In order to mitigate the risk, the following are recommended:

- It is suggested to locate the I-Butanol receiver column circuit towards the eastern side of the unit, away from the Firewater tanks.
- It is also suggested to locate N-Butyraldehyde tank and mixed aldehyde tank towards the southeast side of the unit, away from Oxo Tank Yard and Fire Water Tanks.
- It is recommended to consider blast resistant with positive pressurization construction for control room. The entries / exits to the control room shall face the least hazardous area.

**INCOMING LINES FROM BOO/KOCHI REFINERY:** By observation of consequence analysis results of the incoming lines from BOO/Kochi Refinery, it is found that hazard distances for the selected credible failure scenarios may affect nearby equipment and facilities within the Complex, primarily based on routing of the line & prevalent weather conditions at the time of release.

In order to mitigate the risk, the following are recommended:

- It is suggested to route Propylene line from Kochi refinery to Acrylic Acid unit, preferably away from the tank farms.

**OFFSITE FACILITIES:** Based on consequence analysis of offsite, it is observed that hazard zones for various scenarios might affect nearby facilities within the complex depending upon the equipment location & prevalent weather conditions at the time of release.

**Toxic Release case:**

On account of Toxic dispersion modeling carried out for the offsite and it was observed that in case N-Butanol loading arm rupture case IDLH concentration might get extended up to 119 m from source.

In order to mitigate the risk, the following are recommended:

- It is recommended to re-locate loading gantry or to a safe location so as to contain toxic effects within the PDPP complex
- It is recommended to provide adequate numbers of breathing apparatus within the plant at suitable locations.

**Fire & explosion case:**

**Loading arm rupture scenario:** Overpressure explosion distances on account vapor cloud explosion due to loading arm rupture case may extend outside the boundary of PDPP complex. It may also affect Control room, Admin building, lab area and Fire water pump house.

In order to mitigate the risk, the following are recommended:

- It is recommended to re-locate the Loading gantry to safe location so that overpressure zone is contained within the complex boundary and away from Control room, Admin
building, lab area and Fire water pump house during finalization of overall plot plan and equipment layout.

**Offsite Acrylic acid pump station instrument tapping failure scenario:** It is observed that pool fire in this case shall extend to Tank-farm-1, Tank farm-2 and EAA tank. Hazard may extend beyond tank farm area but shall be limited within the PDPP complex.

In order to mitigate the risk, the following are recommended:

- **It is suggested to locate Acrylic acid pump 76 m away from Tank farm -1, Tank farm – 2 and EAA tank.**

**Note:** The acrylic acid pump being referred in the above point is the pump in offsite (approximately 40m south of southern battery limit of acrylic acid unit) which is different from acrylic acid pump that is located in acrylic acid unit.

- **It is recommended to re-locate parking (which is presently located in west side of admin building) area outside LFL zone from gantry and other sources. This can be avoided if gantry itself is re-located.**

**GENERAL RECOMMENDATIONS**

- As the present study has been done based on preliminary basic information available at time of study with respect to process conditions and location of equipments within the unit, it is recommended to do detailed analysis on final plot plan; and analyze the consequences considering firm data based on licensors’ inputs, equipment spacing and safety zones during detailed engineering phase.

- Ensure that adequate Detection and Isolation provision is considered in the design for mitigation of hazardous scenario.

- Ensure that adequate number of Hydrocarbon and Toxic detectors is provided at suitable locations for early detection.

- In order to prevent secondary incident arising from any failure scenario, it is recommended that sprinklers and other protective devices provided on the tanks are regularly checked and maintained to ensure that they are functional.

- **It is recommended that fugitive emissions from equipment, valve, flange, etc, shall be within the control limit as per prescribed norms. Therefore regular Leak Detection and Repair (LDAR) program shall be planned as a part of effective preventive maintenance.**

- Emergency security / evacuation drills to be organized at organization level to ensure preparedness of the personnel’s working in PDPP complex for handling any extreme situation.

- Ensure that vehicles entering the Complex should be fitted with spark arrestors as a mandatory item.
✓ For positively pressurized building, both Hydrocarbon & Toxic detectors need to be placed at suction duct of HVAC. HVAC should be tripped automatically in the event of the detection of any Hydrocarbon / toxic material by detector.

**Mitigating Measures**

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

✓ Measures for controlling / minimization of Ignition sources inside the complex.
✓ Active and Passive Fire Protection for critical equipment and major structures.
✓ Rapid detection of an uncommon event (HC leak, Toxic gas leak, Flame etc.) and alarm arrangements and development of subsequent quick isolation mechanism for major inventory.
✓ Effective Emergency Response plans to be in place
✓ Detection and isolation

**Ignition Control**

✓ Ignition control will reduce the likelihood of fire events. This is the key for reducing the risk within facilities processing flammable materials. It is recommended to minimize the traffic movement within the Complex.

**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.

**Others**

✓ Recommended to use portable HC detector during sampling and maintenance etc.
✓ Provide breathing apparatus at strategic locations inside Complex.
2 INTRODUCTION

2.1 STUDY AIMS AND OBJECTIVE

The objectives of the Risk Analysis study are 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 analysis 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 Analysis 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. 6.7 developed by DNV Technica.

2.2 SCOPE OF WORK

The study addresses the hazards that can be realized due to operations associated with the facilities under BPCL-Propylene Derivative Petrochemical Complex. It covers the following new proposed facilities of Petrochemical Project:

<table>
<thead>
<tr>
<th>S. No.</th>
<th>Description</th>
<th>Capacity (KTPA)</th>
<th>Products</th>
</tr>
</thead>
<tbody>
<tr>
<td>1.</td>
<td>Acrylic Acid Unit</td>
<td>160</td>
<td>Ester Grade Acrylic Acid</td>
</tr>
<tr>
<td>2.</td>
<td>Oxo Alcohol Unit</td>
<td>212</td>
<td>N-Butanol</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>I-Butanol</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>2-Ethyl Hexanol</td>
</tr>
<tr>
<td>3.</td>
<td>Acrylate Unit</td>
<td>190</td>
<td>Butyl Acrylate</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>2-Ethyl Hexyl Acrylate</td>
</tr>
<tr>
<td>4.</td>
<td>Offsite Facilities</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td></td>
<td>(tanks &amp; loading gantry)</td>
<td></td>
<td>-</td>
</tr>
</tbody>
</table>
3 STUDY METHODOLOGY

The study methodology followed the standard risk assessment steps outlined below. Figure 1 presents a flow chart of the risk assessment steps followed.

Figure 1: Study Methodology Flow Chart

Data Collection

Hazard Identification

Failure Case Listing

Consequence Analysis

Hazard/Risk Reduction Measures

Data Collection

Under this task, relevant data has been obtained with respect to the site, its surroundings, Operating Parameters of Process facilities, PFD’s, P&ID’s, Equipment Datasheets, Equipment layouts as well as Overall Plot plan of the facility.

Hazard Identification

A hazard is an undesired situation or event, which may cause harm to people or to the environment, or damage to property. The main hazard from process facilities is that of an uncontrolled release of hydrocarbons, which may subsequently be ignited, as well as any toxic releases. The causes and consequences of the major hazards with respect to the plant have been studied under this task based on historical accidents at similar installations, HAZOP study, and discussion with the Engineer and expert judgment.

Consequence Analysis

The consequences of releases of hydrocarbons have been modeled in terms of release rate, dispersion and flammability and toxic characteristics.

Hazard / Risk Reduction Measures

Hazard / Risk mitigation measures are suggested based on the findings of the consequence analysis.
4 SITE CONDITION

4.1 GENERAL

This chapter describes the location of BPCL- Petrochemical complex and population distribution around the complex. It also indicates the meteorological data, which have been used for the Risk Analysis study.

4.2 SITE, LOCATION AND VICINITY

The PDPP project shall be located in the proximity of BPCL- KR refinery complex to facilitate easy transportation of Propylene and other utilities & raw materials through pipelines. It is estimated that about 132 acres of total land would be required for the project including the mandatory requirement of green belt area as per MoEF guidelines, Govt. of India.

4.3 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 present Risk Analysis study, Meteorological data of Kochi (nearest observatory) have been taken from the Climatological Tables of Observatories in India (1961-1990) published by Indian Meteorological Department.

Atmospheric Parameters

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

**Table 2: Atmospheric Parameter**

<table>
<thead>
<tr>
<th>Sl. No.</th>
<th>Parameter</th>
<th>Average Value Considered For Study</th>
</tr>
</thead>
<tbody>
<tr>
<td>1.</td>
<td>Ambient Temperature (°C)</td>
<td>29</td>
</tr>
<tr>
<td>2.</td>
<td>Atmospheric Pressure (mm Hg)</td>
<td>760</td>
</tr>
<tr>
<td>3.</td>
<td>Relative Humidity (%)</td>
<td>82</td>
</tr>
<tr>
<td>4.</td>
<td>Solar Radiation flux (kW/m²)</td>
<td>0.50</td>
</tr>
</tbody>
</table>

**Wind Speed and Wind Direction**

**Table 3: Average Mean Wind Speed (m/s)**

<table>
<thead>
<tr>
<th></th>
<th>January</th>
<th>February</th>
<th>March</th>
<th>April</th>
<th>May</th>
<th>June</th>
<th>July</th>
<th>August</th>
<th>September</th>
<th>October</th>
<th>November</th>
<th>December</th>
</tr>
</thead>
<tbody>
<tr>
<td>Jan</td>
<td>1.6</td>
<td>1.7</td>
<td>1.9</td>
<td>2.0</td>
<td>1.92</td>
<td>1.58</td>
<td>1.47</td>
<td>1.61</td>
<td>1.6</td>
<td>1.5</td>
<td>1.416</td>
<td>1.36</td>
</tr>
</tbody>
</table>
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. Table 15 indicates the various Pasquill stability classes.

Table 5: Pasquill Stability Classes

<table>
<thead>
<tr>
<th>Surface Wind Speed (meter/s)</th>
<th>Day time solar radiation</th>
<th>Night time cloud cover</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Strong</td>
<td>Medium</td>
</tr>
<tr>
<td>&lt; 2</td>
<td>A</td>
<td>A – B</td>
</tr>
<tr>
<td>2 – 3</td>
<td>A – B</td>
<td>B</td>
</tr>
<tr>
<td>3 – 5</td>
<td>B</td>
<td>B – C</td>
</tr>
<tr>
<td>5 – 6</td>
<td>C</td>
<td>C – D</td>
</tr>
<tr>
<td>&gt; 6</td>
<td>C</td>
<td>D</td>
</tr>
</tbody>
</table>

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 2F weather condition (i.e. 2 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:

Discussions, conclusions and recommendations pertaining to consequence analysis are based on the worst weather condition. The consequence results are reported in tabular form for all the weather conditions and are represented graphically for worst weather condition.

**Table 6: Weather Conditions**

<table>
<thead>
<tr>
<th>Wind Speed</th>
<th>Pasquill Stability</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>F</td>
</tr>
<tr>
<td>1.5</td>
<td>C/D</td>
</tr>
<tr>
<td>2.5</td>
<td>D</td>
</tr>
</tbody>
</table>
5 HAZARDS ASSOCIATED WITH THE FACILITIES

5.1 GENERAL
Petrochemical complex handles a number of hazardous materials like Cyclohexane, Hydrogen, Propylene, Acrylic Acid, 2-Ethyl Hexanol, 2-Ethyl Hexyl Acrylate and other hydrocarbons which have a potential to cause fire and explosion hazards. The mildly toxic chemicals like N-Butanol, I-Butanol, Isopropyl Acetate and Butyl Acrylate are also being handled in the complex. This chapter describes in brief the hazards associated with these materials.

