RAPID RISK ANALYSIS STUDY

OF

USAR PETROCHEMICAL PROJECT

GAIL (India) LIMITED

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PREFACE

Engineers India Limited (EIL), New Delhi, has been entrusted by M/s GAIL (India) Ltd. to carry out Rapid Risk Analysis study of the facilities under Usar Petrochemical project.

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

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1 EXECUTIVE SUMMARY

1.1 INTRODUCTION

GAIL (India) Limited is India's principal Gas Transmission and Marketing Company under the Ministry of Petroleum and Natural Gas, Government of India. GAIL is also in the business of Gas Processing, Petrochemicals, LPG, Transmission and Telecommunications. The company has also extended its presence in Power, Liquefied Natural Gas regasification, City Gas Distribution and Exploration & Production through equity and joint ventures participations.

GAIL has six LPG recovery plants across various states in India. LPG recovery Plant at Usar was commissioned in 1998 with design capacity to process 5.0 MMSCMD of rich gas. Presently, LPG Usar plant is under shutdown and is in preservation mode due to non-availability of rich gas.

GAIL is planning to utilize the land and other facilities existing at Usar and set up GAIL Petrochemical Complex Project' Usar "wherein a 500 KTPA Propane Dehydrogenation unit integrated with Polypropylene unit is proposed to be set up.

M/s GAIL has entrusted Engineer's India Limited (EIL) to prepare rapid risk analysis report for the proposed project.

The proposed facilities will be set-up along with the existing facilities at USAR. The proposed project shall benefit from the land in possession of GAIL as well as coastal location of the existing facility for both Propane Import and product evacuation, nearby port facility, proximity to highways and ease of getting environmental clearance

This executive summary provides major findings and recommendations arising out of the Rapid Risk Analysis study for the facilities under the scope of the work. The detailed analysis is given in Sections 6 & 7.

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 or reasonably believable failure scenarios for various units 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 Hole on the bottom outlet of Pressure Vessels. 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. Based on effect zones, measures for mitigation of the hazard/risk are suggested.

1.3 MAJOR OBSERVATIONS & RECOMMENDATIONS

The detailed consequence analysis of release of hydrocarbon in case of major credible scenarios is modeled in terms of release rate, dispersion and flammability which have been discussed in detail in the report. The Observations and recommendations arising out of the Rapid Risk analysis study for units under upcoming Usar Petrochemical project are summarized below:

Analysis of high frequency failure scenarios in PDH and PP unit is as given below:

PP Unit

- Instrument tapping failure at Propylene charge pump, it is observed that LFL may reach a distance of 46 m and may extend beyond the unit boundary. The jet fire radiation intensities of 37.5 and 12.5 kW/m^2 may be realized upto 45 and 55 m respectively. The 5 & 3 psi overpressure blast waves may reach a distance of 51 m and 55 m respectively. Similarly in case of Instrument tapping failure at Recycle pump discharge, it is observed that LFL may reach a distance of 46 m from the source. The jet fire radiation intensities of 37.5 and 12.5 kW/m^2 may be realized upto 45 and 54 m respectively. The 5 & 3 psi overpressure blast waves may reach a distance of 51 m and 55 m respectively. However the effects are observed to be largely restricted within the unit provided the equipments are suitably sited.

PDH

- In case of high frequency failure scenarios in PDH unit such as Instrument tapping failure in Propane line at B/L, It is observed that LFL may reach a distance of 42 m and may cross the unit boundary. The jet fire radiation intensities of 37.5 and 12.5 kW/m2 may cause escalation within the unit. The 5 & 3 psi overpressure blast waves, if realized may have an effect zone of 50 m and 54 m respectively. Also in case of Instrument tapping failure at De-ethanizer bottom pump it was observed that LFL may reach a distance of 49 m from the source. The jet fire radiation intensities of 37.5 and 12.5 kW/m2 may reach a distance of 42 m and 51 m respectively with possible localized escalation. The 5 & 3 psi overpressure blast waves may reach a distance of 51 m and 56 m respectively.

