RAPID RISK ANALYSIS REPORT
OF
ETHYLENE & STYRENE RECOVERY UNIT

Job. No. A822

Indian Oil Corporation Limited, Panipat

<table>
<thead>
<tr>
<th>Rev No</th>
<th>Date</th>
<th>Purpose</th>
<th>Prepared By</th>
<th>Reviewed By</th>
<th>Approved By</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>15.02.16</td>
<td>Issued as Final</td>
<td>PS</td>
<td>DK</td>
<td>PJK</td>
</tr>
<tr>
<td>A</td>
<td>07.01.16</td>
<td>Issued for Comments</td>
<td>PS</td>
<td>DK</td>
<td>PJK</td>
</tr>
</tbody>
</table>
PREFACE

Engineers India Limited (EIL), New Delhi, has been entrusted by M/s Indian Oil Corporation Limited (IOCL), Panipat to carry out the Rapid Risk Analysis of the facilities i.e Ethylene recovery Unit (ERU) including Styrene Recovery Unit (STRU) and other facilities like Horton Sphere / Mounded Bullet at Panipat Naphtha Cracker.

M/s Indian Oil Corporation Ltd. (IOCL) is India’s largest public corporation in terms of revenue and is one of the five Maharatna status companies of India. M/s IOCL Panipat Refinery was set up in 1998 at Baholi village, Panipat, Haryana. It is the seventh refinery belonging to IOCL and is one of South East Asia’s largest integrated petrochemicals plants.

Rapid Risk Analysis identifies the Hazards associated with the Facility, analyses the Consequences, draws suitable Conclusions and provides necessary Recommendations to mitigate the Hazard/Risk.

This Rapid Risk Analysis 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.
# TABLE OF CONTENTS

1 EXECUTIVE SUMMARY.............................................................................................................. 5  
1.1 INTRODUCTION .................................................................................................................... 5  
1.2 APPROACH METHODOLOGY............................................................................................... 5  
1.3 MAJOR FINDINGS AND RECOMMENDATIONS .................................................................... 6  
2 INTRODUCTION .......................................................................................................................... 10  
2.1 STUDY AIDS AND OBJECTIVE .......................................................................................... 10  
2.2 SCOPE OF WORK .................................................................................................................. 10  
3 SITE CONDITION ...................................................................................................................... 11  
3.1 GENERAL ............................................................................................................................ 11  
3.2 SITE, LOCATION AND VICINITY ....................................................................................... 11  
3.3 METEOROLOGICAL CONDITIONS ..................................................................................... 11  
4 HAZARDS ASSOCIATED WITH THE FACILITIES ............................................................... 15  
4.1 GENERAL ............................................................................................................................ 15  
4.2 HAZARDS ASSOCIATED WITH FLAMMABLE MATERIALS ............................................ 15  
5 HAZARD IDENTIFICATION ..................................................................................................... 17  
5.1 GENERAL ............................................................................................................................ 17  
5.2 MODES OF FAILURE ......................................................................................................... 17  
5.3 SELECTED FAILURE CASES .............................................................................................. 18  
6 CONSEQUENCE ANALYSIS .................................................................................................. 20  
6.1 GENERAL ............................................................................................................................ 20  
6.2 CONSEQUENCE ANALYSIS MODELLING ......................................................................... 20  
6.2.1 DISCHARGE RATE ...................................................................................................... 20  
6.2.2 DISPERSION .................................................................................................................. 20  
6.2.3 FLASH FIRE .................................................................................................................... 20  
6.2.4 JET FIRE ....................................................................................................................... 21  
6.2.5 POOL FIRE ................................................................................................................... 21  
6.2.6 VAPOUR CLOUD EXPLOSION .................................................................................... 21  
6.2.7 FIREBALL ..................................................................................................................... 21  
6.3 SIZE AND DURATION OF RELEASE .................................................................................. 22  
6.4 DAMAGE CRITERIA ............................................................................................................. 22  
6.4.1 LFL OR FLASH FIRE ..................................................................................................... 22  
6.4.2 THERMAL HAZARD DUE TO POOL FIRE, JET FIRE AND FIRE BALL .................... 22  
6.4.3 VAPOUR CLOUD EXPLOSION .................................................................................... 23  
6.5 CONSEQUENCE ANALYSIS FOR NEW PROPOSED UNITS .................................... 24  
6.5.1 ERU ............................................................................................................................... 24  
6.5.2 STRU ............................................................................................................................. 25  
6.5.3 MOUNDED BULLET & SPHERE ................................................................................... 26  
6.5.4 MODIFICATION IN EXISTING REFINERY .................................................................. 28  
6.5.5 MODIFICATION IN NCU .............................................................................................. 28  
7 CONCLUSIONS & RECOMMENDATIONS .............................................................................. 29  
8 GLOSSARY ................................................................................................................................ 33  
9 REFERENCES ............................................................................................................................ 35  

ANNEXURE-I: CONSEQUENCE ANALYSIS HAZARD DISTANCES  
ANNEXURE-II: FIGURES FOR CONSEQUENCE ANALYSIS
# LIST OF TABLES

Table 1: New Proposed Process Facilities under Modification Project..........................................................10
Table 2: Atmospheric Parameter .........................................................................................................................11
Table 3: Average Mean Wind Speed (m/s).............................................................................................................12
Table 4: Pasquill Stability Classes.......................................................................................................................13
Table 5: Weather Conditions..............................................................................................................................14
Table 6: Size of Release.......................................................................................................................................22
Table 7: Damage Due to Incident Thermal Radiation Intensity ...........................................................................23
Table 8: Damage Effects of Blast Overpressure................................................................................................23
1 EXECUTIVE SUMMARY

1.1 INTRODUCTION

Panipat Naphtha Cracker Complex (PNC) of M/s Indian oil Corporation Ltd (IOCL) processes Naphtha to produce Ethylene and Propylene streams for downstream polymer units and pyrolysis gasoline (Pygas) stream as by-product. Presently capacity of the complex is 800 KTPA ethylene with possibility to extend to 1000 KTPA Ethylene production. The Butadiene Extraction unit (BDEU) is producing Butadiene. IOCL under joint venture has Styrene Butadiene Rubber (SBR) plant at the same location. Presently, only Benzene is being recovered from the Hydrogenated Pygas. This Pygas from PNC has good potential of Styrene which in case recovered can be used as feed to the Unit. The recovered Styrene is planned to be supplied on a dedicated basis to the SBR Plant.

Continuing with tradition of value addition & optimization of resources, another unit - Ethylene recovery unit is also being planned to be set up. This unit - Ethylene Recovery Unit (ERU) will extract Ethane & Ethylene from off gas of Panipat Refinery (from FCCU, DCU units) and send them to Naphtha Cracker Unit (NCU) downstream units and thereby increasing profitability of PNC as well as minimizing impact of refinery off gas to environment.

Therefore, IOCL has proposed production of Styrene (20 KTA), Ethylene (18.8 KTA), Ethane (73.6 KTA), Propane (4.9 KTA), Propylene (12.0 KTA) inside Panipat Naphtha Cracker premises with total plot area 14,000 m² (9000 m² for STRU & 5000 m² for ERU including One Horton sphere & One Mounded Bullet for storage of Hydrogenated C4 Mix/C4 Raffinate.

M/s IOCL entrusted the task of carrying out Risk Analysis study to M/s Engineers India Limited (EIL) for obtaining Environmental Clearance. This Executive Summary provides Major Findings and Recommendations arising out of the Rapid Risk Analysis for the proposed modification in existing Facilities at M/s IOCL, Panipat.

1.2 APPROACH METHODOLOGY

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

RRA involves identification of various potential hazards & credible failure scenarios for proposed ERU & STRU including off-site storages & pumping, etc. and modifications in existing Refinery and NCU complex, 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. Catastrophic Rupture of
Pressure Vessels. Effect zones for various outcomes of failure scenarios (Flash Fire, Jet Fire, Pool Fire, Blast overpressure etc.) are studied and identified in terms of distances on plot plan. Based on affect zones, measures for mitigation of the hazard/risk are suggested.