5.2 HAZARDS ASSOCIATED WITH FLAMMABLE MATERIALS

5.2.1 ACRYLIC ACID
Acrylic acid is a clear, colorless, mobile liquid with string, acrid odor. Acrylic Acid vapors are heavier than air and may travel to source of ignition and flash back. It is a flammable material and may cause flash fire and delayed ignition.

Acrylic Acid is susceptible to auto-oxidation. It is hazardous due to peroxide initiation of polymerization. It is stable at normal temperatures and pressure. If it is released at temperatures higher than the normal boiling point it can flash significantly and would lead to high entrainment of gas phase in the liquid phase. High entrainment of gas phase in the liquid phase can lead to jet fires. On the other hand negligible flashing i.e. release of Acrylic Acid at temperatures near boiling points would lead to formation of pools and then pool fire. Acrylic Acid releases may also lead to explosion in case of delayed ignition.

Inhalation of Acrylic acid vapors by human beings in considerable concentration may cause liver and kidney damage. Inhalation of vapors may cause dizziness, suffocation and chemical burns to respiratory tract. It may be fatal if swallowed. It may cause corrosion and permanent tissue destruction of the esophagus and digestive tract. Refer to below table for properties of Acrylic Acid.

Table 7: Hazardous Properties of Acrylic Acid

<table>
<thead>
<tr>
<th>Sl. No.</th>
<th>Properties</th>
<th>Values</th>
</tr>
</thead>
<tbody>
<tr>
<td>1.</td>
<td>LFL (%v/v)</td>
<td>2.4</td>
</tr>
<tr>
<td>2.</td>
<td>UFL (%v/v)</td>
<td>8.0</td>
</tr>
<tr>
<td>3.</td>
<td>Auto ignition temperature (°C)</td>
<td>390</td>
</tr>
<tr>
<td>4.</td>
<td>Heat of combustion (Kcal/Kg)</td>
<td>4500</td>
</tr>
<tr>
<td>5.</td>
<td>Normal Boiling point (°C)</td>
<td>139</td>
</tr>
<tr>
<td>6.</td>
<td>Flash point (°C)</td>
<td>48</td>
</tr>
</tbody>
</table>

5.2.2 HYDROGEN
Hydrogen (H₂) is a gas lighter than air at normal temperature and pressure. It is highly flammable and explosive. It has the widest range of flammable concentrations in air among all common gaseous fuels. This flammable range of Hydrogen varies from 4% by volume (lower flammable
limit) to 75% by volume (upper flammable limit). Hydrogen flame (or fire) is nearly invisible even though the flame temperature is higher than that of hydrocarbon fires and hence poses greater hazards to persons in the vicinity.

Constant exposure of certain types of ferrite steels to hydrogen results in the embrittlement of the metals. Leakage can be caused by such embrittlement in pipes, welds, and metal gaskets.

In terms of toxicity, hydrogen is a simple asphyxiant. Exposure to high concentrations may exclude an adequate supply of oxygen to the lungs. No significant effect to human through dermal absorption and ingestion is reported. Refer to below table for properties of hydrogen.

Table 8: Hazardous Properties of Hydrogen

<table>
<thead>
<tr>
<th>Sl. No.</th>
<th>Properties</th>
<th>Values</th>
</tr>
</thead>
<tbody>
<tr>
<td>1.</td>
<td>LFL (%v/v)</td>
<td>4.12</td>
</tr>
<tr>
<td>2.</td>
<td>UFL (%v/v)</td>
<td>74.2</td>
</tr>
<tr>
<td>3.</td>
<td>Auto ignition temperature (°C)</td>
<td>500</td>
</tr>
<tr>
<td>4.</td>
<td>Heat of combustion (Kcal/Kg)</td>
<td>28700</td>
</tr>
<tr>
<td>5.</td>
<td>Normal Boiling point (°C)</td>
<td>-252</td>
</tr>
<tr>
<td>6.</td>
<td>Flash point (°C)</td>
<td>N.A.</td>
</tr>
</tbody>
</table>

5.2.3 PROPYLENE

Propylene is a colorless compressed gas with mild olefinic odor. It is highly flammable and explosive. It reacts with oxides of nitrogen to form explosive products. It may explode at higher temperature and pressures (955 atm, 327 °C). It is stable under recommended storage conditions. Propylene is incompatible with oxidizing agents, molten sulfur and halogenated compounds.

In terms of toxicity, Propylene is a simple asphyxiant. It may cause suffocation by displacing oxygen in air. Lack of sufficient oxygen may cause serious injury or death. It may cause nervous system depression with nausea, dizziness, etc. Refer to below table for properties of Propylene.

Table 9: Hazardous Properties of Propylene

<table>
<thead>
<tr>
<th>Sl. No.</th>
<th>Properties</th>
<th>Values</th>
</tr>
</thead>
<tbody>
<tr>
<td>1.</td>
<td>LFL (%v/v)</td>
<td>2.1</td>
</tr>
<tr>
<td>2.</td>
<td>UFL (%v/v)</td>
<td>11</td>
</tr>
<tr>
<td>3.</td>
<td>Auto ignition temperature (°C)</td>
<td>460</td>
</tr>
<tr>
<td>4.</td>
<td>Heat of combustion (Kcal/Kg)</td>
<td>10940</td>
</tr>
<tr>
<td>5.</td>
<td>Normal Boiling point (°C)</td>
<td>-47.7</td>
</tr>
<tr>
<td>6.</td>
<td>Flash point (°C)</td>
<td>-108</td>
</tr>
</tbody>
</table>
5.2.4 2-ETHYL HEXANOL

2-Ethyl Hexanol is a clear, low volatility solvent with characteristic odor. It is miscible with most of the organic solvents. It is a flammable and combustible material. 2-Ethyl Hexanol vapor/air mixtures are explosive above 75°C. Vapors may travel to source of ignition and flash back. Inhalation of vapors, mist or liquid may cause irritation to eyes and respiratory tract especially when heated. It may affect central nervous system and have a narcotic effect. Refer to below table for properties of 2-Ethyl Hexanol.

Table 10: Hazardous Properties of 2-Ethyl Hexanol

<table>
<thead>
<tr>
<th>S. No.</th>
<th>Properties</th>
<th>Values</th>
</tr>
</thead>
<tbody>
<tr>
<td>1.</td>
<td>LFL (%v/v)</td>
<td>1.1</td>
</tr>
<tr>
<td>2.</td>
<td>UFL (%v/v)</td>
<td>7.7</td>
</tr>
<tr>
<td>3.</td>
<td>Auto ignition temperature (°C)</td>
<td>270</td>
</tr>
<tr>
<td>4.</td>
<td>Heat of combustion (Kcal/Kg)</td>
<td>9084.9</td>
</tr>
<tr>
<td>5.</td>
<td>Normal Boiling point (°C)</td>
<td>184.6</td>
</tr>
<tr>
<td>6.</td>
<td>Flash point (°C)</td>
<td>75</td>
</tr>
</tbody>
</table>

5.2.5 2-ETHYL HEXYL ACRYLATE

2-Ethyl Hexyl Acrylate is water white liquid with characteristic odor. It is a stable product with negligible solubility with water. It is combustible material and containers may explode in fire. Water may be ineffective on fire. It is incompatible with strong acids, strong bases and strong oxidizing agents.

Inhalation of concentrated vapor causes drowsiness and convulsions. Liquid causes irritation of eyes and may irritate skin on prolonged exposure. Refer to below table for properties of 2-Ethyl Hexyl Acrylate.

Table 11: Hazardous Properties of 2-Ethyl Hexyl Acrylate

<table>
<thead>
<tr>
<th>S. No.</th>
<th>Properties</th>
<th>Values</th>
</tr>
</thead>
<tbody>
<tr>
<td>1.</td>
<td>LFL (%v/v)</td>
<td>0.8</td>
</tr>
<tr>
<td>2.</td>
<td>UFL (%v/v)</td>
<td>6.4</td>
</tr>
<tr>
<td>3.</td>
<td>Auto ignition temperature (°C)</td>
<td>258</td>
</tr>
<tr>
<td>4.</td>
<td>Heat of combustion (Kcal/Kg)</td>
<td>8600</td>
</tr>
<tr>
<td>5.</td>
<td>Normal Boiling point (°C)</td>
<td>216</td>
</tr>
<tr>
<td>6.</td>
<td>Flash point (°C)</td>
<td>82</td>
</tr>
</tbody>
</table>

5.2.6 CYCLOHEXANE

Cyclohexane is a clear colorless liquid with mild sweet odor. It is a highly flammable material and will be easily ignited by heat, sparks or flames. It may explode in presence of mechanical impact.
Slightly explosive in presence of open flames and sparks. Vapor may travel considerable distance to source of ignition and flash back.

In terms of toxicity, Cyclohexane is slightly hazardous in case of skin contact. It may be toxic to kidneys, liver, cardiovascular system. Repeated or prolonged exposure can produce target organs damage. The STEL value as per UK authorities is 300 ppm. Refer to below table for properties of Cyclohexane.

**Table 12: Hazardous Properties of Cyclohexane**

<table>
<thead>
<tr>
<th>S. No.</th>
<th>Properties</th>
<th>Values</th>
</tr>
</thead>
<tbody>
<tr>
<td>1.</td>
<td>LFL (%v/v)</td>
<td>1.3</td>
</tr>
<tr>
<td>2.</td>
<td>UFL (%v/v)</td>
<td>8.4</td>
</tr>
<tr>
<td>3.</td>
<td>Auto ignition temperature (°C)</td>
<td>245</td>
</tr>
<tr>
<td>4.</td>
<td>Heat of combustion (Kcal/Kg)</td>
<td>10380</td>
</tr>
<tr>
<td>5.</td>
<td>Normal Boiling point (°C)</td>
<td>80.7</td>
</tr>
<tr>
<td>6.</td>
<td>Flash point (°C)</td>
<td>-18</td>
</tr>
</tbody>
</table>

**5.2.7 N-BUTYRALDEHYDE**

N-Butyraldehyde is a clear colorless liquid with pungent odor. It is extremely flammable material and will be easily ignited by heat, sparks or flames. Vapor poses a risk for explosion or flash fire and can travel long distances and accumulate in low-lying areas. It may form explosive peroxides on prolonged storage. It is incompatible with oxidizing agents, strong reducing agents, strong acids and strong bases.

N-Butyraldehyde may cause respiratory tract irritation. It may cause narcotic effect in high concentration. It may cause severe eye irritation with corneal injury, which may result in permanent impairment of vision, even blindness. Refer to below table for properties of N-Butyraldehyde.

**Table 13: Hazardous Properties of N-Butyraldehyde**

<table>
<thead>
<tr>
<th>S. No.</th>
<th>Properties</th>
<th>Values</th>
</tr>
</thead>
<tbody>
<tr>
<td>1.</td>
<td>LFL (%v/v)</td>
<td>1.4</td>
</tr>
<tr>
<td>2.</td>
<td>UFL (%v/v)</td>
<td>12.5</td>
</tr>
<tr>
<td>3.</td>
<td>Auto ignition temperature (°C)</td>
<td>230</td>
</tr>
<tr>
<td>4.</td>
<td>Heat of combustion (Kcal/Kg)</td>
<td>8450</td>
</tr>
<tr>
<td>5.</td>
<td>Normal Boiling point (°C)</td>
<td>75</td>
</tr>
<tr>
<td>6.</td>
<td>Flash point (°C)</td>
<td>-6</td>
</tr>
</tbody>
</table>
### 5.2.8 I-BUTYRALDEHYDE

I-Butyraldehyde is a clear colorless liquid. It is extremely flammable material and will be easily ignited by heat, sparks or flames. Vapor may cause flash fire. It is stable under normal temperature and pressures. It slowly oxidizes by atmospheric oxygen. It is incompatible with strong oxidizing agents.