  Similar effect distances are noticed in case of Instrument tapping failure at De-ethanizer feed dryer inlet line and Instrument tapping failure at Reject C4 Pump.

Note: The loss of containment scenarios, equipment locations and conditions are indicative and need further assessment during detailing. It may also be noted that, there exists a possibility of other loss of containment scenarios, whose blast overpressure waves may effect the new control room based on the location of equipment in the unit and technology selected.

LPG unit

- From the high frequency failure scenarios such as Instrument tapping failure at LPG column bottom line/NGL pump inlet, it is observed that LFL may reach a distance of 80 m from the source. The jet fire radiation intensities of 37.5 and 12.5 kW/m^2 may lead to localized escalation. The Late pool fire radiation intensities of 12.5 kW/m^2 may be realized at a distance of 33 m from the source. The 5 psi overpressure blast wave may possibly affect the control room. The existing Lab building may be subjected to 3 psi overpressure blast waves.

  In case of a 20mm Leak in LP separator bottom outlet, it is observed that LFL may reach a distance of 86 m from the source. The jet fire radiation intensities of 37.5 and 12.5 kW/m^2 may lead to a localized escalation. The 5 & 3 psi overpressure blast waves may reach a distance of 99 m and 107 m which may affect the existing control room and PDH unit partially. Similar effects are noticed in case of 20mm Leak in HP separator bottom outlet.

Hence based on the above consequences, following are recommended:

- *Provide adequate number of gas detectors (H_2 &/HC) at suitable locations within unit (PDH/PP/LPG) for early leak detection. Also philosophy for quick isolation (through ROV's) for vessels and columns containing inventories of C4/C5 and lighters should be developed for PDH/PP plants as a part of good safety design practice.*
- *In PP unit, it is suggested locate the extrusion and pellet handling sections towards the western side for enhanced safety.*
- *It is advisable to consider blast resistant construction of new MCR.*
- *It is suggested to relocate the existing lab building to a safe location beyond the explosion effects based on scenarios arising out of LPG unit.*
- *Ensure LPG control room is of blast resistant construction (or) explore integration of the same with New MCR.*

In case of low frequency high consequence credible failure scenarios in PDH unit such as:

- Large hole at Product Splitter bottom, it is observed that LFL distances may reach up to 112 m. The jet fire radiation intensities of 37.5 kW/m2 and 12.5 kW/m2 may reach a distance of 82 m and 100 m (@2F condition) respectively. The 5 & 3 psi overpressure blast waves may reach a distance of 131 m and 140 m respectively and may affect new MCR and existing MCR depending on the location of equipment in the unit. Similarly in case of large hole at de-ethanizer reflux drum bottom, it is observed that LFL distances may be realized up to 131 m and may affect MCR, control room and LPG recovery unit depending on the location of the equipment. The jet fire radiation intensities of 37.5 & 12.5 kW/m2 may reach a distance of 78 m and 95 m respectively (@2F condition). The 5 & 3 psi overpressure blast waves may reach a distance of 155 m and 164 m respectively.

In case of low frequency high consequence credible failure scenarios in PP unit such as:

- Large hole at Propylene dryer bottom: it is observed that LFL distance of 157 m may reach SRR, warehouse and PDH plant. The jet fire radiation intensities of 37.5 and 12.5 kW/m^2 may be realized upto 103 and 125m respectively @ 2F condition. The 5 & 3 psi overpressure blast waves may reach a distance of 178 m and 188 m and may affect SRR, Sub Station, PDH unit and warehouse depending on the location of equipment.