1.3 MAJOR FINDINGS AND RECOMMENDATIONS

Based upon Consequence Analysis (section 6.5), the major Observations arising out of the Consequence Analysis for Proposed Modifications are summarized below:

**Ethylene Recovery Unit**

1. “Instrument Tapping Failure at De-ethaniser Bottom Pump in ERU” (Case no. 6.5.1.1), and “Instrument Tapping Failure at EBR Compressor in ERU” (Case no. 6.5.1.3), has been modeled as a failure scenario for the Risk Analysis. The affect zone of these failure scenario will remain mostly within unit B/L & does not pose any significant Risk on other existing unit, however local impact may damage nearby equipment. (Refer Figure 6.5.1.1.1, 6.5.1.1.2, 6.5.1.1.3, 6.5.1.3.1, 6.5.1.3.2, 6.5.1.3.3)

2. The affect zone of “Catastrophic Rupture of De-ethaniser Reflux Drum in ERU” (Case no. 6.5.1.2) failure scenario in case of thermal radiation intensity of 37.5 kW/m$^2$ will remain limited within unit B/L. In case of Late Ignition Explosion, the Overpressure of 5 psi level will extend up to Substation and reaching beyond North, South side B/L. The results of this scenario may be utilized while formulating/updating of Disaster Management Plan. (Refer Figure 6.5.1.2.1, 6.5.1.2.2, 6.5.1.2.3)

**Styrene Recovery Unit**

3. “Catastrophic Rupture of DWC Feed Surge Drum for STRU” (Case No. 6.5.2.3) may result in late ignition explosion due to which 3 psi Overpressure waves will extend up to substation-1, SRR-1, Benzene/C7-C8 tanks in TF-9, Master Control room, Parking area and some parts of units like NCU & AU. (Refer Figure 6.5.2.3.2). The affect Zone of flash fire may reach up to substation-1, SRR-1, Master Control room & Parking area.

   *It is suggested to locate DWC Feed Surge Drum during detail engineering in such a way that flash fire zone shall not reach up to Master Control Room parking.*

4. The affect zone of “Bottom Nozzle Failure of DWC Column Overhead Receiver for STRU” (Case No. 6.5.2.1) failure scenario in case of thermal radiation intensity of 8.0 kW/m$^2$ due to Jet Fire may reach upto proposed offsite area of Styrene unit. (Refer Figure 6.5.2.1.2).
It is recommended to locate Styrene and Solvent tanks in proposed offsite area of Styrene unit during detail engineering in such a way that effects from thermal radiation of intensity 8.0 kW/m² due to above failure scenario shall not reach up to these tanks.

5. For failure cases like “Instrument Tapping Failure of Reactor Feed Pump for STRU” (Case No. 6.5.2.2), “Flange Gasket Failure of Hydro OVHD Product Separator for STRU” (Case No. 6.5.2.4) & “Instrument Tapping Failure of EDC Reflux Pump for STRU” (Case No. 6.5.2.5), “instrument tapping failure of Styrene Product daily tank pump” (Case No. 6.5.2.6) consequence analysis has been carried out. The 5 psi Overpressure waves due to Late Ignition Explosion may remain within STRU. (Refer Graph 6.5.2.2.3, 6.5.2.4.3, 6.5.2.5.3, 6.5.2.6.3). The affect zone due to flammable impacts like Jet fire and Pool fire, will remain mostly within STRU B/L and may affect nearby equipment. (Refer Graph 6.5.2.2.2, 6.5.2.4.2, 6.5.2.5.2, 6.5.2.6.2 & 6.5.2.6.4).

Mounded Bullets and Sphere

6. The 5 psi Overpressure waves due to Late Ignition Explosion in case of “Instrument Tapping Failure at pump discharge in Mounded bullet pump house” (Case no. 6.5.3.1) affect OC-01 in TF-4. (Refer Graph 6.5.3.1.3). The affect zone due to flammable impacts (Thermal Radiation of 12.5 kW/m²) like Jet fire in this case extend up to OC-01 in TF-4. (Refer Graph No. 6.5.3.1.2).

It is recommended either to relocate OC-01 present in TF-4 in safe location or make blast resistant construction with positive pressurization as per applicable standard.

7. The 5 psi Overpressure waves due to Late Ignition Explosion & thermal radiation of intensity 12.5 kW/m² due to Jet Fire in case of “Flange Gasket Failure at pump discharge in C4 Mix Sphere pump house” (Case no. 6.5.3.3) will be realized in TF-7 & pipe rack in this area which can turn into major hazard if left unchecked. (Refer Graph No. 6.5.3.3.2 & 6.5.3.3.3).

It is recommended to ensure fire proofing of Sphere & pipe rack supports falling in Thermal Radiation of Intensity 12.5 kW/m² affect zone.

8. It is observed that LFL zone will remain within the boundary of IOCL Panipat complex for “Catastrophic Rupture of C4 mix off spec Sphere” (Case No. 6.5.3.2). However, overpressure of 3 psi is reaching 220 Meter outside of east side boundary wall of IOCL, Panipat complex. (Refer graph no. 6.5.3.2.1, 6.5.3.2.2 & 6.5.3.2.3)

It is recommended no permanent habitation up to 220 meter from east side boundary wall of IOCL, Panipat complex.
Panipat Refinery & NCU

9. Flammable and Explosive Scenarios like “Top Nozzle Failure of Refinery Off Gas KOD”, (Case No. 6.5.4.1) and “Flange Gasket Failure of Heat Exchanger”, (Case No. 6.5.5.1) were modeled for Modified section in Refinery area near DCU and NCU respectively, it is observed that the Consequence Outcomes like Late Ignition Explosion (5 psi) as well as Thermal Radiation (12.5 kW/m²) will remain within B/L of specific unit. No significant consequence has been observed in Modified section in Refinery area near DCU and NCU.

a) Recommendations for Construction Safety during execution of Modification Project

✔ Proper Barricading of the proposed unit to be done from live running process units during construction phase. Hydrocarbon detectors to be provided along the barricading to detect any hydrocarbon in vicinity of construction area.

✔ Proper material movement path within the IOCL Panipat Refinery and NCU Complex to be identified during the construction phase of the project.

b) General Recommendations

✔ Cases like catastrophic Rupture are highly unlikely events and pose significant consequence hence their Results should be utilized while formulating/updating of Disaster Management Plan (DMP).

✔ Proper checking of personnel at entry gates for Inflammable materials to be ensured to avoid presence of any unidentified source of ignition.

✔ Safe Escape Route and Access route during high severity situation like catastrophic Rupture and high frequency cases like instrument tapping failure should be identified.

✔ Emergency Mock drills & Fire Drill to be carried out at organization level to ensure preparation of the personnel working in IOCL Panipat Refinery and NCU Complex for handling any emergency situation.

c) General Mitigating Measures

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

✔ Rapid detection of an uncommon event (HC leak, Flame etc.) and alarm arrangement and development of subsequent quick isolation mechanism for major inventory.

✔ Measures for controlling / minimization of Ignition sources inside the IOCL Panipat Refinery and NCU Complex. Active and Passive Fire Protection for critical equipment and major structures.