Inhalation of vapors, mist or liquid may cause irritation to respiratory tract. It may cause gastrointestinal irritation with nausea, vomiting and diarrhea. Inhalation of vapors may cause dizziness, throat irritation, headache and drowsiness. Refer to below table for properties of I-Butyraldehyde.

**Table 14: Hazardous Properties of I-Butyraldehyde**

<table>
<thead>
<tr>
<th>S. No.</th>
<th>Properties</th>
<th>Values</th>
</tr>
</thead>
<tbody>
<tr>
<td>1.</td>
<td>LFL (%v/v)</td>
<td>1.6</td>
</tr>
<tr>
<td>2.</td>
<td>UFL (%v/v)</td>
<td>10.6</td>
</tr>
<tr>
<td>3.</td>
<td>Auto ignition temperature (°C)</td>
<td>190</td>
</tr>
<tr>
<td>4.</td>
<td>Heat of combustion (Kcal/Kg)</td>
<td>7693</td>
</tr>
<tr>
<td>5.</td>
<td>Normal Boiling point (°C)</td>
<td>63</td>
</tr>
<tr>
<td>6.</td>
<td>Flash point (°C)</td>
<td>-24</td>
</tr>
</tbody>
</table>

### 5.3 HAZARDS ASSOCIATED WITH TOXIC/CARCINOGENIC MATERIALS

#### 5.3.1 N-BUTANOL

N-Butanol is colorless liquid with a strong; characteristic, alcoholic odor. It is a flammable material and may cause flash fire and delayed ignition. N-Butanol vapors tend to degrade in air as a result of reactions with photochemically generated hydroxyl radicals.

Inhalation of N-Butanol may cause central nervous system depression and possible death due to respiratory failure. Inhalation of N-Butanol vapors by human beings in considerable concentration may cause liver and kidney damage. Inhalation of vapors may cause dizziness, suffocation and in advanced stages unconsciousness and coma. In term of toxicity, N-Butanol is mildly toxic with IDLH value of 1400 ppm. Due to higher IDLH value, toxic effects of N-Butanol are not considered. Refer to below table for properties of N-Butanol.

**Table 15: Hazardous Properties of N-Butanol**

<table>
<thead>
<tr>
<th>S. No.</th>
<th>Properties</th>
<th>Values</th>
</tr>
</thead>
<tbody>
<tr>
<td>1.</td>
<td>LFL (%v/v)</td>
<td>1.4</td>
</tr>
<tr>
<td>2.</td>
<td>UFL (%v/v)</td>
<td>11.2</td>
</tr>
<tr>
<td>3.</td>
<td>Auto ignition temperature (°C)</td>
<td>343</td>
</tr>
<tr>
<td>4.</td>
<td>Heat of combustion (Kcal/Kg)</td>
<td>7906</td>
</tr>
<tr>
<td>5.</td>
<td>Normal Boiling point (°C)</td>
<td>114.7</td>
</tr>
</tbody>
</table>
### Table 16: Toxic Properties of N-Butanol

<table>
<thead>
<tr>
<th>Sl. No.</th>
<th>Properties</th>
<th>Values</th>
</tr>
</thead>
<tbody>
<tr>
<td>6.</td>
<td>Flash point (°C)</td>
<td>37</td>
</tr>
</tbody>
</table>

### 5.3.2 I-Butanol

I-Butanol is colorless oily liquid with a sweet, musty odor. It is a highly flammable material and will be easily ignited by heat, sparks or flames. I-Butanol vapors may travel to source of ignition and flash back. Vapors may explode if ignited in an enclosed area. It is incompatible with strong oxidizing agents.

Inhalation of vapors, mist or liquid may cause irritation to the mucous membranes of the nose and throat and can produce serious chemical burns. Inhalation of vapors may cause dizziness, throat irritation, headache and drowsiness. In term of toxicity, I-Butanol is mildly toxic with IDLH value of 1600 ppm. Due to higher IDLH value, toxic effects of I-Butanol are not considered. Refer to below table for properties of I-Butanol.

### Table 17: Hazardous Properties of I-Butanol

<table>
<thead>
<tr>
<th>Sl. No.</th>
<th>Properties</th>
<th>Values</th>
</tr>
</thead>
<tbody>
<tr>
<td>1.</td>
<td>LFL (%v/v)</td>
<td>1.7</td>
</tr>
<tr>
<td>2.</td>
<td>UFL (%v/v)</td>
<td>10.6</td>
</tr>
<tr>
<td>3.</td>
<td>Auto ignition temperature (°C)</td>
<td>415</td>
</tr>
<tr>
<td>4.</td>
<td>Heat of combustion (Kcal/Kg)</td>
<td>7900</td>
</tr>
<tr>
<td>5.</td>
<td>Normal Boiling point (°C)</td>
<td>108</td>
</tr>
<tr>
<td>6.</td>
<td>Flash point (°C)</td>
<td>28</td>
</tr>
</tbody>
</table>

### Table 18: Toxic Properties of I-Butanol

<table>
<thead>
<tr>
<th>Sl. No.</th>
<th>Threshold Limits</th>
<th>Concentration (PPM)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1.</td>
<td>Odor threshold</td>
<td>NA</td>
</tr>
<tr>
<td>2.</td>
<td>Threshold Limit Value (TLV)</td>
<td>50</td>
</tr>
<tr>
<td>3.</td>
<td>Short Term Exposure Limit (STEL) (15 Minutes)</td>
<td>NA</td>
</tr>
</tbody>
</table>
5.3.3 ISOPROPYL ACETATE

Isopropyl Acetate is a colorless liquid with fruity odor. Isopropyl Acetate is flammable in presence of open flames and sparks. It is slightly flammable and explosive in presence of oxidizing materials, acids or alkalis. It is stable under normal conditions. It is moisture sensitive material. If it is released at temperatures higher than the normal boiling point it can flash significantly and would lead to high entrainment of gas phase in the liquid phase. High entrainment of gas phase in the liquid phase can lead to jet fires. On the other hand negligible flashing i.e. release of Isopropyl Acetate at temperatures near boiling points would lead to formation of pools and then pool fire. Inhalation of Isopropyl Acetate can cause drowsiness, dizziness, rapid heart rate, headaches and unconsciousness. In term of toxicity, Isopropyl Acetate is mildly toxic with IDLH value of 1800 ppm. Due to higher IDLH value, toxic effects of Isopropyl Acetate are not considered. Refer to below tables for hazardous properties of Isopropyl Acetate.

Table 19: Hazardous Properties of Isopropyl Acetate

<table>
<thead>
<tr>
<th>Sl. No.</th>
<th>Properties</th>
<th>Values</th>
</tr>
</thead>
<tbody>
<tr>
<td>1.</td>
<td>LFL (%v/v)</td>
<td>1.8</td>
</tr>
<tr>
<td>2.</td>
<td>UFL (%v/v)</td>
<td>7.8</td>
</tr>
<tr>
<td>3.</td>
<td>Auto ignition temperature (°C)</td>
<td>460</td>
</tr>
<tr>
<td>4.</td>
<td>Flash point (°C)</td>
<td>4</td>
</tr>
<tr>
<td>5.</td>
<td>Heat of combustion (KCAL/Kg)</td>
<td>81</td>
</tr>
<tr>
<td>6.</td>
<td>Normal Boiling point (°C)</td>
<td>89</td>
</tr>
</tbody>
</table>

Table 20: Toxic Properties of Isopropyl Acetate

<table>
<thead>
<tr>
<th>Sl. No.</th>
<th>Threshold Limits</th>
<th>Concentration (PPM)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1.</td>
<td>Odor threshold</td>
<td>0.045</td>
</tr>
<tr>
<td>2.</td>
<td>Threshold Limit Value (TLV)</td>
<td>250</td>
</tr>
<tr>
<td>3.</td>
<td>Short Term Exposure Limit (STEL) (15 Minutes)</td>
<td>310</td>
</tr>
<tr>
<td>4.</td>
<td>Immediately Dangerous to Life and Health (IDLH) level (for 30 min exposure)</td>
<td>1800</td>
</tr>
</tbody>
</table>

5.3.4 BUTYL ACRYLATE

Butyl Acrylate is colorless viscous liquid with strong fruity odor. It is flammable and highly reactive, may contain inhibitor to prevent polymerization. It is incompatible with strong acids, alkalis,
amines, halogens, oxidizers, heat, flame and sunlight. Above 36 °C, it forms explosive mixture with air.

If it is released at temperatures higher than the normal boiling point it can flash significantly and would lead to high entrainment of gas phase in the liquid phase. High entrainment of gas phase in the liquid phase can lead to jet fires. On the other hand negligible flashing i.e. release of Butyl Acrylate at temperatures near boiling points would lead to formation of pools and then pool fire. Inhalation of Butyl Acrylate may cause irritation in upper respiratory system. It may cause breathing difficulty, abdominal pain and sensitization dermatitis. In term of toxicity, Butyl Acrylate is toxic with TLV value of 2 ppm. However IDLH and STEL values are not listed in ACGIH and NIOSH, toxic effects of Butyl Acrylate are not considered. Refer to below tables for hazardous properties of Butyl Acrylate.

Table 21: Hazardous Properties of Butyl Acrylate

<table>
<thead>
<tr>
<th>Sl. No.</th>
<th>Properties</th>
<th>Values</th>
</tr>
</thead>
<tbody>
<tr>
<td>1.</td>
<td>LFL (%v/v)</td>
<td>1.5</td>
</tr>
<tr>
<td>2.</td>
<td>UFL (%v/v)</td>
<td>9.9</td>
</tr>
<tr>
<td>3.</td>
<td>Auto ignition temperature (°C)</td>
<td>267</td>
</tr>
<tr>
<td>4.</td>
<td>Flash point (°C)</td>
<td>36</td>
</tr>
<tr>
<td>5.</td>
<td>Heat of combustion (KCAL/Kg)</td>
<td>7700</td>
</tr>
<tr>
<td>6.</td>
<td>Normal Boiling point (°C)</td>
<td>145</td>
</tr>
</tbody>
</table>

Table 22: Toxic Properties of Butyl Acrylate

<table>
<thead>
<tr>
<th>Sl. No.</th>
<th>Threshold Limits</th>
<th>Concentration (PPM)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1.</td>
<td>Odor threshold</td>
<td>NA</td>
</tr>
<tr>
<td>2.</td>
<td>Threshold Limit Value(TLV)</td>
<td>2</td>
</tr>
<tr>
<td>3.</td>
<td>Short Term Exposure Limit (STEL) (15 Minutes)</td>
<td>NA</td>
</tr>
<tr>
<td>4.</td>
<td>Immediately Dangerous to Life and Health (IDLH) level (for 30 min exposure)</td>
<td>NA</td>
</tr>
</tbody>
</table>
6 HAZARD IDENTIFICATION

6.1 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.

- Small hole, cracks or small bore failure (i.e. instrument tapping failure, drains/vents failure etc.) in piping and vessels
- Flange leaks
- Leaks from pump glands and similar seals
- Large holes

6.2 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

### 6.3 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, failure of drains, vents, 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 holes in lines, process 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 PDPP complex. Although the list does not give complete failure incidents considering all equipments, units, but the consequence of a similar incident considered in the list below could be used to foresee the consequence of that particular accident.
For selected credible failure scenarios and likely consequences for facilities of BPCL - PDPP Complex refer Section-7.
7 CONSEQUENCE ANALYSIS

7.1 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.