Based on the above consequence, following are recommended:

- *Include these scenarios outcomes as an input to the Disaster Management Plan (DMP) & Emergency Response Plan (ERP).*

OFFSITES

In case of high frequency failure scenarios in Offsites such as:

Instrument tapping failure at Propane Pump discharge it is observed that LFL may reach a distance of 43 m from the source. The jet fire radiation intensities of 32 and 8 kW/m^2 may reach a distance of 45 m and 58 m respectively and may have a localized effect. The 5 & 3 psi overpressure blast waves may reach a distance of 51 m and 55 m respectively. Similar effect distances are noticed in case of Instrument tapping failure at Propylene Pump discharge and Instrument tapping failure at metering area.

In case of Instrument tapping failure at H2 Bullet, it was observed that LFL may reach a distance of 48 m from the source. The jet fire radiation intensities of 32 and 8 kW/m^2 may reach a distance of 19 m and 23 m respectively and may affect the adjacent bullet. The 5 & 3 psi overpressure blast waves may reach a distance of 48 m and 51 m respectively.

Based on the above consequence, following are recommended:

- *Provide gas and optical flame detectors at pump houses, metering station and H2 bullet area for quick detection and early action in loss of containment.*
- *Consider fireproofing of H2 bullet for jet fire hazards.*

2 INTRODUCTION

2.1 STUDY AIMS AND OBJECTIVE

The objectives of the Rapid Risk Analysis study are to identify all potential failure modes that may lead to hazardous consequences. Typical hazardous consequences include fire, explosion and toxic releases. Identifying the hazardous consequences having impacts on population and property in the vicinity of the facilitiesprovides 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 facilities
b) Evaluate process hazards emanating from the identified potential accident scenarios.
c) Analyze the damage effects to surroundings due to such incidents.
d) Suggest mitigating measures to reduce the hazard / risk.

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

2.2 SCOPE OF WORK

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

Table 1: New Proposed Process Facilities

S. No.	Description
1.	Polypropylene Unit (PPU)
2.	Propane Dehydrogenation Unit (PDH)

**Novolen and CB & I are selected as Licensors for the purpose of study*

3 SITE CONDITION

3.1 GENERAL

This chapter describes the location of GAIL Usar Site and meteorological data, which has been used for the Rapid Risk Analysis study.

3.2 SITE, LOCATION AND VICINITY

The complex is located at Usar, Maharashtra, India with co-ordinates:18°35'58.9"N 72°58'22.3"E

Figure 1: GAIL UsarSite

3.3 METEOROLOGICAL CONDITIONS

The consequences of released flammable material are largely dependent on the prevailing weather conditions. For the assessment of major scenarios involving release of 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 ambient 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 Alibag has beenculled from the Climatological Tables of Observatories in India (1981-2010) published by Indian Meteorological Department(IMD), Pune.

Atmospheric Parameters

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

Table 2: Atmospheric Parameter

Sl. No.	Parameter	Average Value Considered For Study
1.	Ambient Temperature (^{O}C)	28
2.	Atmospheric Pressure (mm Hg)	760
3.	Relative Humidity (%)	75
4.	Solar Radiation flux (kW/m^2)	0.7

Wind Speed

The averages mean speed in various months is as in table below. From IMD data, the average wind speed is around 2 m/s. It is also observed that wind speeds>3 m/sec and 6 m/sec may occur for some part of the time. The study of oktas (all clouds) shows that in a majority of days in the months of June to September medium to overcast conditions prevail, with thin cloud cover prevailing in the months of October to May.

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

Jan	Feb	Mar	April	May	June	July	Aug	Sep	Oct	Nov	Dec
2.11	2.36	2.83	3.05	3.83	5.42	6.86	6.14	3.25	2.19	1.92	1.89