Content under para C is for guidance.
d) Ignition Control

- Ignition control will reduce the likelihood of fire events. This is the key for reducing the risk within facilities processing flammable materials. As part of mitigation measure it is strongly recommended to consider minimization of the traffic movement within the IOCL Panipat Refinery and NCU Complex (Classification of Roads).

e) Preventive Maintenance for Critical Equipments

- In order to reduce the failure frequency of critical Equipments, the following are recommended:
  - Instrument tapping, small bore tapping and process vessels should be inspected regularly for integrity check. Periodic health check of equipment, instruments and maintenance of all equipment & piping are required to be ensured. Periodic calibration of instruments and testing of alarms, trips, interlocks should be given due attention
  - High head pumps, which are handling Hydrocarbon, are needed to be identified.
    i. Their seals, instruments and accessories are to be monitored closely
    ii. A detailed preventive maintenance plan to be prepared and followed.
  - Surge Drums, Reflux drums and high inventory vessels whose rupture may lead to massive consequences, to be identified and following to be ensured:
    i. Monitoring of vessel internals during shut down.
    ii. A detailed preventive maintenance plan to be prepared and followed.
2 INTRODUCTION

2.1 STUDY AIMS AND OBJECTIVE

The objectives of the Rapid Risk Analysis 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 Rapid 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 Rapid 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 Accidental 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 proposed facilities under Modification Project. It covers the following proposed facilities of M/s IOCL, Panipat Complex:

Table 1: New Proposed Process Facilities under Modification Project

<table>
<thead>
<tr>
<th>S. No.</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>1.</td>
<td>Ethylene Recovery Unit(ERU)</td>
</tr>
<tr>
<td>2.</td>
<td>Styrene Recovery Unit(STRU)</td>
</tr>
<tr>
<td>3.</td>
<td>Mounded Bullets/Sphere</td>
</tr>
</tbody>
</table>
3 SITE CONDITION

3.1 GENERAL

This chapter describes the location of M/s IOCL Panipat Refinery and NCU Complex and Meteorological Data, which have been used for the Rapid Risk Analysis.

3.2 SITE, LOCATION AND VICINITY

The proposed project site for setting up of Styrene Recovery unit (STRU) and Ethylene Recovery unit (ERU) for of M/s IOCL is located at village Baljatan, Tehsil Matlauda, district Panipat in the state of Haryana.

3.3 METEOROLOGICAL CONDITIONS

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

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

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>28</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>56</td>
</tr>
<tr>
<td>4.</td>
<td>Solar Radiation flux (kW/m²)</td>
<td>0.70</td>
</tr>
</tbody>
</table>
Wind Speed and Wind Direction

Based on the Meteorological data provided by IOCL, it is observed that calm weather conditions can be experienced for 22% of the time in a year. Average wind speed of magnitude less than 1 m/s blows for around 34% of the time in a year and wind speed more than 1 m/s blows for 44% of the time. Predominant wind speed for IOCL-Panipat is 2 m/s. The predominant wind direction is from NW and SE directions.

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

<table>
<thead>
<tr>
<th></th>
<th>Jan</th>
<th>Feb</th>
<th>Mar</th>
<th>April</th>
<th>May</th>
<th>June</th>
<th>July</th>
<th>Aug</th>
<th>Sep</th>
<th>Oct</th>
<th>Nov</th>
<th>Dec</th>
</tr>
</thead>
<tbody>
<tr>
<td>N</td>
<td>1.39</td>
<td>1.39</td>
<td>1.54</td>
<td>1.88</td>
<td>2.15</td>
<td>1.97</td>
<td>1.80</td>
<td>1.34</td>
<td>1.26</td>
<td>0.90</td>
<td>0.97</td>
<td>1.09</td>
</tr>
<tr>
<td>D</td>
<td>0.66</td>
<td>0.68</td>
<td>0.71</td>
<td>0.84</td>
<td>1.17</td>
<td>1.44</td>
<td>1.10</td>
<td>0.71</td>
<td>0.66</td>
<td>0.39</td>
<td>0.35</td>
<td>0.48</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. Below Table indicates the various Pasquill stability classes.
Table 4: 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:

Wind speed less than 1 m/s would be experienced for 34% of time in a year. In order to realize the hazardous distances, weather stability of “F” was selected with wind speed 1 m/s & average wind speed of 2 m/s with stability class of “D” was selected. In the present study, the entire range of representative wind speeds and associated wind directions, both during the day and night, and cloud amount have been considered.

The consequence results are reported in tabular form for all the weather conditions and are represented graphically for prevalent weather condition.
Table 5: 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>2</td>
<td>D</td>
</tr>
</tbody>
</table>

Note: For RRA following plot plan has been used.
1. Overall Plot Plan of Naphtha Cracker Complex (Doc. No.: 6556-00-16-47-0001 Rev H)
2. Overall Plot Plan of Panipat Refinery (Doc. No.:6673-LAY-000-LD-0001 Rev 00)
3. Overall Plot Plan of NCU+AU (Doc. No.:6673-LAY-910-LD-0001 Rev 00)
4 HAZARDS ASSOCIATED WITH THE FACILITIES

4.1 GENERAL

Ethylene, Styrene Recovery & offsite Mounded Bullets/Sphere handles a number of hazardous materials like Styrene, C4 Mix, Ethylene which have a potential to cause fire and explosion hazards. This chapter describes in brief the hazards associated with these materials.

4.2 HAZARDS ASSOCIATED WITH FLAMMABLE MATERIALS

STYRENE, ETHYLENE & C4 Mix

The major hazards from these types of hydrocarbons are fire and radiation. Any spillage or loss of containment of heavier hydrocarbons may create a highly flammable pool of liquid around the source of release.

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 at temperatures near boiling points would lead to formation of pools and then pool fire.

Vapors may be ignited rapidly when exposed to heat, spark, open flame or other source of ignition. When mixed with air and exposed to an ignition source, flammable vapors can burn in the open or explode in confined spaces. Being heavier than air, vapors may travel long distances to an ignition source and flash back. Runoff to sewer may cause fire or explosion hazard. Refer to below table for properties of these Hydrocarbons.

<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>6.1</td>
</tr>
<tr>
<td>3.</td>
<td>Auto ignition temperature (°C)</td>
<td>490</td>
</tr>
<tr>
<td>4.</td>
<td>Normal Boiling point (°C)</td>
<td>145.2</td>
</tr>
<tr>
<td>5.</td>
<td>Heat of combustion (Kj/mol)</td>
<td>4219000</td>
</tr>
</tbody>
</table>

Template No. 5-0000-0001-T2 Rev. 2 28.11.14  
Copyrights EIL  All rights reserved
### Ethylene

<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>2.3</td>
</tr>
<tr>
<td>2.</td>
<td>UFL (%v/v)</td>
<td>3.2</td>
</tr>
<tr>
<td>3.</td>
<td>Auto ignition temperature (°C)</td>
<td>450</td>
</tr>
<tr>
<td>4.</td>
<td>Normal Boiling point (°C)</td>
<td>-104</td>
</tr>
<tr>
<td>5.</td>
<td>Heat of combustion (Kj/mol)</td>
<td>1323000</td>
</tr>
</tbody>
</table>

### C4 Mix

<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</td>
</tr>
<tr>
<td>3.</td>
<td>Normal Boiling point (°C)</td>
<td>-4.5</td>
</tr>
<tr>
<td>4.</td>
<td>Heat of combustion (Kj/mol)</td>
<td>2521000</td>
</tr>
</tbody>
</table>
5 HAZARD IDENTIFICATION

5.1 GENERAL

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

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

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

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

5.2 MODES OF FAILURE

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

Material/Construction Defects

- Incorrect selection or supply of materials of construction
- Incorrect use of design codes
- Weld failures
- Failure of inadequate pipeline supports
Pre-Operational Failures
- Failure induced during delivery at site
- Failure induced during installation
- Pressure and temperature effects
- Overpressure
- Temperature expansion/contraction (improper stress analysis and support design)
- Low temperature brittle fracture (if metallurgy is incorrect)
- Fatigue loading (cycling and mechanical vibration)

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

Failures due to Operational Errors
- Human error
- Failure to inspect regularly and identify any defects

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

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

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

- Cases with high chance of occurrence but having low consequence: Example of such failure cases includes two-bolt gasket leak for flanges, seal failure for pumps, instrument tapping failure, etc. The consequence results will provide enough data for planning routine safety exercises. This will emphasize the area where operator’s vigilance is essential.