7.2 CONSEQUENCE ANALYSIS MODELLING

7.2.1 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.

7.2.2 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.

7.2.3 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.
7.2.4 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.

7.2.5 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.

7.2.6 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 the mass of hydrocarbon vapor between its lower and upper explosive limits.

7.2.7 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. H₂S, 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.

7.3 SIZE AND DURATION OF RELEASE
Leak size considered for selected failure cases are listed below.

Table 23: Size of Release

<table>
<thead>
<tr>
<th>Failure Description</th>
<th>Leak Size</th>
</tr>
</thead>
<tbody>
<tr>
<td>Pump seal failure</td>
<td>6 mm hole size</td>
</tr>
<tr>
<td>Flange gasket failure</td>
<td>10 mm hole size</td>
</tr>
<tr>
<td>Instrument tapping failure</td>
<td>20 mm hole size</td>
</tr>
<tr>
<td>Large Hole</td>
<td>50 mm, complete rupture of 2” drain line</td>
</tr>
</tbody>
</table>
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.

7.4 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.

7.4.1 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.

7.4.2 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 24: Damage Due to Incident Thermal Radiation Intensity

<table>
<thead>
<tr>
<th>Incident Radiation Intensity (Kw/M²)</th>
<th>Type Of Damage</th>
</tr>
</thead>
<tbody>
<tr>
<td>37.5</td>
<td>Sufficient to cause damage to process equipment</td>
</tr>
<tr>
<td>32.0</td>
<td>Maximum flux level for thermally protected tanks containing flammable liquid</td>
</tr>
<tr>
<td>12.5</td>
<td>Minimum energy required for piloted ignition of wood, melting of plastic tubing etc.</td>
</tr>
<tr>
<td>8.0</td>
<td>Maximum heat flux for un-insulated tanks</td>
</tr>
<tr>
<td>4.0</td>
<td>Sufficient to cause pain to personnel if unable to reach cover within 20 seconds. However blistering of skin (1st degree burns) is likely.</td>
</tr>
</tbody>
</table>

The hazard distances to the 37.5 kW/m², 32 kW/m², 12.5 kW/m², 8 kW/m² and 4 kW/m² radiation levels, selected based on their effect on population, buildings and equipment were modeled using PHAST.

7.4.3 VAPOUR 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 25: Damage Effects of Blast Overpressure**

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

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.

**7.4.4 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.

**7.5 CONSEQUENCE ANALYSIS FOR NEW PROPOSED UNITS**

This section discusses the consequences of selected failure scenarios whose affect zones crosses the respective unit’s battery limit and causes worst consequences. The consequence distances are reported in tabular form for all weather conditions and are represented graphically in **Annexure-II** for the all failure scenarios in a unit for worst weather conditions.

Note: The term ‘battery limit of unit’ shall refer to the boundary of the respective unit and not the boundary of PDPP complex. In case of reference of complex boundary, it shall be specified at respective places.

**7.5.1 ACRYLIC ACID**

**NOTE:** Refer Figures 7.5.1.1 to 7.5.1.7 in Annexure-II

**Instrument Tapping Failure at Propylene Inlet Line:** From the consequence analysis of selected failure scenario it can be observed that LFL shall be travelling up to a distance of 5 m. The Jet
Fire Radiation Intensity of 37.5 kW/m² may not be realized and 12.5 kW/m² may extend up to a distance of 7 m. 

*Based upon the hazard distances it may be observed that hazardous affect zones for the selected failure scenario will be contained within the Battery Limit of the unit.*

**Seal Failure at Acrylic Acid Pump:** From the consequence modeling of the selected failure scenario, it can be observed that LFL may be spreading up to a distance of 7 m from leak source. The Jet Fire Radiation Intensity of 37.5 kW/m² may not be realized and 12.5 kW/m² may extend up to a distance of 7 m. The Pool Fire radiation intensity of 37.5 & 12.5 kW/m² would spread up to a distance of 20 m & 27 m respectively. 

*Based upon the hazard distances it may be observed that hazardous affect zones for the selected failure scenario will be contained within the Battery Limit of the unit.*

**Large Hole at Acrylic Acid Tank Manifold:** From the consequence results and graphs of the selected credible scenario, it can be concluded that LFL may be extended up to a distance of 7 m. The Jet Fire Radiation Intensity of 37.5 kW/m² may not be realized and 12.5 kW/m² may extend up to a distance of 9 m. The Pool Fire radiation intensity of 37.5 & 12.5 kW/m² would spread up to a distance of 62 m & 91 m respectively.

*Based upon the consequence analysis of this scenario is observed that hazard distances in event of realization of this failure scenario may extend beyond the Battery Limit of the unit. However it shall be contained within complex premises.*

**Instrument Tapping Failure at Cyclohexane Pump:** From the incident outcome analysis of the selected failure scenario it is observed that LFL hazard distance is extended up to 78 m up to the road along unit. The Jet Fire radiation intensity of 37.5 & 12.5 kW/m² would extend up to a distance of 49 m & 58 m respectively. The Pool Fire radiation intensity of 37.5 & 12.5 kW/m² would extend up to a distance of 43 m & 65 m respectively. The 5 & 3 psi blast waves may reach up to a distance of 89 m & 97 m.

*Based upon the consequence analysis of this scenario is observed that the hazardous affect zones may spread throughout the unit & may also extend beyond the Battery Limit of the unit affecting nearby facilities within the complex. It is recommended that road along the unit should be classified and no normal vehicles should be allowed.*

**Large Hole at Cyclohexane Tank Manifold:** From the event outcome of the selected failure scenario it can be observed that LFL may be extended up to a distance of 52 m and reaching up to incinerator area. The Jet Fire radiation intensity of 37.5 & 12.5 kW/m² would be getting extended up to 46 m & 54 m respectively. The Pool Fire radiation intensity of 37.5 & 12.5 kW/m² would extend up to a distance of 49m & 75 m respectively. Taking the fact that concrete wall exists at plant boundary, it may be inferred that the radiation intensity of 4kW/m² shall also be contained with the boundary limit of the plant which would otherwise extend beyond the plant.
boundary by 50m on east and 40m on west. The 5 & 3 psi blast waves may reach up to a distance of 64 m & 69 m respectively.

*Based upon the consequence analysis, it can be observed that though selected failure scenario have very low probability of occurrence but if realized at any instant in plant life, the hazardous affect zones may spread throughout the unit & may also extend beyond the Battery Limit of the unit affecting nearby facilities within the complex. It is also recommended that road along the unit should be classified and no normal vehicles should be allowed.*

**Instrument Tapping Failure at Isopropyl Acetate Pump - Toxic:** From the incident outcome analysis of the selected failure scenario it is observed that LFL hazard distance is extended up to 37 m. The Jet Fire radiation intensity of 37.5 & 12.5 kW/m$^2$ would extend up to a distance of 45m & 53 m respectively. The Pool Fire Radiation Intensity of 37.5 kW/m$^2$ may not be realized and 12.5 kW/m$^2$ may extend up to a distance of 36 m. The 5 & 3 psi blast waves may reach up to a distance of 39 m & 42 m.

The Isopropyl Acetate IDLH concentration may reach up to a downwind distance of 241 m on both east and west side of the plant, affecting any individual present in the area. But considering the fact that isopropyl acetate is much heavier than air with molecular mass 102g/mol as compared to 29g/mol for air, it can be inferred that the cloud of the compound will settle down gradually. During detail engineering, depending on the layout of piping and instrumentation, the exact (and conservative) height of release shall be modeled and the height of boundary wall shall be modified accordingly so as to contain the cloud within the plant boundary.

*Relocating the acrylic acid unit is an option which shall considered at the time of detail engineering of facilities so as to contain the toxic effects within the complex.*

*It is also recommended to provide adequate numbers of breathing apparatus within the plant at suitable locations.*

**Large Hole at Isopropyl Acetate Tank Manifold:** From the event outcome of the selected failure scenario it can be observed that LFL may be extended up to a distance of 25 m. The Jet Fire Radiation Intensity of 37.5 kW/m$^2$ may not be realized and 12.5 kW/m$^2$ may extend up to a distance of 8 m. The Pool Fire Radiation Intensity of 37.5 kW/m$^2$ may not be realized and 12.5 kW/m$^2$ may extend up to a distance of 18 m. The 5 & 3 psi blast waves may reach up to a distance of 29 m & 33 m respectively.

*Based upon the consequence analysis of this scenario is observed that hazard distances in event of realization of this failure scenario may extend beyond the Battery Limit of the unit. However it shall be contained within complex premises.*

In addition to above scenarios, Seal Failure of Cyclohexane Pumps and Flange Leakage at Acrylic Acid Tank were also modeled. It is observed that hazardous affect zones might be restricted to Battery Limit of the unit.
7.5.2 ACRYLATE UNIT

NOTE: Refer Figures 7.5.2.1 to 7.5.2.13 in Annexure-II

Instrument Tapping Failure at Acrylic Acid Inlet Line: From the consequence results and graphs of the selected credible failure scenario, it can be observed that LFL may be extended up to a distance of 8 m. The Jet Fire Radiation Intensity of 37.5 kW/m² may not be realized and 12.5 kW/m² may extend up to a distance of 13 m. The Pool Fire radiation intensity of 37.5 & 12.5 kW/m² would extend up to a distance of 40 m & 57 m respectively.

Based upon the consequence analysis of this scenario is observed that hazard distances in event of realization of this failure scenario may extend beyond the Battery Limit of the unit. However it shall be contained within complex premises.

Instrument Tapping Failure at N-Butanol Inlet Line - Toxic: From the consequence results and graphs of failure scenario, it can be observed that LFL distances may reach up to a distance of 9 m. The Jet Fire Radiation Intensity of 37.5 & 12.5 kW/m² can extend up to a distance of 16 m & 19 m respectively. The Pool Fire radiation intensity of 37.5 & 12.5 kW/m² would extend up to a distance of 33 m & 55 m respectively. The N-Butanol IDLH concentration may reach up to a downwind distance of 84 m, affecting any individual present in the area.

Based upon the consequence analysis of this scenario is observed that hazard distances in event of realization of this failure scenario may extend beyond the Battery Limit of the unit. However it shall be contained within complex premises.

Large Hole at Esterification Reactor: From the consequence analysis of the selected failure scenario, it can be concluded that LFL may be extended up to a distance of 31 m. The Jet Fire Radiation Intensity of 37.5 & 12.5 kW/m² may spread up to a distance of 76 m & 88 m respectively and may affect tanks in Tank Farm 2 area. The Pool Fire radiation intensity of 37.5 & 12.5 kW/m² would extend up to a distance of 49 m & 75 m respectively and may affect tanks in Tank Farm 2 area. It is suggested to locate Esterification reactors and pump towards south-west side of the unit, away from Tank farms. The 5 & 3 psi blast wave may extend up to a distance of 39 m & 43 m respectively.

Based upon the consequence analysis of this scenario is observed that hazard distances in event of realization of this failure scenario may extend beyond the Battery Limit of the unit. However it shall be contained within complex premises.

Instrument Tapping Failure at Esterification Pump: From the event outcome of the selected failure scenario it can be observed that LFL may be extended up to a distance of 3 m. The Jet Fire Radiation Intensity of 37.5 kW/m² and 12.5 kW/m² is not realized in this failure scenario.

Based upon the hazard distances it may be observed that hazardous affect zones for the selected failure scenario will be contained within the Battery Limit of the unit.
Large Hole at Alcohol Receiver: From the incident outcome analysis of the selected failure scenario it is observed that LFL hazard distance is extended up to a distance of 18 m. The Jet Fire Radiation Intensity of 37.5 & 12.5 kW/m$^2$ may spread up to a distance of 27 m & 38 m respectively. The Pool Fire Radiation Intensity of 37.5 & 12.5 kW/m$^2$ may spread up to a distance of 52 m & 87 m respectively and may affect tanks in Tank Farm 2 area. The 5 & 3 psi blast wave may spread up to a distance of 12 m and 12 m respectively.