Weather Category

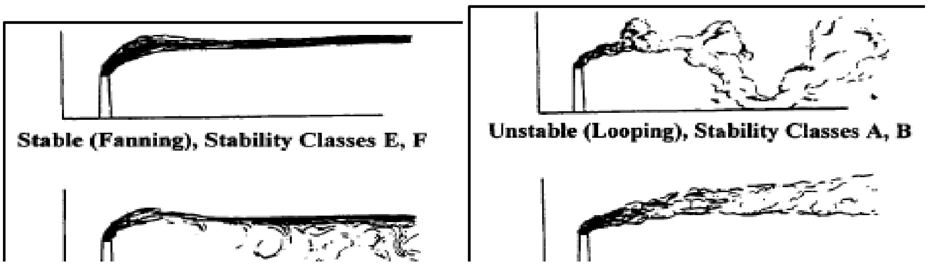
One of the most important characteristics of atmosphere is its stability. Stability of atmosphere is its tendency to resist vertical motion or to suppress existing turbulence. This tendency directly influences the ability of atmosphere to disperse pollutants emitted into it from the facilities. In most 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

Wind speed (m/sec.)	Day-time Insolation			Night-time condition		Anytime Overcast
	Strong	Moderate	Slight	Thin overcast or ≥ 4/8 low clouds	≤3/8 cloudiness	
< 2	A	A – B	B	E	F	D
2 – 3	A – B	B	C	E	F	D
3 – 5	B	B – C	C	D	E	D
5 – 6	C	C – D	D	D	D	D
> 6	C	D	D	D	D	D

Source: CCPS: Guidelines for Chemical Process Quantitative Risk Analysis (2nd Edition) Chap 2c
A = Very unstable, B = Unstable, C = moderately unstable, D = Neutral, E = moderately stable, F = stable



Source: CCPS Book on A Guide to Quantitative Risk Analysis

Table 5: Method for estimating insolation category

Degree of Cloudiness	*Solar elevation angle >60 Deg	*Solar Elevation angle≤ 60^0 but > 35^0	*Solar elevation angle≤ 35^0 but > 15^0
4/8 (50%) or less or any amount of high, thin clouds	Strong	Slight	Slight
5/8 to 7/8 middle clouds (2000m to 5000m base)	Moderate	Slight	Slight

Degree of Cloudiness	*Solar elevation angle >60 Deg	*Solar Elevation angle≤ 60^0 but > 35^0	*Solar elevation angle≤ 35^0 but > 15^0
5/8 to 7/8 low clouds (less than 2000m base)	Slight	Slight	Slight

**In India the solar elevation angle is normally > 35 &< 60 deg during winters and >60 deg during summer period.*

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

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

Literature suggests that Category ‘D’ is more probable at coastal sites in moderate climates, and may occur for upto 45% of the day time of the year and 33% of the night time. Also other stability categories such as “C” may prevail when the skies are clear/ partly cloudy during daytime (55% of the time) and “F” during the night time (66% of the time). The weather conditions selected for Usar (Alibag) are as presented below:

Table 6: Weather Conditions

Wind Speed	Pasquill Stability
2	F
3	C
6	D

Note: For RRA Study Plot Plan (Doc. No.: B078-000-81-41-00001 REV I-Model) has been used.

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

4 HAZARDS ASSOCIATED WITH THE FACILITIES

4.1 GENERAL

Petrochemical complex handles a number of hazardous materials like LPG, Hydrogen, Propane, Propylene and other hydrocarbons 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

4.2.1 LIQUIFIED PETROLEUM GAS

LPG is a colorless liquefied gas that is heavier than air and may have a foul smelling odorant added to it. It is a flammable gas and may cause flash fire and delayed ignition.

LPG is incompatible to oxidizing and combustible materials. 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 LPG at temperatures near boiling points would lead to formation of pools and then pool fire. LPG releases may also lead to explosion in case of delayed ignition.

Inhalation of LPG vapors by human beings in considerable concentration may affect the central nervous system and lead to depression. Inhalation of extremely high concentration of LPG may lead to death due to suffocation from lack of oxygen. Contact with liquefied LPG may cause frostbite. Refer to belowtable for properties of LPG.