- Cases with low chance of occurrence but having high consequence (The example includes Large hole on the outlet of Pressure vessels, Catastrophic Rupture 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 ERU, STRU & Mounded Bullets/Sphere. Although the list does not give complete failure incidents considering all equipment's, units, but the consequence of a similar incident considered in the list below could be used to foresee the consequence of that particular accident.

For selected credible failure scenarios and likely consequences (Hazard Distances due to Flammable and Explosive Accidents) for proposed Facilities of M/s IOCL, Panipat, refer Section-6.

<table>
<thead>
<tr>
<th>S. No.</th>
<th>Details of Failure Case Selected</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Unit: ERU</strong></td>
<td></td>
</tr>
<tr>
<td>1.</td>
<td>Instrument Tapping Failure De-ethaniser Bottom Pump discharge line</td>
</tr>
<tr>
<td>2.</td>
<td>Catastrophic Rupture of De-ethaniser Reflux Drum</td>
</tr>
<tr>
<td>3.</td>
<td>Instrument Tapping Failure at EBR Compressor</td>
</tr>
<tr>
<td><strong>Unit: STRU</strong></td>
<td></td>
</tr>
<tr>
<td>4.</td>
<td>Bottom Nozzle Failure of DW Column Overhead Receiver</td>
</tr>
<tr>
<td>5.</td>
<td>Instrument Tapping Failure at Reactor Feed Pump Discharge line</td>
</tr>
<tr>
<td>6.</td>
<td>Catastrophic Rupture DWC Feed Surge Drum</td>
</tr>
<tr>
<td>7.</td>
<td>Flange Gasket Failure of Hydro overhead product Separator</td>
</tr>
<tr>
<td>8.</td>
<td>Instrument Tapping Failure at EDC Reflux Pump</td>
</tr>
<tr>
<td>9.</td>
<td>Instrument tapping failure of Styrene product daily tank pump (P-220A/B)</td>
</tr>
<tr>
<td><strong>Unit: Mounded Bullet and Sphere</strong></td>
<td></td>
</tr>
<tr>
<td>10.</td>
<td>Instrument Tapping Failure at Mounded Bullet Pump discharge line at pump house</td>
</tr>
<tr>
<td>11.</td>
<td>Catastrophic Rupture of C4 mix off spec Sphere</td>
</tr>
<tr>
<td>12.</td>
<td>Flange Gasket Failure at Pump discharge line at Sphere Pump house</td>
</tr>
<tr>
<td><strong>Unit: ERU at PR</strong></td>
<td></td>
</tr>
<tr>
<td>13.</td>
<td>Top Nozzle Failure at Refinery off gas KOD(17-V-9001)</td>
</tr>
<tr>
<td><strong>Unit: NCU</strong></td>
<td></td>
</tr>
<tr>
<td>14.</td>
<td>Flange Gasket Failure at Heat exchanger(11-E-1303) Tube side</td>
</tr>
</tbody>
</table>
6 CONSEQUENCE ANALYSIS

6.1 GENERAL

Consequence analysis involves the application of the mathematical, analytical and computer models for calculation of the effects and damages subsequent to a hydrocarbon / toxic release accident. Computer models are used to predict the physical behavior of hazardous incidents. The model uses below mentioned techniques to assess the consequences of identified scenarios:

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

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

6.2 CONSEQUENCE ANALYSIS MODELLING

6.2.1 DISCHARGE RATE

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

6.2.2 DISPERSION

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

6.2.3 FLASH FIRE

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

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

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

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

6.2.7 FIREBALL
A fire, burning sufficiently rapidly for the burning mass to rise into air as cloud or ball. The Thermal radiation output from a fireball is characterized in terms of the fraction of combustion energy released through radiation, emissive power, view factor and its dependence on the release pressure.
6.3 SIZE AND DURATION OF RELEASE

Leak size considered for selected failure cases are listed below.

Table 6: 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 in the Piping</td>
<td>50 mm, complete rupture of 2&quot; drain line at the pressure vessel outlet</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 and initiate control actions. However credit for adequate safeguards is also considered wherever required like any interlock, automatic tripping of pump/compressor, gas detector, any other detection devices if provided.

6.4 DAMAGE CRITERIA

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

6.4.1 LFL OR FLASH FIRE

Hydrocarbon vapor released accidentally will spread out in the direction of wind. If a source of ignition finds an ignition source before being dispersed below lower flammability limit (LFL), a flash fire is likely to occur and the flame will travel back to the source of leak. Any person caught in the flash fire is likely to suffer fatal burn injury. Therefore, in consequence analysis, the distance of LFL value is usually taken to indicate the area, which may be affected by the flash fire. Flash fire (LFL) events are considered to cause direct harm to the population present within the flammability range of the cloud. Fire escalation from flash fire such that process or storage equipment or building may be affected is considered unlikely.

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

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

---

1 Release duration is based on Chemical Process Quantitative Risk Analysis, CCPS.
Table 7: 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, 12.5 kW/m², and 4 kW/m² radiation levels, selected based on their effect on population, buildings and equipment were modeled using PHAST 6.7.

6.4.3 VAPOR CLOUD EXPLOSION

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

Table 8: Damage Effects of Blast Overpressure

<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>2.0</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 6.7.
6.5 CONSEQUENCE ANALYSIS FOR NEW PROPOSED UNITS

This section discusses the consequences of selected failure scenarios for modifications under ERU & STRU Project whose affect zones pose significant consequence and subsequent Risk on Facility. The consequence distances are reported in tabular form for all weather conditions in Annexure-I. The consequences has been analyzed and represented graphically in Annexure-II for the prevalent weather condition.

6.5.1 ERU

NOTE: Refer Figures 6.5.1.1.1 to 6.5.1.3.3 in Annexure-II

6.5.1.1 Instrument Tapping Failure of De-ethaniser Bottom Pump: From the Consequence Analysis, it can be observed that LFL shall be travelling up to a distance of 41 m. The Jet Fire radiation intensity of 4, 12.5 & 37.5 kW/m² would extend up to a distance of 60 m, 48 & 41 m respectively. The 2, 3 & 5 psi blast overpressures distance shall extend up to a distance of 57 m, 53 m & 49 m respectively.

Based upon the hazard distances it may be observed that hazardous affect zones for the selected failure scenario shall not be extending beyond the B/L’s of the unit and may cause damage to the nearby equipment & Substation. (Refer graph no. 6.5.1.1.1, 6.5.1.1.2 & 6.5.1.1.3)

6.5.1.2 Catastrophic Rupture of De-ethaniser Reflux Drum: From the Consequence Analysis, it can be concluded that LFL may be extended up to a distance of 26 m. The Fireball radiation intensity of 4, 12.5 & 37.5 kW/m² would extend up to a distance of 240 m, 127 & 41 m respectively. The 2, 3 & 5 psi blast overpressures wave will travel up to a distance of 122 m, 99 m & 77 m respectively.

By analyzing the above results, it can be observed that thermal radiation distances of 37.5 kW/m² will remain with B/L of this unit. The 5 psi blast overpressure is extending beyond the North, South side B/L’s & may cause damage to the nearby equipment & Substation. (Refer graph no. 6.5.1.2.1, 6.5.1.2.2 & 6.5.1.2.3)

6.5.1.3 Instrument Tapping Failure at EBR Compressor: From the Consequence Analysis, it can be concluded that LFL may be extended up to a distance of 17 m. The Jet Fire radiation intensity of 4, 12.5 k & 37.5 W/m² would extend up to a distance of 37 m, 30 m & 25 m respectively. The 2, 3 & 5 psi blast overpressures wave would travel up to a distance of 17 m, 15 m & 14 m respectively.
Based upon the hazard distances it may be observed that hazardous affect zones for the selected failure scenario shall not be extending beyond the B/L’s of the unit and may cause damage to the nearby equipment. (Refer graph no. 6.5.1.3.1, 6.5.1.3.2 & 6.5.1.3.3)

6.5.2 STRU

NOTE: Refer Figures 6.5.2.1.1 to 6.5.2.6.4 in Annexure-II

6.5.2.1 Bottom Nozzle Failure of DWC Column Overhead Receiver: From the consequence analysis of the selected failure scenario it is observed that LFL hazard distance is extended up to 60 m. The Jet Fire Radiation Intensity of 4, 12.5 & 37.5 kW/m2 would extend up to a distance of 111 m, 86 m & 71 m respectively. The 2, 3 & 5 psi blast overpressure waves travel up to a distance of 90 m, 83 m & 77 m respectively.