*Based upon the consequence analysis of this scenario is observed that hazard distances in event of realization of this failure scenario may extend beyond the Battery Limit of the unit. However it shall be contained within complex premises.*

Instrument Tapping Failure at Alcohol Reflux Pump - Toxic: From the consequence analysis of the selected failure scenario, it can be concluded that LFL may be extended up to a distance of 8 m. The Jet Fire Radiation Intensity of 37.5 & 12.5 kW/m$^2$ may spread up to a distance of 18 m & 25 m respectively. The Pool Fire Radiation Intensity of 37.5 & 12.5 kW/m$^2$ may spread up to a distance of 26 m & 45 m respectively. The N-Butanol IDLH concentration may reach up to a downwind distance of 111 m, affecting any individual present in the area.

*Based upon the hazard distances it may be observed that hazardous affect zones for the selected failure scenario will be contained within the Battery Limit of the unit.*

Large Hole at Butyl Acrylate Tank: From the event outcome of the selected failure scenario it can be observed that LFL may be extended up to a distance of 7 m. The Jet Fire Radiation Intensity of 37.5 & 12.5 kW/m$^2$ may reach up to a distance of 10 m & 12 m respectively. The Pool Fire Radiation Intensity of 37.5 kW/m$^2$ may not be realized and 12.5 kW/m$^2$ may extend up to a distance of 32 m.

*Based upon the hazard distances it may be observed that hazardous affect zones for the selected failure scenario will be contained within the Battery Limit of the unit.*

Instrument Tapping Failure at Butyl Acrylate Pump: From the incident outcome analysis of the selected failure scenario it is observed that LFL hazard distance is extended up to a distance of 11 m. The Jet Fire Radiation Intensity of 37.5 & 12.5 kW/m$^2$ can spread up to a distance of 19 m and 22 m respectively. The Pool Fire Radiation Intensity of 37.5 kW/m$^2$ may not be realized and 12.5 kW/m$^2$ may extend up to a distance of 29 m. The 5 & 3 psi blast wave may spread up to a distance of 13 m and 14 m respectively.

*Based upon the hazard distances it may be observed that hazardous affect zones for the selected failure scenario will be contained within the Battery Limit of the unit.*

Instrument Tapping Failure at 2-Ethyl Hexanol Inlet Line: From the event outcome of the selected failure scenario it can be observed that LFL may be extended up to a distance of 9 m. The Jet Fire Radiation Intensity of 37.5 kW/m$^2$ may not be realized and 12.5 kW/m$^2$ may extend up to a
distance of 4 m. The Pool Fire Radiation Intensity of 37.5 kW/m$^2$ may not be realized and 12.5 kW/m$^2$ may extend up to a distance of 27 m.

*Based upon the hazard distances it may be observed that hazardous affect zones for the selected failure scenario will be contained within the Battery Limit of the unit.*

**Large Hole at Esterification Reactor:** From the consequence analysis of the selected failure scenario, it can be concluded that LFL may be extended up to a distance of 40 m. The Jet Fire Radiation Intensity of 37.5 & 12.5 kW/m$^2$ may spread up to a distance of 70 m & 83 m respectively. The Pool Fire Radiation Intensity of 37.5 kW/m$^2$ may not be realized and 12.5 kW/m$^2$ may extend up to a distance of 36 m. The 5 & 3 psi blast wave may extend up to a distance of 50 m & 54 m respectively.

*Based upon the consequence analysis of this scenario may be observed that hazard distances in event of realization of this failure scenario may extend beyond the Battery Limit of the unit but shall be contained within complex. It is recommended that road along reactor-side of unit should be classified and no normal vehicles should be allowed.*

**Instrument Tapping Failure at Esterification Pump:** From the event outcome of the selected failure scenario it can be observed that LFL may be extended up to a distance of 14 m. The Jet Fire Radiation Intensity of 37.5 & 12.5 kW/m$^2$ may reach up to a distance of 29 m & 36 m respectively. The Pool Fire Radiation Intensity of 37.5 kW/m$^2$ may not be realized and 12.5 kW/m$^2$ may extend up to a distance of 18 m. The 5 & 3 psi blast wave may reach up to a distance of 14 m & 15 m respectively.

*Based upon the consequence analysis of this scenario it may be observed that hazard distances in event of realization of this failure scenario may extend beyond the Battery Limit of the unit. However it shall be contained within complex premises.*

**Large Hole at 2-Ethyl Hexyl Acrylate Tank:** From the event outcome of the selected failure scenario it can be observed that LFL may be extended up to a distance of 5 m. The Jet Fire Radiation Intensity of 37.5 & 12.5 kW/m$^2$ may not be realized. The Pool Fire Radiation Intensity of 37.5 kW/m$^2$ may not be realized and 12.5 kW/m$^2$ may extend up to a distance of 30 m.

*Based upon the hazard distances it may be observed that hazardous affect zones for the selected failure scenario will be contained within the Battery Limit of the unit.*

**Instrument Tapping Failure at 2-Ethyl Hexyl Acrylate Pump:** From the incident outcome analysis of the selected failure scenario it is observed that LFL hazard distance is extended up to a distance of 10 m. The Jet Fire Radiation Intensity of 37.5 & 12.5 kW/m$^2$ can spread up to a distance of 4 m and 5 m respectively. The Pool Fire Radiation Intensity of 37.5 kW/m$^2$ may not be realized and 12.5 kW/m$^2$ may extend up to a distance of 28 m.
Based upon the hazard distances it may be observed that hazardous affect zones for the selected failure scenario will be contained within the Battery Limit of the unit.

In addition to the above-mentioned scenarios, Seal Failure at Esterification Pump and 2-Ethyl Hexyl Acrylate pump was also modeled. It is observed that hazardous affect zone might be restricted to Battery Limit of the unit.

7.5.3 OXO ALCOHOL UNIT

NOTE: Refer Figures 7.5.3.1 to 7.5.3.9 in Annexure-II

Instrument Tapping Failure at Syn Gas Inlet Line: From the consequence analysis of the selected failure scenario it is observed that LFL hazard distance is extended up to a distance of 7 m. The Jet Fire Radiation Intensity of 37.5 & 12.5 kW/m² is not realized in this failure scenario.

Based upon the hazard distances it may be observed that hazardous affect zones for the selected failure scenario will be contained within the Battery Limit of the unit.

Instrument Tapping Failure at Propylene Inlet Line: From the event outcome of the selected failure scenario it can be observed that LFL may be extended up to a distance of 46 m. The Jet Fire Radiation Intensity of 37.5 & 12.5 kW/m² can extend up to a distance of 51 m & 59 m respectively. The 5 & 3 psi blast wave may reach up to a distance of 51 m and 55 m respectively.

Based upon the consequence analysis of this scenario is observed that hazard distances in event of realization of this failure scenario may extend beyond the Battery Limit of the unit. However it shall be contained within complex premises. It is recommended that road along B/L of unit should be classified and no normal vehicles should be allowed.

Instrument Tapping Failure at Hydrogen Inlet Line: From the incident outcome analysis of the selected failure scenario it is observed that LFL hazard distance is extended up to a distance of 23 m. The Jet Fire Intensity Radiation of 37.5 kW/m² is not realized &12.5 kW/m² can reach up to a distance of 13 m. The 5 & 3 psi blast wave can extend up to a distance of 26 m & 28 m respectively.

Based upon the hazard distances it may be observed that hazardous affect zones for the selected failure scenario will be contained within the Battery Limit of the unit.

Large Hole at I-Butanol Receiver Column: From the consequence results and graphs, it is observed that LFL hazard may spread up to a distance of 36 m. The Jet Fire Radiation of 37.5 & 12.5 kW/m² can reach up to a distance of 72 m & 85 m respectively. The Pool Fire Radiation of 37.5, 12.5 and 8 kW/m² can reach up to a distance of 99 m, 146 m & 167 m respectively.

Considering the fact that concrete wall exists at plant boundary, it may be inferred that the radiation intensity of 4kW/m² shall also be contained with the boundary limit of the plant which would otherwise extend beyond the plant boundary by 90m on east. The 5 & 3 psi blast wave can extend up to a distance of 39 m & 42 m respectively.
Based upon the consequence analysis, it can be observed that though selected failure scenario have very low probability of occurrence but if realized at any instant in plant life, the hazardous affect zones may spread throughout the unit & may also extend beyond the Battery Limit of the unit affecting nearby facilities within the complex. It is recommended to have exit/entrance facility for control room from least hazardous side. It is also recommended to locate Fire water tanks outside 8 KW/ m² hazardous zone from the column.

Seal Failure at I-Butanol Pump: From the event outcome of the selected failure scenario it can be observed that LFL may be extended up to a distance of 11 m. The Jet Fire Radiation of 37.5 & 12.5 kW/m² can reach up to a distance of 17 m & 20 m respectively. The Pool Fire Radiation of 37.5 & 12.5 kW/m² can reach up to a distance of 17 m & 26 m respectively The 5 & 3 psi blast wave can spread up to a distance of 13 m & 14 m respectively.

Based upon the hazard distances it may be observed that hazardous affect zones for the selected failure scenario will be contained within the Battery Limit of the unit.

Flange Leakage at N-Butanol Outlet Line - Toxic: From the consequence modeling for this failure event, it is observed that LFL will extend only up to a distance of 21 m. The Jet Fire Radiation of 37.5 & 12.5 kW/m² can reach up to a distance of 9 m & 11 m respectively. The Pool Fire Radiation of 37.5 & 12.5 kW/m² can reach up to a distance of 33 m & 46 m respectively The 5 & 3 psi blast wave concentration may reach up to a downwind distance of 111 m, affecting any individual present in the area.

Based upon the consequence analysis of this scenario is observed that hazard distances in event of realization of this failure scenario may extend beyond the Battery Limit of the unit. However it shall be contained within complex premises.

Flange Leakage at 2-Ethyl Hexanol Outlet Line: From the consequence modeling for this failure event, it is observed that LFL will extend only up to a distance of 21 m. The Jet Fire Radiation of 37.5 & 12.5 kW/m² can reach up to a distance of 9 m & 11 m respectively. The Pool Fire Radiation Intensity of 37.5 kW/m² may not be realized and 12.5 kW/m² may extend up to a distance of 38 m. The 5 & 3 psi blast wave can spread up to a distance of 23 m & 24 m respectively.

Based upon the hazard distances it may be observed that hazardous affect zones for the selected failure scenario will be contained within the Battery Limit of the unit.

Large Hole at N-Butyraldehyde Tank manifold: From the consequence modeling for this failure event, it is observed that LFL will extend only up to a distance of 63 m. The Jet Fire Radiation of 37.5 & 12.5 kW/m² can reach up to a distance of 31 m & 38 m respectively. The Pool Fire Radiation of 37.5 & 12.5 kW/m² can reach up to a distance of 61 m & 98 m respectively. Taking the fact that concrete wall exists at plant boundary, it may be inferred that the radiation intensity of 4kW/m² shall also be contained with the boundary limit of the plant which would otherwise extend...
beyond the plant boundary by 30m on east and 15m on north. The 5 & 3 psi blast wave can spread up to a distance of 82 m & 91 m respectively.