Table 7: Hazardous Properties of LPG

Sl. No.	Properties	Values
1.	LFL/Flash Fire zone (%v/v)	1.7
2.	UFL (%v/v)	9.0
3.	Auto ignition temperature (°C)	420-540
4.	Heat of combustion (Kcal/Kg)	10960
5.	Normal Boiling point (°C)	-20 to –27
6.	Flash point (°C)	- 60

4.2.2 HYDROGEN

Hydrogen (H_2) 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 ferritic 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

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

4.2.3 PROPYLENE

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

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

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

Table 9: Hazardous Properties of Propylene

Sl. No.	Properties	Values
1.	LFL (%v/v)	2
2.	UFL (%v/v)	11
3.	Auto ignition temperature (°C)	497
4.	Heat of combustion (KCAL/Kg)	10941
5.	Normal Boiling point (°C)	-47.7

5 HAZARD IDENTIFICATION

5.1 GENERAL

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

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

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

- Catastrophic Rupture of Pressure vessel

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

5.2 MODES OF FAILURE

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

Material/Construction Defects

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

Pre-Operational Failures

- Failure induced during delivery at site
- Failure induced during installation
- Pressure and temperature effects
- Overpressure
- Temperature expansion/contraction (improper stress analysis and support design)
- Low temperature brittle fracture (if metallurgy is incorrect)
- Fatigue loading (cycling and mechanical vibration)

Corrosion Failures

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

Failures due to Operational Errors

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

External Impact Induced Failures

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

Failure due to Fire

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

5.3 SELECTED FAILURE CASES

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

- Cases with high chance of occurrence but having low consequence: Example of such failure cases includes two-bolt gasket leak for flanges (1 x10^{-4} /year), seal failure (0.6 /year) for pumps, instrument tapping failure(5 x10^{-4} /year), 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 (1 x10^{-6} /M-year to 1 x10^{-7} /M-year), Catastrophic Rupture of Pressure Vessels (3 x10^{-6} /year), etc.)

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

For selected credible failure scenarios and likely consequences forunits understudy are as follows, refer Section-6.

Note: References of frequencies are taken from:

- Classification of Hazardous Locations, A.W.Cox, F.P.Lees and M.L.Ang, Published by the Institution of Chemical Engineers, U.K.
- Loss Prevention in the Process Industries, Hazard Identification, Assessment and Control, Frank.P.Lees, 2nd Edition, Published by Butterworth-Heinemann, U.K.

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 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 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 vapor dispersion, fire or explosion or both.

6.2 CONSEQUENCE ANALYSIS MODELLING

- **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.

- **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/Flash Fire zone) are important in determining whether the release will ignite. In this study, the results of dispersion modeling for flammable materials are presented LFL/Flash Fire zone quantity.

- **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/Flash Fire zone.

- **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.

- **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.

- **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.

6.3 SIZE AND DURATION OF RELEASE

Leak size considered for selected failure cases are listed below[1]. Leak sizes considered here are representative sizes in the upstream/ downstream circuit of particular equipment for which failure scenario has been considered.

Table 10: Size of Release

Failure Description	Leak Size
Pump seal failure	6 mm hole size
Flange gasket failure	10 mm hole size
Instrument tapping failure	20 mm hole size
Large Hole in the Piping	50 mm, complete rupture of 2" drain line at the Process vessel outlet
Catastrophic Rupture	Complete Rupture of the Pressure Vessels

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

6.4 DAMAGE CRITERIA

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

6.4.1 LFL/FLASH FIRE ZONE 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/Flash Fire zone), 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/Flash Fire zone value is usually taken to indicate the area, which may be affected by the flash fire.

Flash fire (LFL/Flash Fire zone) 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

[1] Refer to Guideline for Quantitative Risk assessment 'Purple Book'.
[2] Release duration is based on Chemical Process Quantitative Risk Analysis, CCPS.

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 11: Damage Due to Incident Thermal Radiation Intensity

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

*separation distance for tanks w/o fixed firefighting system

The hazard distances to the 37.5 kW/m^2, 32 kW/m^2, 12.5 kW/m^2, 8 kW/m^2 and 4 kW/m^2 radiation levels, selected based on their effect on population, buildings and equipment were modeled using PHAST.