Based upon the hazard distances it may be observed that LFL & overpressure of magnitude of 5 psi affect zones for the selected failure scenario is extending beyond the West side B/L’s of the unit and South side access to STRU. The thermal radiation of intensity 8.0 kW/m2 is reaching up to proposed Styrene offsite area. (Refer graph no. 6.5.2.1.1, 6.5.2.1.2 & 6.5.2.1.3)

6.5.2.2 Instrument Tapping Failure of Reactor Feed Pump: From the consequence analysis of the selected failure scenario it is observed that LFL hazard distance is extended up to 30 m. The Jet Fire Radiation Intensity of 4, 12.5 & 37.5 kW/m2 would extend up to a distance of 53 m, 41 m & 35 m respectively. The 2, 3 & 5 psi blast overpressure waves travel up to a distance of 43 m, 40 m & 38 m respectively.

Based upon the hazard distances it may be observed that hazardous affect zones for the selected failure scenario shall not be extending beyond the B/L’s of the unit and may cause damage to the nearby equipment. (Refer graph no. 6.5.2.2.1, 6.5.2.2.2 & 6.5.2.2.3)

6.5.2.3 Catastrophic Rupture of DWC Feed Surge Drum: From the consequence analysis of the selected failure scenario it is observed that LFL hazard distance is extended up to 142 m. The 2, 3 & 5 psi blast overpressure waves travel up to a distance of 229 m, 198 m & 180 m respectively.

Based upon the hazard distances it may be observed that hazardous affect zones (LFL) for the selected failure scenario shall be extending beyond the West and South side of B/L’s of the unit and may reach up to Substation-1,SRR-1 & parking of Master control room. The hazard distance due to overpressure of magnitude of 3 psi is reaching upto Benzene/C7-C8 tanks in TF-9,SRR-1,S/S-1,Master control room & some parts of units like NCU,AU. (Refer graph no. 6.5.2.3.1 & 6.5.2.3.2).
6.5.2.4 Flange Gasket Failure of Hydro OVHD Product Separator: From the consequence analysis of the selected failure scenario it is observed that LFL hazard distance is extended up to 14 m. The Jet Fire Radiation Intensity of 4, 8 & 12.5 would extend up to a distance of 29 m, 24 m & 21 m respectively. The 2, 3 & 5 psi blast overpressure waves travel up to a distance of 18 m, 16 m & 15 m respectively.

Based upon the hazard distances it may be observed that hazardous affect zones for the selected failure scenario shall not be extending beyond the B/L’s of the unit and may cause damage to the nearby equipment. (Refer graph no. 6.5.2.4.1, 6.5.2.4.2 & 6.5.2.4.3).

6.5.2.5 Instrument Tapping Failure of EDC Reflux Pump: From the consequence analysis of the selected failure scenario it is observed that LFL hazard distance is extended up to 31 m. The Jet Fire Radiation Intensity of 4, 8, 12.5 & 37.5 kW/m\(^2\) would extend up to a distance of 53 m, 46 m, 42 m & 35 m respectively. The 2, 3 & 5 psi blast overpressure waves travel up to a distance of 44 m, 41 m & 38 m respectively.

Based upon the hazard distances it may be observed that hazardous affect zones for the selected failure scenario shall be extending beyond the South side of B/L’s of the unit and may cause damage to the nearby equipment. (Refer graph no. 6.5.2.5.1, 6.5.2.5.2 & 6.5.2.5.3).

6.5.2.6 Instrument Tapping Failure of Styrene Product daily tank Pump: It is observed from the consequence analysis of the selected failure scenario that LFL hazard distance is extended up to 17 m. The Jet Fire Radiation Intensity of 4, 8, 12.5 & 37.5 kW/m\(^2\) would extend up to a distance of 30 m, 26 m, 24 m & 19 m respectively. The Late Pool Fire Radiation Intensity of 4, 8, 12.5 & 37.5 kW/m\(^2\) would extend up to a distance of 33 m, 25 m, 20 m & 9 m respectively. The 2, 3 & 5 psi blast overpressure waves travel up to a distance of 16 m, 15 m & 14 m respectively.

Based upon the hazard distances it may be observed that hazardous affect zones for the selected failure scenario shall be reaching up to East side access road and may cause damage to the nearby equipment. (Refer graph no. 6.5.2.6.1, 6.5.2.6.2, 6.5.2.6.3 & 6.5.2.6.4).

6.5.3 MOUNDED BULLET & SPHERE

NOTE: Refer Figures 6.5.3.1.1 to 6.5.3.3.3 in Annexure- II

6.5.3.1 Instrument Tapping Failure at pump discharge at Mounded bullet pump house: From the Consequence results, it can be observed that LFL may be extended up to a distance of 51 m. The Thermal radiation distance due to jet fire of radiation Intensity of 4, 12.5 & 37.5 kW/m\(^2\) can
extend up to a distance of 69 m, 55 m & 46 m respectively. The over pressure distances due to late ignition explosion of 2,3 & 5 psi blast wave may reach up to a distance of 71 m, 66 m & 62 m.

Based on consequence analysis of failure scenario it could be realized that hazardous zone may cross the West side B/L’s of the mounded bullet pump house, reach up to the hydrogenated C4 mounded bullet, North, South, West side access and may damage West side Operator Cabin (OC-1) in TF4, and nearby equipment (due to flammable and explosive impacts). The mounded bullets are quite safe and do not pose major risk as it provides intrinsically passive and safe environment and eliminates the possibility of Boiling Liquid Expanding Vapor Explosion (BLEVE). The cover of the mound protects the vessel from fire engulfment, radiation from a fire in close proximity. (Refer graph no. 6.5.3.1.1, 6.5.3.1.2, 6.5.3.1.3)

**6.5.3.2 Catastrophic Rupture of C4 mix Off Spec Sphere**: From the Consequence results, it can be observed that LFL may be extended up to a distance of 475 m. The Thermal radiation distance due to Fireball of radiation Intensity of 4 & 12.5 kW/m² can extend up to a distance of 1090 m, & 559 m respectively. The over pressure distances due to late ignition explosion of 2,3 & 5 psi blast wave may reach up to a distance of 839 m, 700 m & 627 m.

Based on Consequence Analysis, the LFL zone is not extending beyond B/L of the IOC Panipat Complex. The overpressure 3 psi is reaching beyond the boundary wall of IOC Panipat Complex. The probability of realization of this event is very less and hence the results so obtained may be referred as guideline for preparing Disaster Management plan. (Refer graph no. 6.5.3.2.1, 6.5.3.2.2, 6.5.3.2.3).

**6.5.3.3 Flange Gasket Failure of pump discharge at Sphere Area**: From the Consequence results of the selected failure scenario it can be observed that LFL may be extended up to a distance of 20 m. The Thermal radiation distance due to Jet fire of radiation Intensity of 4, 12.5 & 37.5 kW/m² can extend up to a distance of 30 m, 29 m & 24 m respectively. The over pressure distances due to late ignition explosion of 2,3 & 5 psi blast wave may reach up to a distance of 29 m, 27 m & 25 m respectively.