*Based upon the consequence analysis, it can be observed that though selected failure scenario have very low probability of occurrence but if realized at any instant in plant life, the hazardous affect zones may spread throughout the unit & may also extend beyond the Battery Limit of the unit affecting nearby facilities within the complex. It is also recommended to have blast proof construction for control room. It is recommended to have exit/entrance facility for control room from least hazardous side. It is recommended that road along B/L of unit should be classified and no normal vehicles should be allowed.*

**Large Hole at Mixed Tank:** From the consequence modeling for this failure event, it is observed that LFL will extend only up to a distance of 77 m. The Jet Fire Radiation of 37.5 & 12.5 kW/m² can reach up to a distance of 31 m & 38 m respectively. The Pool Fire Radiation of 37.5 & 12.5 kW/m² can reach up to a distance of 58 m & 95 m respectively. The 5 & 3 psi blast wave can spread up to a distance of 98 m & 108 m respectively.

*Based upon the consequence analysis, it can be observed that though selected failure scenario have very low probability of occurrence but if realized at any instant in plant life, the hazardous affect zones may spread throughout the unit & may also extend beyond the Battery Limit of the unit affecting nearby facilities within the complex. It is also recommended to have blast proof construction for control room. It is recommended to have exit/entrance facility for control room from least hazardous side. It is recommended that road along B/L of unit should be classified and no normal vehicles should be allowed.*

**7.5.4 INCOMING LINES FROM BOO / KOCHI REFINERY**

**NOTE:** Refer Figure 7.5.4.1 to 7.5.4.3 in Annexure-II

**Instrument Tapping Failure at Propylene Inlet Line:** From the consequence modeling results it is observed that LFL hazard distance is extended up to 48 m. The Jet Fire Radiation Intensity of 37.5 & 12.5 kW/m² may travel up to a distance of 51 m & 57 m respectively. The 5 & 3 psi blast wave can extend up to a distance of 52 m & 56 m respectively.

*Based upon the consequence analysis of this scenario is observed that hazard distances in event of realization of this failure scenario may extend beyond the Battery Limit of the unit. However it shall be contained within complex premises.*

**Instrument Tapping Failure at Hydrogen Inlet Line:** From the consequence modeling results it is observed that LFL hazard distance is extended up to 22 m. The Jet Fire Radiation Intensity of 37.5 may not be realized & 12.5 kW/m² may travel up to a distance of 13 m. The 5 & 3 psi blast wave can extend up to a distance of 26 m & 28 m respectively.
Based upon the hazard distances it may be observed that hazardous affect zones for the selected failure scenario will be contained within the Battery Limit of the unit.

**Instrument Tapping Failure at Syn Gas Inlet Line:** From the consequence modeling results it is observed that LFL hazard distance is extended up to 7 m. The Jet Fire Radiation Intensity of 37.5 may not be realized & 12.5 kW/m$^2$ may travel up to a distance of 10 m.

Based upon the hazard distances it may be observed that hazardous affect zones for the selected failure scenario will be contained within the Battery Limit of the unit.

### 7.5.5 OFFSITE

**NOTE:** Refer Figure 7.5.5.1 to 7.5.5.5 in Annexure-II

**Large Hole at Acrylic Acid Tank Manifold:** From the incident outcome analysis of selected failure scenario it is observed that LFL for this case may reach up to a distance of 8 m. The Jet Fire Intensity Radiation of 37.5 kW/m$^2$ is not realized &12.5 kW/m$^2$ can reach up to a distance of 18 m. The Pool Fire Radiation of 37.5 & 8 kW/m$^2$ can reach up to a distance of 76 m & 118 m respectively.

*Based upon the consequence analysis of this scenario is observed that hazard distances in event of realization of this failure scenario may extend beyond the Battery Limit of the unit. However it shall be contained within complex premises.*

**Instrument Tapping Failure at Acrylic Acid Pump:** From the incident outcome analysis of selected failure scenario it is observed that LFL for this case may reach up to a distance of 11 m. The Jet Fire Radiation of 37.5 & 12.5 kW/m$^2$ can reach up to a distance of 15 m & 21 m respectively. The Pool Fire Radiation of 37.5 & 8 kW/m$^2$ can reach up to a distance of 50 m & 76 m respectively and may affect tanks in TF-1, TF-2 & EAA Tank. *It is suggested to locate Acrylic acid pump 76 m away from Tank farm -1, Tank farm – 2 and EAA Tank.* The 5 & 3 psi blast wave can extend up to a distance of 12 m & 13 m respectively.

*Based upon the consequence analysis of this scenario is observed that hazard distances in event of realization of this failure scenario may extend beyond the Battery Limit of the unit. However it shall be contained within complex premises.*

**Large Hole at Butyl Acrylate Tank Manifold:** From the incident outcome analysis of selected failure scenario it is observed that LFL for this case may reach up to a distance of 9 m. The Jet Fire Intensity Radiation of 37.5 & 12.5 kW/m$^2$ can reach up to a distance of 16 m & 20 m respectively. The Pool Fire Intensity Radiation of 37.5 kW/m$^2$ is not realized &12.5 kW/m$^2$ can reach up to a distance of 51 m.

*Based upon the hazard distances it may be observed that hazardous affect zones for the selected failure scenario will be contained within the Battery Limit of the unit.*
Instrument Tapping Failure at Butyl Acrylate Pump: From the incident outcome analysis of selected failure scenario it is observed that LFL for this case may reach up to a distance of 12 m. The Jet Fire Radiation of 37.5 & 12.5 kW/m2 can reach up to a distance of 22 m & 28 m respectively. The Pool Fire Intensity Radiation of 37.5 kW/m2 is not realized & 12.5 kW/m2 can reach up to a distance of 41 m. The 5 & 3 psi blast wave can extend up to a distance of 13 m & 14 m respectively.

Based upon the hazard distances it may be observed that hazardous affect zones for the selected failure scenario will be contained within the Battery Limit of the unit.

Large Hole at N-Butanol Tank Manifold: From the incident outcome analysis of selected failure scenario it is observed that LFL for this case may reach up to a distance of 13 m. The Jet Fire Radiation of 37.5 & 12.5 kW/m2 can reach up to a distance of 19 m &24 m respectively. The Pool Fire Radiation of 37.5 & 12.5 kW/m2 can reach up to a distance of 68 m & 116 m respectively. The 5 & 3 psi blast wave can extend up to a distance of 12 m & 13 m respectively.

Based upon the consequence analysis of this scenario is observed that hazard distances in event of realization of this failure scenario may extend beyond the Battery Limit of the unit. However it shall be contained within complex premises.

Instrument Tapping Failure at N-Butanol Pump: From the incident outcome analysis of selected failure scenario it is observed that LFL for this case may reach up to a distance of 13 m. The Jet Fire Radiation of 37.5 & 12.5 kW/m2 can reach up to a distance of 24 m &30 m respectively. The Pool Fire Radiation of 37.5 & 12.5 kW/m2 can reach up to a distance of 46 m & 75 m respectively. The 5 & 3 psi blast wave can extend up to a distance of 12 m & 13 m respectively.

Based upon the hazard distances it may be observed that hazardous affect zones for the selected failure scenario will be contained within the Battery Limit of the unit.

Loading Arm Rupture at Loading Gantry while loading N-Butanol: From the incident outcome analysis of selected failure scenario it is observed that LFL for this case may reach up to a distance of 113 m up to parking area. The Jet Fire Radiation of 37.5 & 12.5 kW/m2 can reach up to a distance of 46 m & 56 m respectively. The 5 & 3 psi blast wave can extend up to a distance of 141 m & 152 m respectively and may affect Control room, Admin building, lab area and Fire water pump house.

It is recommended to re-locate the Loading gantry to safe location away from Control room, Admin building, lab area and Fire water pump house. It is recommended to locate parking area outside LFL zone from gantry.

Loading Arm Rupture at Loading Gantry while loading Butyl Acrylate: From the incident outcome analysis of selected failure scenario it is observed that LFL for this case may reach up to a distance of 93 m up to parking area. The Jet Fire Radiation of 37.5 & 12.5 kW/m2 can reach up to
a distance of 42 m & 51 m respectively. The 5 & 3 psi blast wave can extend up to a distance of
118 m & 129 m respectively may affect Control room, Admin building, lab area and Fire water
pump house.

*It is recommended to re-locate the Loading gantry to safe location away from Control room,
Admin building, lab area and Fire water pump house. It is recommended to locate parking area
outside LFL zone from gantry.*
8 MAJOR FINDINGS & RECOMMENDATIONS

The detailed consequence analysis of release of hydrocarbon in case of major credible scenarios has been modeled in terms of release rate, dispersion, flammability and toxic characteristics, which have been discussed in detail in the report.

Following are the major findings & recommendations for the respective units considering proposed location of the units:

**ACRYLIC ACID UNIT:** Various credible failure scenarios were modeled and studied for this unit.

**Toxic release case:**

On account of toxic dispersion modeling carried out for the units, it was observed that, Isopropyl Acetate IDLH concentration may reach up to a downwind distance of 241 m from the release source. Considering the fact that isopropyl acetate is much heavier than air with molecular mass 102 g/mol as compared to 29 g/mol for air, the vapor cloud may settle down gradually. Since the Plume Side View indicates that, the top of the plume rises 2 meters in the vertical direction from the source of release and then slumps. Therefore, the toxic effects can be restrained within the complex by providing boundary wall of adequate height around the plant.

In order to mitigate the risk, the following are recommended:

- Relocation of acrylic acid unit may be considered as an option at the time of detail engineering of facilities so as to contain the toxic effects within the complex.
- It is recommended to provide adequate numbers of breathing apparatus within the plant at suitable locations.

**Fire and explosion case:**

The hazard due to fire and explosion may cross the Battery Limit of Acrylic acid unit but shall be contained within the complex. It may affect the nearby tank farm area located inside PDPP complex depend upon the equipment location & prevalent weather conditions at the time of release.

In order to mitigate the risk, the following are recommended:

- It is suggested to locate the Cyclohexane tank, Cyclohexane pump, Acrylic acid day tank and Acrylic acid pump in the south-east side of the unit away from the Tank farm-1 (Tank farm-1 is the tank farm on west side of Acrylic acid unit).

*Note:* The acrylic acid pump being referred in the above point is the pump in the Acrylic acid unit which is different from acrylic acid pump that is located in offsite (approximately 40m south of southern battery limit of acrylic acid unit).

- It is recommended that road along the unit should be classified and no normal vehicles should be allowed.
✓ It is recommended to consider blast resistant with positive pressurization construction for control room. The entries / exits to the control room shall face the least hazardous area.

**ACRYLATE UNIT:** Credible scenarios ranging from both high frequency & low consequence cases to low frequency & high consequence were modeled for this unit and analyzed.

**Toxic release case:**

Toxic dispersion modeling was carried out for the unit and it was observed that N-Butanol IDLH concentration was found to be contained within the complex.

In order to mitigate the risk, the following are recommended:

✓ It is recommended to provide adequate numbers of breathing apparatus within the plant at suitable locations.

**Fire and explosion case:**

Hazard on account of fire & explosion is contained within the PDPP complex. Although it is observed that hazard may extend beyond the Battery Limit of Acrylate Unit and affect the nearby facilities within the complex depending upon the equipment location & prevalent weather conditions at the time of release.

In order to mitigate the risk, the following are recommended:

✓ It is suggested to locate Esterification reactors and pump towards south-west side of the unit, away from Tank farms (Tank farm-1 is the tank farm on west side of Acrylic acid unit and tank farm-2 is on the west side of Acrylate unit).

**OXO ALCOHOL UNIT:** Various credible failure scenarios were modeled and studied for this unit.

**Toxic release case:**

It is observed that hazard due toxic release may get extended beyond the Battery Limit of Oxo alcohol unit and affect the nearby facilities within the complex depending upon the equipment location & prevalent weather conditions at the time of release. The N-Butanol IDLH concentration may get extended up to 121 m from source but limited within PDPP complex.