Based upon the hazard distances it may be observed that hazardous affect zones for the selected failure scenario shall be extending beyond the B/L’s of the Sphere pump-house, East side access and may cause damage to the nearby equipment & East side pipe rack. (Refer graph no. 6.5.3.3.1, 6.5.3.3.2 & 6.5.3.3.3).
6.5.4 MODIFICATION IN EXISTING REFINERY

6.5.4.1 Top Nozzle Failure of Refinery Off gas KOD: From the Consequence results of the selected failure scenario it can be observed that LFL may be extended up to a distance of 26 m. The Thermal radiation distance due to Jet Fire of radiation Intensity of 4 & 12.5 kW/m² can extend up to a distance of 30 m & 22m respectively. The over pressure distances due to late ignition explosion of 2,3 & 5 psi blast wave may reach up to a distance of 31 m, 28 m & 26 m respectively.

Based on consequence analysis of failure scenario it could be realized that hazardous zone is crossing the B/L’s of the new ERU-Amine Area. As per figure 6.5.4.1.3, the over pressure distance of 5 Psi level is crossing the B/L’s of the new ERU-Amine Area & may cause damage to the nearby equipment. As per figure 6.5.4.1.2 the Jet fire thermal distances of radiation Intensity of 12.5 kW/m² crossing the B/L’s of the new ERU-Amine Area. (Refer graph no. 6.5.4.1.1, 6.5.4.1.2 & 6.5.4.1.3).

6.5.5 MODIFICATION IN NCU

6.5.5.1 Flange Gasket Failure of Heat Exchanger: From the Consequence results of the selected failure scenario it can be observed that LFL may be extended up to a distance of 4 m. The Thermal radiation distance due to Jet fire radiation Intensity of 4 kW/m² can extend up to a distance of 8 m.

Based on consequence analysis of failure scenario it could be realized that hazardous zone may not cross the B/L’s of the unit. (Refer graph no. 6.5.5.1.1 & 6.5.5.1.2).
7 CONCLUSIONS & RECOMMENDATIONS

The detailed consequence analysis of release of inventory in case of failure scenarios has been modeled in terms of Release Rate, Dispersion, Flammability and Explosive characteristics, which have been discussed in detail in this Report. Based upon Consequence Analysis (section 6.5), the major Observations arising out of the Consequence Analysis for Proposed Modifications are summarized below:

Ethylene Recovery Unit

1. “Instrument Tapping Failure at De-ethaniser Bottom Pump in ERU” (Case no. 6.5.1.1), and “Instrument Tapping Failure at EBR Compressor in ERU” (Case no. 6.5.1.3), has been modeled as a failure scenario for the Risk Analysis. The affect zone of these failure scenario will remain mostly within unit B/L & does not pose any significant Risk on other existing unit, however local impact may damage nearby equipment. (Refer Figure 6.5.1.1.1, 6.5.1.1.2, 6.5.1.1.3, 6.5.1.3.1, 6.5.1.3.2, 6.5.1.3.3)

2. The affect zone of “Catastrophic Rupture of De-ethaniser Reflux Drum in ERU” (Case no. 6.5.1.2) failure scenario in case of thermal radiation intensity of 37.5 kW/m² will remain limited within unit B/L. In case of Late Ignition Explosion, the Overpressure of 5 psi level will extend up to Substation and reaching beyond North, South side B/L. The results of this scenario may be utilized while formulating/updating of Disaster Management Plan. (Refer Figure 6.5.1.2.1, 6.5.1.2.2, 6.5.1.2.3)

Styrene Recovery Unit

3. “Catastrophic Rupture of DWC Feed Surge Drum for STRU” (Case No. 6.5.2.3) may result in late ignition explosion due to which 3 psi Overpressure waves will extend up to substation-1, SRR-1, Benzene/C7-C8 tanks in TF-9, Master Control room, Parking area and some parts of units like NCU & AU. (Refer Figure 6.5.2.3.2). The affect Zone of flash fire may reach up to substation-1, SRR-1, Master Control room & Parking area.

   It is suggested to locate DWC Feed Surge Drum during detail engineering in such a way that flash fire zone shall not reach up to Master Control Room parking.

4. The affect zone of “Bottom Nozzle Failure of DWC Column Overhead Receiver for STRU” (Case No. 6.5.2.1) failure scenario in case of thermal radiation intensity of 8.0 kW/m² due to Jet Fire may reach upto proposed offsite area of Styrene unit. (Refer Figure 6.5.2.1.2).
It is recommended to locate Styrene and Solvent tanks in proposed offsite area of Styrene unit during detail engineering in such a way that effects from thermal radiation of intensity 8.0 kW/m² due to above failure scenario shall not reach up to these tanks.

5. For failure cases like “Instrument Tapping Failure of Reactor Feed Pump for STRU” (Case No. 6.5.2.2), “Flange Gasket Failure of Hydro OVHD Product Separator for STRU” (Case No. 6.5.2.4) & “Instrument Tapping Failure of EDC Reflux Pump for STRU” (Case No. 6.5.2.5), “instrument tapping failure of Styrene Product daily tank pump” (Case No. 6.5.2.6) consequence analysis has been carried out. The 5 psi Overpressure waves due to Late Ignition Explosion may remain within STRU. (Refer Graph 6.5.2.2.3, 6.5.2.4.3, 6.5.2.5.3, 6.5.2.6.3). The affect zone due to flammable impacts like Jet fire and Pool fire, will remain mostly within STRU B/L and may affect nearby equipment. (Refer Graph 6.5.2.2.2, 6.5.2.4.2, 6.5.2.5.2, 6.5.2.6.2 & 6.5.2.6.4).

**Mounded Bullets and Sphere**

6. The 5 psi Overpressure waves due to Late Ignition Explosion in case of “Instrument Tapping Failure at pump discharge in Mounded bullet pump house” (Case no. 6.5.3.1) affect OC-01 in TF-4. (Refer Graph 6.5.3.1.3). The affect zone due to flammable impacts (Thermal Radiation of 12.5 kW/m²) like Jet fire in this case extend up to OC-01 in TF-4. (Refer Graph No. 6.5.3.1.2).

> It is recommended either to relocate OC-01 present in TF-4 in safe location or make blast resistant construction with positive pressurization as per applicable standard.

7. The 5 psi Overpressure waves due to Late Ignition Explosion & thermal radiation of intensity 12.5 kW/m² due to Jet Fire in case of “Flange Gasket Failure at pump discharge in C4 Mix Sphere pump house” (Case no. 6.5.3.3) will be realized in TF-7 & pipe rack in this area which can turn into major hazard if left unchecked. (Refer Graph No. 6.5.3.3.2 & 6.5.3.3.3).

> It is recommended to ensure fire proofing of Sphere & pipe rack supports falling in Thermal Radiation of Intensity 12.5 kW/m² affect zone.

8. It is observed that LFL zone will remain within the boundary of IOCL Panipat complex for “Catastrophic Rupture of C4 mix off spec Sphere” (Case No. 6.5.3.2). However, overpressure of 3 psi is reaching 220 Meter outside of east side boundary wall of IOCL, Panipat complex. (Refer graph no. 6.5.3.2.1, 6.5.3.2.2 & 6.5.3.2.3)

> It is recommended no permanent habitation up to 220 meter from east side boundary wall of IOCL, Panipat complex.
Panipat Refinery & NCU

9. Flammable and Explosive Scenarios like “Top Nozzle Failure of Refinery Off Gas KOD”, (Case No. 6.5.4.1) and “Flange Gasket Failure of Heat Exchanger”, (Case No. 6.5.5.1) were modeled for Modified section in Refinery area near DCU and NCU respectively, it is observed that the Consequence Outcomes like Late Ignition Explosion (5 psi) as well as Thermal Radiation (12.5 kW/m²) will remain within B/L of specific unit. No significant consequence has been observed in Modified section in Refinery area near DCU and NCU.

a) Recommendations for Construction Safety during execution of Modification Project

✓ Proper Barricading of the proposed unit to be done from live running process units during construction phase. Hydrocarbon detectors to be provided along the barricading to detect any hydrocarbon in vicinity of construction area.

✓ Proper material movement path within the IOCL Panipat Refinery and NCU Complex to be identified during the construction phase of the project.

b) General Recommendations

✓ Cases like catastrophic Rupture are highly unlikely events and pose significant consequence hence their Results should be utilized while formulating/updating of Disaster Management plan (DMP).

✓ Proper checking of personnel at entry gates for Inflammable materials to be ensured to avoid presence of any unidentified source of ignition.

✓ Safe Escape Route and Access route during high severity situation like catastrophic Rupture and high frequency cases like instrument tapping failure should be identified

✓ Emergency Mock drills & Fire Drill to be carried out at organization level to ensure preparation of the personnel working in IOCL Panipat Refinery and NCU Complex for handling any emergency situation.

c) General Mitigating Measures

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

✓ Rapid detection of an uncommon event (HC leak, Flame etc.) and alarm arrangement and development of subsequent quick isolation mechanism for major inventory.

✓ Measures for controlling / minimization of Ignition sources inside the IOCL Panipat Refinery and NCU Complex. Active and Passive Fire Protection for critical equipment and major structures.
Content under para C is for guidance.

d) Ignition Control

✓ Ignition control will reduce the likelihood of fire events. This is the key for reducing the risk within facilities processing flammable materials. As part of mitigation measure it is strongly recommended to consider minimization of the traffic movement within the IOCL Panipat Refinery and NCU Complex (Classification of Roads).

e) Preventive Maintenance for Critical Equipments

✓ In order to reduce the failure frequency of critical Equipments, the following are recommended:

- Instrument tapping, small bore tapping and process vessels should be inspected regularly for integrity check. Periodic health check of equipment, instruments and maintenance of all equipment & piping are required to be ensured. Periodic calibration of instruments and testing of alarms, trips, interlocks should be given due attention

- High head pumps, which are handling Hydrocarbon, are needed to be identified.
  - Their seals, instruments and accessories are to be monitored closely
  - A detailed preventive maintenance plan to be prepared and followed.

- Surge Drums , Reflux drums and high inventory vessels whose rupture may lead to massive consequences , to be identified and following to be ensured:
  - Monitoring of vessel internals during shut down.
  - A detailed preventive maintenance plan to be prepared and followed.
8 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).
<table>
<thead>
<tr>
<th><strong>PASQUILL CLASS</strong></th>
<th>Classification to qualify the stability of the atmosphere, indicated by a letter ranging from A, for very unstable, to F, for stable.</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>FREQUENCY</strong></td>
<td>The number of times an outcome is expected to occur in a given period of time.</td>
</tr>
</tbody>
</table>
9 REFERENCES

2. AICHE, CCPS, Chemical process Quantitative Risk Analysis
4. IS: 15656
5. IMD Table
Annexure-I

Consequence Analysis Summary Result
### Consequence Analysis Summary Result for IOCL ERU & STRU Project

<table>
<thead>
<tr>
<th>Unit</th>
<th>S.No</th>
<th>Equipment</th>
<th>Failure Case</th>
<th>Operating Condition</th>
<th>Weather Condition</th>
<th>LFL</th>
<th>Weather Temp (°C)</th>
<th>Jet Fire (KW/M²)</th>
<th>Pool Fire (KW/M²)</th>
<th>Fire Ball (KW/M²)</th>
<th>Over Pressure (PSI)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Ethylene Recovery Unit</td>
<td>1</td>
<td>Deethanizer bottom Pump (17-P-9104A/B)</td>
<td>Instrument tapping failure</td>
<td>-16</td>
<td>23.54</td>
<td>1F</td>
<td></td>
<td>43</td>
<td>53</td>
<td>12.5</td>
<td>58</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>2D</td>
<td></td>
<td>41</td>
<td>48</td>
<td>12.5</td>
<td>57</td>
</tr>
<tr>
<td></td>
<td>2</td>
<td>Deethanizer reflux Drum (17-V-9104)</td>
<td>Catastrophic Rupture</td>
<td>-12.7</td>
<td>18.6</td>
<td>1F</td>
<td></td>
<td>22</td>
<td></td>
<td></td>
<td>124</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>2D</td>
<td></td>
<td>26</td>
<td>127</td>
<td>122</td>
<td>99</td>
</tr>
<tr>
<td></td>
<td>3</td>
<td>EBR Compressor (17-K-9201)</td>
<td>Instrument tapping failure</td>
<td>85.4</td>
<td>30.3</td>
<td>1F</td>
<td></td>
<td>19</td>
<td>33</td>
<td>28</td>
<td>17</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>2D</td>
<td></td>
<td>17</td>
<td>30</td>
<td>25</td>
<td>17</td>
</tr>
<tr>
<td></td>
<td>4</td>
<td>DWC Column OVHD Receiver (D-101)</td>
<td>Bottom Nozzle failure</td>
<td>150</td>
<td>3.5</td>
<td>1F</td>
<td></td>
<td>70</td>
<td>118</td>
<td>94</td>
<td>104</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>2D</td>
<td></td>
<td>60</td>
<td>111</td>
<td>94</td>
<td>90</td>
</tr>
<tr>
<td></td>
<td>5</td>
<td>Reactor Feed pump (P-103A/B)</td>
<td>Instrument tapping failure</td>
<td>150</td>
<td>6.5</td>
<td>1F</td>
<td></td>
<td>32</td>
<td>56</td>
<td>45</td>
<td>45</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>2D</td>
<td></td>
<td>30</td>
<td>53</td>
<td>41</td>
<td>43</td>
</tr>
<tr>
<td></td>
<td>6</td>
<td>DWC Feed Surge Drum (D-103)</td>
<td>Catastrophic Rupture</td>
<td>100</td>
<td>3.5</td>
<td>1F</td>
<td></td>
<td>100</td>
<td></td>
<td></td>
<td>231</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>2D</td>
<td></td>
<td>142</td>
<td></td>
<td></td>
<td>229</td>
</tr>
<tr>
<td></td>
<td>7</td>
<td>Hydro OVHD Product Separator (D-201)</td>
<td>Flange Gasket failure</td>
<td>100</td>
<td>3.5</td>
<td>1F</td>
<td></td>
<td>16</td>
<td>31</td>
<td>23</td>
<td>18</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>2D</td>
<td></td>
<td>14</td>
<td>29</td>
<td>21</td>
<td>18</td>
</tr>
<tr>
<td></td>
<td>8</td>
<td>EDC reflux pump (P-202A/B)</td>
<td>Instrument tapping failure</td>
<td>150</td>
<td>7.3</td>
<td>1F</td>
<td></td>
<td>33</td>
<td>57</td>
<td>50</td>
<td>45</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>2D</td>
<td></td>
<td>31</td>
<td>43</td>
<td>46</td>
<td>44</td>
</tr>
<tr>
<td></td>
<td>9</td>
<td>Styrene Product Daily Tank Pump (P-220 A/B)</td>
<td>Instrument tapping failure</td>
<td>65</td>
<td>1.9</td>
<td>1F</td>
<td></td>
<td>25</td>
<td>32</td>
<td>28</td>
<td>30</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>2D</td>
<td></td>
<td>17</td>
<td>30</td>
<td>24</td>
<td>16</td>
</tr>
<tr>
<td></td>
<td>10</td>
<td>Pump Discharge in Mounded bullet Pump House</td>
<td>Instrument tapping failure</td>
<td>41</td>
<td>17</td>
<td>1F</td>
<td></td>
<td>56</td>
<td>74</td>
<td>59</td>
<td>74</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>2D</td>
<td></td>
<td>51</td>
<td>69</td>
<td>55</td>
<td>71</td>
</tr>
<tr>
<td></td>
<td>11</td>
<td>C4 Mix Offspec Sphere</td>
<td>Catastrophic Rupture</td>
<td>43</td>
<td>4</td>
<td>1F</td>
<td></td>
<td>411</td>
<td></td>
<td></td>
<td>1090</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>2D</td>
<td></td>
<td>475</td>
<td></td>
<td></td>
<td>1090</td>
</tr>
<tr>
<td></td>
<td>12</td>
<td>Pump Discharge in Sphere Area</td>
<td>Flange Gasket failure</td>
<td>41</td>
<td>17</td>
<td>1F</td>
<td></td>
<td>23</td>
<td>39</td>
<td>32</td>
<td>31</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>2D</td>
<td></td>
<td>20</td>
<td>30</td>
<td>29</td>
<td>29</td>
</tr>
<tr>
<td></td>
<td>13</td>
<td>Refinery Offgas KOD (17-V-9001)</td>
<td>Top Nozzle Failure</td>
<td>40</td>
<td>11.5</td>
<td>1F</td>
<td></td>
<td>30</td>
<td>30</td>
<td>22</td>
<td>42</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>2D</td>
<td></td>
<td>26</td>
<td>30</td>
<td>22</td>
<td>31</td>
</tr>
<tr>
<td></td>
<td>14</td>
<td>Heat exchanger (11-E-1303) tube side</td>
<td>Flange Gasket Failure</td>
<td>60</td>
<td>12.34</td>
<td>1F</td>
<td></td>
<td>4</td>
<td>8</td>
<td></td>
<td>5</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>2D</td>
<td></td>
<td>4</td>
<td>8</td>
<td></td>
<td>8</td>
</tr>
</tbody>
</table>
Annexure-II