In order to mitigate the risk, the following are recommended:

✓ It is recommended to provide adequate numbers of breathing apparatus within the plant at suitable locations.

**Fire & explosion case:**

It is observed that hazard due to fire & explosion may get extended beyond the Battery Limit of Oxo alcohol unit but shall be contained within the complex. It may affect the nearby facilities within the complex depending upon the equipment location & prevalent weather conditions at the time of release.
In order to mitigate the risk, the following are recommended:

- **It is suggested to locate the I-Butanol receiver column circuit towards the eastern side of the unit, away from the Firewater tanks.**
- **It is also suggested to locate N-Butyraldehyde tank and mixed aldehyde tank towards the southeast side of the unit, away from Oxo Tank Yard and Fire Water Tanks.**
- **It is recommended to consider blast resistant with positive pressurization construction for control room. The entries / exits to the control room shall face the least hazardous area.**

**INCOMING LINES FROM BOO/KOCHI REFINERY:** By observation of consequence analysis results of the incoming lines from BOO/Kochi Refinery, it is found that hazard distances for the selected credible failure scenarios may affect nearby equipment and facilities within the Complex, primarily based on routing of the line & prevalent weather conditions at the time of release.

In order to mitigate the risk, the following are recommended:

- **It is suggested to route Propylene line from Kochi refinery to Acrylic Acid unit, preferably away from the tank farms.**

**OFFSITE FACILITIES:** Based on consequence analysis of offsite, it is observed that hazard zones for various scenarios might affect nearby facilities within the complex depending upon the equipment location & prevalent weather conditions at the time of release.

**Toxic Release case:**

On account of Toxic dispersion modeling carried out for the offsite and it was observed that in case N-Butanol loading arm rupture case IDLH concentration might get extended up to 119 m from source.

In order to mitigate the risk, the following are recommended:

- **It is recommended to re-locate loading gantry or to a safe location so as to contain toxic effects within the PDPP complex**
- **It is recommended to provide adequate numbers of breathing apparatus within the plant at suitable locations.**

**Fire & explosion case:**

**Loading arm rupture scenario:** Overpressure explosion distances on account vapor cloud explosion due to loading arm rupture case may extend outside the boundary of PDPP complex. It may also affect Control room, Admin building, lab area and Fire water pump house.

In order to mitigate the risk, the following are recommended:

- **It is recommended to re-locate the Loading gantry to safe location so that overpressure zone is contained within the complex boundary and away from Control room, Admin**
building, lab area and Fire water pump house during finalization of overall plot plan and equipment layout.

**Offsite Acrylic acid pump station instrument tapping failure scenario:** It is observed that pool fire in this case shall extend to Tank-farm-1, Tank farm-2 and EAA tank. Hazard may extend beyond tank farm area but shall be limited within the PDPP complex.

In order to mitigate the risk, the following are recommended:

- **It is suggested to locate Acrylic acid pump 76 m away from Tank farm -1, Tank farm – 2 and EAA tank.**

**Note:** The acrylic acid pump being referred in the above point is the pump in offsite (approximately 40m south of southern battery limit of acrylic acid unit) which is different from acrylic acid pump that is located in acrylic acid unit.

- **It is recommended to re-locate parking (which is presently located in west side of admin building) area outside LFL zone from gantry and other sources. This can be avoided if gantry itself is re-located.**

**GENERAL RECOMMENDATIONS**

- As the present study has been done based on preliminary basic information available at time of study with respect to process conditions and location of equipments within the unit, it is recommended to do detailed analysis on final plot plan; and analyze the consequences considering firm data based on licensors’ inputs, equipment spacing and safety zones during detailed engineering phase.

- Ensure that adequate Detection and Isolation provision is considered in the design for mitigation of hazardous scenario.

- Ensure that adequate number of Hydrocarbon and Toxic detectors is provided at suitable locations for early detection.

- In order to prevent secondary incident arising from any failure scenario, it is recommended that sprinklers and other protective devices provided on the tanks are regularly checked and maintained to ensure that they are functional.

- It is recommended that fugitive emissions from equipment, valve, flange, etc, shall be within the control limit as per prescribed norms. Therefore regular Leak Detection and Repair (LDAR) program shall be planned as a part of effective preventive maintenance.

- Emergency security / evacuation drills to be organized at organization level to ensure preparedness of the personnel’s working in PDPP complex for handling any extreme situation.

- Ensure that vehicles entering the Complex should be fitted with spark arrestors as a mandatory item.
✓ For positively pressurized building, both Hydrocarbon & Toxic detectors need to be placed at suction duct of HVAC. HVAC should be tripped automatically in the event of the detection of any Hydrocarbon / toxic material by detector.

Mitigating Measures

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

✓ Measures for controlling / minimization of Ignition sources inside the complex.
✓ Active and Passive Fire Protection for critical equipment and major structures.
✓ Rapid detection of an uncommon event (HC leak, Toxic gas leak, Flame etc.) and alarm arrangements and development of subsequent quick isolation mechanism for major inventory.
✓ Effective Emergency Response plans to be in place
✓ Detection and isolation

Ignition Control

✓ Ignition control will reduce the likelihood of fire events. This is the key for reducing the risk within facilities processing flammable materials. It is recommended to minimize the traffic movement within the Complex.

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.

Others

✓ Recommended to use portable HC detector during sampling and maintenance etc.
✓ Provide breathing apparatus at strategic locations inside Complex.
9 GLOSSARY

CASUALTY Someone who suffers serious injury or worse i.e. including fatal injuries. As a rough guide fatalities are likely to be half the total casualties. But this may vary depending on the nature of the event.

HAZARD A chemical or physical condition with the potential of causing damage.

FLAMMABILITY LIMITS In fuel-air systems, a range of compositions exists inside which a (UFL – LFL) flame will propagate substantial distance from an ignition source. The limiting fuel concentrations are termed as Upper flammability or explosives limit (Fuel concentrations exceeding this are too rich) and Lower flammability or explosives limit (Fuel concentrations below this are too lean).

FLASH FIRE The burning of a vapor cloud at very low flame propagation speed. Combustion products are generated at a rate low enough for expansion to take place easily without significant overpressure ahead or behind the flame front. The hazard is therefore only due to thermal effects.

OVERPRESSURE Maximum pressure above atmosphere pressure experiences during the passage of a blast wave from an explosion expressed in this report as pounds per square inch (psi).

EXPLOSION A rapid release of energy, which causes a pressure discontinuity or shock wave moving away from the source. An explosion can be produced by detonation of a high explosive or by the rapid burning of a flammable gas cloud. The resulting overpressure is sufficient to cause damage inside and outside the cloud as the shock wave propagation into the atmosphere beyond the cloud. Some authors use the term deflagration for this type of explosion.

DOMINO EFFECT The effect that loss of containment of one installation leads to loss of containment of other installations.

EVENT TREE A logic diagram of success and failure combinations of events used to identify accident sequences leading to all possible consequences of a given initiating event.

TLV “Threshold limit value” is defined as the concentration of the substance in air that can be breathed for five consecutive 8 hours work day (40 hours work week) by most people without side effect.

STEL “Short Term Exposure Limit” is the maximum permissible average exposure for the time period specified (15 minutes).
IDLH

“Immediate Dangerous to Life and Health” is the maximum concentration level from which one could escape within 30 minutes without any escape impairing symptoms.

PASQUILL CLASS

Classification to qualify the stability of the atmosphere, indicated by a letter ranging from A, for very unstable, to F, for stable.

FREQUENCY

The number of times an outcome is expected to occur in a given period of time.

F-N CURVE

log-Log graph, where the X-axis represents the number of deaths, N, and the Y-axis represents the cumulative frequency of the accidents, with the number of deaths equal to N or more.

INDIVIDUAL RISK

The probability that in one year a person will become a victim to an accident if the person remains permanently and unprotected in a certain locations. Often the probability of occurrence in one year is replaced by the frequency of occurrence per year. The individual risk at different locations around a particular plant varies.

SOCIETAL RISK

The relationship between frequency and the number of people suffering from a specified level of harm in a given population from the realization of specified hazards. Societal risk is normally presented in the form of F-N curves, which is a graph of the chance or frequency (F) of events, which can result in N or more fatalities.
10 REFERENCES

1. Classification of hazardous locations, A. W. Cox, F. P. Lees and M. L. Ang, Published by the Institute of Chemical engineers, U. K.


5. AICHE, CCPS, Chemical process Quantitative Risk Analysis

Annexure - I

Consequence Analysis Hazard Distances
1. Process Units
<table>
<thead>
<tr>
<th>Unit</th>
<th>ID No.</th>
<th>Equipment</th>
<th>Failure Case</th>
<th>Composition</th>
<th>Design Condition</th>
<th>Service Conditions</th>
<th>Leak Rate (L/s)</th>
<th>Blackout</th>
<th>Multi-Year</th>
<th>Multi-Year</th>
<th>Blast Over Pressure (psi)</th>
<th>Worst Case Distance (m)</th>
<th>Notes</th>
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Annexure - II

Figures For Consequence Analysis
1. Acrylic Acid Unit
Figure 7.5.1.1 A: Acrylic Acid: Instrument Tapping Failure at Propylene Inlet Line; Flash Fire Distances (m)
Figure 7.5.1.1 B: Acrylic Acid: Instrument Tapping Failure at Propylene Inlet Line; Jet Fire Distances (m)
Figure 7.5.1.2 A: Acrylic Acid: Seal Failure at Acrylic Acid Pump; Flash Fire Distances (m)
Figure 7.5.1.2 B: Acrylic Acid: Seal Failure at Acrylic Acid Pump; Jet Fire Distances (m)
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Figure 7.5.1.4 B: Acrylic Acid: Instrument Tapping Failure at Cyclohexane Pump Discharge; Jet Fire Distances (m)
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Figure 7.5.1.4 D: Acrylic Acid: Instrument Tapping Failure at Cyclohexane Pump Discharge; Pool Fire Distances (m)
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Figure 7.5.1.5 B: Acrylic Acid: Large Hole at Cyclohexane Tank; Jet Fire Distances (m)
Figure 7.5.1.5 C: Acrylic Acid: Large Hole at Cyclohexane Tank; Over Pressure Distances (m)
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Figure 7.5.1.6 B: Acrylic Acid: Instrument Tapping Failure at Isopropyl Acetate Pump; Jet Fire Distances (m)
Figure 7.5.1.6 C: Acrylic Acid: Instrument Tapping Failure at Isopropyl Acetate Pump; Over Pressure Distances (m)
Figure 7.5.1.6 D: Acrylic Acid: Instrument Tapping Failure at Isopropyl Acetate Pump; Pool Fire Distances (m)
Figure 7.5.1.6 E: Acrylic Acid: Instrument Tapping Failure at Isopropyl Acetate Pump; IDLH Concentration Distances (m)
Figure 7.5.1.6 F: Acrylic Acid: Instrument Tapping Failure at Isopropyl Acetate Pump; Toxic Release Side View

Study Folder: PDPP_IEP_KOCHI
Audit No: 1953631
Model: IPAC Pump IF
Weather: Category 1/F
Material: ISOPROPYL ACETATE
Averaging Time: Toxic(600 s)
C/L Offset: 0 m
Concentration
Time: 545.1 s

- 1800 ppm
- 1.76e+004 ppm
- 7.2e+004 ppm
Figure 7.5.1.7 A: Acrylic Acid: Large Hole at Isopropyl Acetate Tank; Flash Fire Distances (m)
Figure 7.5.1.7 B: Acrylic Acid: Large Hole at Isopropyl Acetate Tank; Jet Fire Distances (m)
Figure 7.5.1.7 C: Acrylic Acid: Large Hole at Isopropyl Acetate Tank; Over Pressure Distances (m)
Figure 7.5.1.7 D: Acrylic Acid: Large Hole at Isopropyl Acetate Tank; Pool Fire Distances (m)
2. **Acrylate unit**
Figure 7.5.2.1 A: Acrylate Unit: Instrument Tapping Failure at Acrylic Acid Inlet Line; Flash Fire Distances (m)
Figure 7.5.2.1 B: Acrylate Unit: Instrument Tapping Failure at Acrylic Acid Inlet Line; Jet Fire Distances (m)
Figure 7.5.2.1 C: Acrylate Unit: Instrument Tapping Failure at Acrylic Acid Inlet Line; Pool Fire Distances (m)
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Figure 7.5.2.2 B: Acrylate Unit: Instrument Tapping Failure at N-Butanol Inlet Line; Jet Fire Distances (m)
Figure 7.5.5.2 C: Acrylate Unit: Instrument Tapping Failure at N-Butanol Inlet Line; Pool Fire Distances (m)
Figure 7.5.5.2 D: Acrylate Unit: Instrument Tapping Failure at N-Butanol Inlet Line; IDLH Concentration Distances (m)
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Figure 7.5.2.3 B: Acrylate Unit: Large Hole at Esterification Reactor; Jet Fire Distances (m)
Figure 7.5.2.3 C: Acrylate Unit: Large Hole at Esterification Reactor; Over Pressure Distances (m)
Figure 7.5.2.3 D: Acrylate Unit: Large Hole at Esterification Reactor; Pool Fire Distances (m)
Figure 7.5.2.4 A: Acrylate Unit: Instrument Tapping Failure at Esterification Pump; Flash Fire Distances (m)
Figure 7.5.2.4 B: Acrylate Unit: Instrument Tapping Failure at Esterification Pump; Jet Fire Distances (m)
Figure 7.5.2.5 A: Acrylate Unit: Large Hole at Alcohol Receiver; Flash Fire Distances (m)
Figure 7.5.2.5 B: Acrylate Unit: Large Hole at Alcohol Receiver; Jet Fire Distances (m)
Figure 7.5.2.5 C: Acrylate Unit: Large Hole at Alcohol Receiver; Over Pressure Distances (m)
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Figure 7.5.2.6 B: Acrylate Unit: Instrument Tapping Failure at Alcohol Reflux Pump; Jet Fire Distances (m)
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Figure 7.5.2.6 D: Acrylate Unit: Instrument Tapping Failure at Alcohol Reflux Pump; IDLH Concentration Distances (m)
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Figure 7.5.2.7 B: Acrylate Unit: Large Hole at Butyl Acrylate Tank; Jet Fire Distances (m)
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Figure 7.5.2.8 B: Acrylate Unit: Instrument Tapping Failure at Butyl Acrylate Pump Discharge; Jet Fire Distances (m)
Figure 7.5.2.8 C: Acrylate Unit: Instrument Tapping Failure at Butyl Acrylate Pump Discharge; Over Pressure Distances (m)
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Figure 7.5.2.9 B: Acrylate Unit: Instrument Tapping Failure at 2-Ethyl Hexanol Inlet Line; Jet Fire Distances (m)
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Figure 7.5.2.10 A: Acrylate Unit: Large Hole at Esterification reactor; Flash Fire Distances (m)
Figure 7.5.2.10 B: Acrylate Unit: Large Hole at Esterification reactor; Jet Fire Distances (m)
Figure 7.5.2.10 C: Acrylate Unit: Large Hole at Esterification reactor; Over Pressure Distances (m)
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Figure 7.5.2.11 A: Acrylate Unit: Instrument Tapping Failure at Esterification Pump; Flash Fire Distances (m)
Figure 7.5.2.11 B: Acrylate Unit: Instrument Tapping Failure at Esterification Pump; Jet Fire Distances (m)
Figure 7.5.2.11 C: Acrylate Unit: Instrument Tapping Failure at Esterification Pump; Over Pressure Distances (m)
Figure 7.5.2.11 D: Acrylate Unit: Instrument Tapping Failure at Esterification Pump; Pool Fire Distances (m)
Figure 7.5.2.12 A: Acrylate Unit: Large Hole at 2-Ethyl Hexyl Acrylate Tank; Flash Fire Distances (m)
Figure 7.5.2.12 B: Acrylate Unit: Large Hole at 2-Ethyl Hexyl Acrylate Tank; Jet Fire Distances (m)
Figure 7.5.2.12 C: Acrylate Unit: Large Hole at 2-Ethyl Hexyl Acrylate Tank; Pool Fire Distances (m)
Figure 7.5.2.13 A: Acrylate Unit: Instrument Tapping Failure at 2-Ethyl Hexyl Acrylate Pump; Flash Fire Distances (m)
Figure 7.5.2.13 B: Acrylate Unit: Instrument Tapping Failure at 2-Ethyl Hexyl Acrylate Pump; Jet Fire Distances (m)
Figure 7.5.2.13 C: Acrylate Unit: Instrument Tapping Failure at 2-Ethyl Hexyl Acrylate Pump; Pool Fire Distances (m)
3. Oxo Alcohol Unit
Figure 7.5.3.1 A: Oxo Alcohol Unit: Instrument Tapping Failure at Syn Gas Inlet Line; Flash Fire Distances (m)
Figure 7.5.3.1 B: Oxo Alcohol Unit: Instrument Tapping Failure at Syn Gas Inlet Line; Jet Fire Distances (m)
Figure 7.5.3.2 A: Oxo Alcohol Unit: Instrument Tapping Failure at Propylene Inlet Line; Flash Fire Distances (m)
Figure 7.5.3.2 B: Oxo Alcohol Unit: Instrument Tapping Failure at Propylene Inlet Line; Jet Fire Distances (m)
Figure 7.5.3.2 C: Oxo Alcohol Unit: Instrument Tapping Failure at Propylene Inlet Line; Over Pressure Distances (m)
Figure 7.5.3.3 A: Oxo Alcohol Unit: Instrument Tapping Failure at Hydrogen Inlet Line; Flash Fire Distances (m)
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Figure 7.5.3.3 C: Oxo Alcohol Unit: Instrument Tapping Failure at Hydrogen Inlet Line; Over Pressure Distances (m)
Figure 7.5.3.4 A: Oxo Alcohol Unit: Large Hole at I-Butanol Receiver Column; Flash Fire Distances (m)
Figure 7.5.3.4 B: Oxo Alcohol Unit: Large Hole at I-Butanol Receiver Column; Jet Fire Distances (m)
Figure 7.5.3.4 C: Oxo Alcohol Unit: Large Hole at I-Butanol Receiver Column; Over Pressure Distances (m)
Figure 7.5.3.4 D: Oxo Alcohol Unit: Large Hole at 1-Butanol Receiver Column; Pool Fire Distances (m)
Figure 7.5.3.5 A: Oxo Alcohol Unit: Seal Failure at I-Butanol Pump; Flash Fire Distances (m)
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Figure 7.5.3.6 C: Oxo Alcohol Unit: Flange Leakage at N-Butanol Outlet Line; Over Pressure Distances (m)
Figure 7.5.3.6 D: Oxo Alcohol Unit: Flange Leakage at N-Butanol Outlet Line; Pool Fire Distances (m)
Figure 7.5.3.6 E: Oxo Alcohol Unit: Flange Leakage at N-Butanol Outlet Line; IDLH Concentration Distances (m)
Figure 7.5.3.7 A: Oxo Alcohol Unit: Flange Leakage at 2-Ethyl Hexanol Outlet Line; Flash Fire Distances (m)
Figure 7.5.3.7 B: Oxo Alcohol Unit: Flange Leakage at 2-Ethyl Hexanol Outlet Line; Jet Fire Distances (m)
Figure 7.5.3.7 C: Oxo Alcohol Unit: Flange Leakage at 2-Ethyl Hexanol Outlet Line; Over Pressure Distances (m)
Figure 7.5.3.7 D: Oxo Alcohol Unit: Flange Leakage at 2-Ethyl Hexanol Outlet Line; Pool Fire Distances (m)
Figure 7.5.3.8 A: Oxo Alcohol Unit: Large Hole at N-Butyraldehyde Tank; Flash Fire Distances (m)
Figure 7.5.3.8 B: Oxo Alcohol Unit: Large Hole at N-Butyraldehyde Tank; Jet Fire Distances (m)
Figure 7.5.3.8 C: Oxo Alcohol Unit: Large Hole at N-Butyraldehyde Tank; Over Pressure Distances (m)
Figure 7.5.3.8 D: Oxo Alcohol Unit: Large Hole at N-Butyraldehyde Tank; Pool Fire Distances (m)
Figure 7.5.3.9 A: Oxo Alcohol Unit: Large Hole at Mixed Tank; Flash Fire Distances (m)
Figure 7.5.3.9 B: Oxo Alcohol Unit: Large Hole at Mixed Tank; Jet Fire Distances (m)
Figure 7.5.3.9 C: Oxo Alcohol Unit: Large Hole at Mixed Tank; Over Pressure Distances (m)
Figure 7.5.3.9 D: Oxo Alcohol Unit: Large Hole at Mixed Tank; Pool Fire Distances (m)
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Figure 7.5.4.1 C: Lines from Boo/Kochi Refinery: Instrument Tapping failure at Propylene Inlet Line; Over Pressure Distances (m)
Figure 7.5.4.2 A: Lines from Boo/Kochi Refinery: Instrument Tapping failure at Hydrogen Inlet Line; Flash Fire Distances (m)
Figure 7.5.4.2 B: Lines from Boo/Kochi Refinery: Instrument Tapping failure at Hydrogen Inlet Line; Jet Fire Distances (m)
Figure 7.5.4.2 C: Lines from Boo/Kochi Refinery: Instrument Tapping failure at Hydrogen Inlet Line; Over Pressure Distances (m)
Figure 7.5.4.3 A: Lines from Boo/Kochi Refinery: Instrument Tapping failure at Syn Gas Inlet Line; Flash Fire Distances (m)
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5. Offsite Facilities
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Figure 7.5.5.1 B: Offsite: Instrument Tapping Failure at Acrylic Acid Pump; Jet Fire Distances (m)
Figure 7.5.5.1 C: Offsite: Instrument Tapping Failure at Acrylic Acid Pump; Over Pressure Distances (m)
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Figure 7.5.5.2 C: Offsite: Instrument Tapping failure at Butyl Acrylate Pump; Over Pressure Distances (m)
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Figure 7.5.5.3 A: Offsite: Instrument Tapping Failure at N-Butanol Pump; Flash Fire Distances (m)
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Figure 7.5.4 A: Offsite: Loading Arm Failure at Loading Gantry- N-Butanol; Flash Fire Distances (m)
Figure 7.5.5.4 B: Offsite: Loading Arm Failure at Loading Gantry - N-Butanol; Jet Fire Distances (m)
Figure 7.5.5.4 C: Offsite Loading Arm Failure at Loading Gantry- N-Butanol; Over Pressure Distances (m)
Figure 7.5.5.5 A: Offsite: Loading Arm Failure at Loading Gantry - Butyl Acrylate; Flash Fire Distances (m)
Figure 7.5.5.5 B: Offsite: Loading Arm Failure at Loading Gantry - Butyl Acrylate; Jet Fire Distances (m)
Figure 7.5.5.5 C: Offsite: Loading Arm Failure at Loading Gantry - Butyl Acrylate; Over Pressure Distances (m)