Figures for Consequence Analysis
Figure 6.5.1.1.1 ERU-INSTRUMENT TAPPING FAILURE OF DEETHANISER REFLUX PUMP (FLASH FIRE):
Figure 6.5.1.1.2 ERU-INSTRUMENT TAPPING FAILURE OF DEETHANISER BOTT PUMP (JET FIRE):
Figure 6.5.1.1.3 ERU-INSTRUMENT TAPPING FAILURE OF DEETHANISER BOTT PUMP (OVER PRESSURE):
Figure 6.5.1.2.1 ERU-DEETHANISER REFLUX DRUM CATASTROPHIC FAILURE (FLASH FIRE):
Figure 6.5.1.2.2 ERU-DEETHANISER REFLUX DRUM CATASTROPHIC FAILURE (FIRE BALL):
Figure 6.5.1.2.3 ERU-DEETHANISER REFLUX DRUM CATASTROPHIC FAILURE (OVER PRESSURE):
Figure 6.5.1.3.1 ERU-STR TAPP FAILURE OF EBR COMPRESSOR (FLASH FIRE):
Figure 6.5.1.3.2 ERU-INSTR TAPP FAILURE OF EBR COMPRESSOR (JET FIRE):
Figure 6.5.1.3.3 ERU-INSTR TAPP FAILURE OF EBR COMPRESSOR (OVER PRESSURE):
Figure 6.5.2.1.1 STRU-BOTTOM NOZZLE FAILURE OF DWC COLUMN OVHD RECEIVER (FLASH FIRE):
Figure 6.5.2.1.2 STRU-BOTTOM NOZZLE FAILURE OF DWC COLUMN OVHD RECEIVER (JET FIRE):
Figure 6.5.2.1.3 STRU-BOTTOM NOZZLE FAILURE OF DWC COLUMN OVHD RECEIVER (OVER PRESSURE):
Figure 6.5.2.2.1 STRU-INSTR TAPP FAILURE OF REACTOR FEED PUMP (FLASH FIRE):
Figure 6.5.2.2.2 STRU-INSTR TAPP FAILURE OF REACTOR FEED PUMP (JET FIRE):
Figure 6.5.2.2.3 STRU-INSTR TAPP FAILURE OF REACTOR FEED PUMP (OVER PRESSURE):
Figure 6.5.2.3.1 STRU-CATASTROPHIC RUPTURE OF DWC FSD (FLASH FIRE):
Figure 6.5.2.3.2 STRU-CATASTROPHIC RUPTURE OF DWC FSD (OVER PRESSURE):
Figure 6.5.2.4.1 STRU-FLANGE GASKET FAILURE OF HYDRO OVHD PRDT SEPARATOR (FLASH FIRE):
Figure 6.5.2.4.2 STRU-FLANGE GASKET FAILURE OF HYDRO OVHD PRDT SEPARATOR (JET FIRE):
Figure 6.5.2.4.3 STRU-FLANGE GASKET FAILURE OF HYDRO OVHD PRDT SEPARATOR (OVER PRESSURE):
Figure 6.5.2.5.1 STRU-INSTR TAPP FAILURE OF EDC REFLUX PUMP (FLASH FIRE):
Figure 6.5.2.5.2 STRU-INSTR TAPP FAILURE OF EDC OVHD ACCUM REFLUX PUMP (JET FIRE):
Figure 6.5.2.5.3 STRU-INSTR TAPP FAILURE OF EDC OVHD ACCUM REFLUX PUMP (OVER PRESSURE):
Figure 6.5.2.6.1 STRU-INSTRUMENT TAPPING FAILURE OF STYRENE PRODUCT DAILY TANK PUMP (P-220A/B)-FLASH FIRE:
Figure 6.5.2.6.2  STRU-INSTRUMENT TAPPING FAILURE OF STYRENE PRODUCT DAILY TANK PUMP (P-220A/B)- JET FIRE
Figure 6.5.2.6.3 STRU- INSTRUMENT TAPPING FAILURE OF STYRENE PRODUCT DAILY TANK PUMP (P-220A/B) - OVER PRESSURE
Figure 6.5.2.6.4  STRU-INSTRUMENT TAPPING FAILURE OF STYRENE PRODUCT DAILY TANK PUMP (P-220A/B) – Late Pool Fire
Figure 6.5.3.1.1 INSTR TAPP FAILURE AT PUMP DISCHARGE IN MOUNDED BULLET PUMP HOUSE (FLASH FIRE):
Figure 6.5.3.1.2 INSTR TAPP FAILURE AT PUMP DISCHARGE IN MOUNDED BULLET PUMP HOUSE (JET FIRE):
Figure 6.5.3.1.3 INSTR TAPP FAILURE AT PUMP DISCHARGE IN MOUNDED BULLET PUMP HOUSE (OVER PRESSURE):
Figure 6.5.3.2.1 CATASTROPHIC RUPTURE OF C4 MIX OFFSPEC SPHERE (FLASH FIRE):
Figure 6.5.3.2.2 CATASTROPHIC RUPTURE OF C4 SPHERE (FIRE BALL):
Figure 6.5.3.2.3 CATASTROPHIC RUPTURE OF C4 SPHERE (OVER PRESSURE):
Figure 6.5.3.3.1 FLANGE GASKET FAILURE AT PUMP DISCHARGE IN C4 MIX SPHERE PUMP HOUSE (FLASH FIRE):
Figure 6.5.3.3.2 FLANGE GASKET FAILURE AT PUMP DISCHARGE IN C4 MIX SPHERE PUMP HOUSE (JET FIRE):
Figure 6.5.3.3.3 FLANGE GASKET FAILURE AT PUMP DISCHARGE IN C4 MIX SPHERE PUMP HOUSE (OVER PRESSURE):
Figure 6.5.4.1.1 REFINERY - TOP NOZZLE FAILURE OF REFINERY OFFGAS KOD (17-V-9001) FLASH FIRE:
Figure 6.5.4.1.2 REFINERY- TOP NOZZLE FAILURE OF REFINERY OFFGAS KOD (JET FIRE):
Figure 6.5.4.1.3 REFINERY - TOP NOZZLE FAILURE OF REFINERY OFFGAS KOD (OVER PRESSURE):
Figure 6.5.5.1.1 NCU-FLANGE GASKET FAILURE OF HEAT EXCHANGER (FLASH FIRE):
Figure 6.5.5.1.2 NCU-FLANGE GASKET FAILURE OF HEAT EXCHANGER (JET FIRE):