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 12: Damage Effects of Blast Overpressure

Blast Overpressure (PSI)	Damage Level
5.0	Major structure damage
3.0	Oil storage tank failure
2.5	Eardrum rupture
2.0	Repairable damage, pressure vessels remain intact, light structures

Blast Overpressure (PSI)	Damage Level
	collapse
1.0	Window pane breakage possible, causing some injuries

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

6.5 CONSEQUENCE ANALYSISFOR PPU AND PDH UNITS

This section discusses the consequences of selected failure scenarios for PPU, PDH and existing LPG recovery unit. The consequence distances are reported in tabular form for all weather conditions in **Annexure-I** and are represented graphically in **Annexure-II** for the all failure scenarios in a unit for the worst case weather conditions.

6.5.1 PPU

Figures 1.1 A to 1.5 C in Annexure II

- Instrument tapping failure at Propylene charge pump*:* From the consequence analysis, it is observed that LFL may reach a distance of 46 m and may extend beyond the unit boundary. The jet fire radiation intensities of 37.5 and 12.5 kW/m^2 may be realized upto 45 and 55 m respectively. The 5 & 3 psi overpressure blast waves may reach a distance of 51 m and 55 m respectively.
- Large hole at Propylene dryer bottom: From the event outcome analysis, it is observed that LFL distance of 157 m may reach SRR, warehouse and PDH plant depending on the location of the equipment. The jet fire radiation intensities of 37.5 and 12.5 kW/m^2 may be realized upto 103 and 125m respectively @ 2F condition. The 5 & 3 psi overpressure blast waves may reach a distance of 178 m and 188 m and may affect SRR, Sub Station, PDH unit and warehouse depending on the location of equipment.
- Instrument tapping failure at Recycle pump discharge*:* From the consequence analysis, it is observed that LFL may reach a distance of 46 m from the source. The jet fire radiation intensities of 37.5 and 12.5 kW/m^2 may be realized upto 45 and 54 m respectively. The 5 & 3 psi overpressure blast waves may reach a distance of 51 m and 55 m respectively.

  In addition to the above mentioned scenarios, Instrument Tapping Failure at H_2 Compressor, Flange Leakage at RG Compressor were also modeled. It is observed that hazardous affect zones from these scenarios are largely restricted to the unit depending upon the prevailing weather conditions at the time of release and location inside the unit.

6.5.2 PDH

Figures 2.1 A to 2.9 C in Annexure II

- Instrument tapping failure in Propane line at B/L*:* From the consequence analysis, it is observed that LFL may reach a distance of 42 m and may cross the unit boundary. The jet fire radiation intensities of 37.5 and 12.5 kW/m^2 may reach a distance of 43 m and 52 m respectively. The 5 & 3 psi overpressure blast waves may reach a distance of 50 m and 54 m respectively.
- Instrument tapping failure at De-ethanizer feed dryer inlet line*:* From the consequence analysis, it was observed that LFL may reach a distance of 39 m from the source. The jet fire radiation intensities of 37.5 and 12.5 kW/m^2 may reach a distance of 36 m and 45 m respectively with possible localized escalation. The 5 & 3 psi overpressure blast waves may reach a distance of 39 m and 42 m respectively.
- Instrument tapping failure at De-ethanizer bottom pump*:* From the consequence analysis, it was observed that LFL may reach a distance of 49 m from the source. The jet fire radiation intensities of 37.5 and 12.5 kW/m^2 may reach a distance of 42 m and 51 m respectively with possible localized escalation. The 5 & 3 psi overpressure blast waves may reach a distance of 51 m and 56 m respectively.
- Large hole at de-ethanizer reflux drum bottom: It was observed that LFL distances may be realized up to 131 m and may affect MCR, control room and LPG recovery unit depending on the location of the equipment. The jet fire radiation intensities of 37.5 & 12.5 kW/m^2 may reach a distance of 78 m and 95 m respectively(@2F condition). The 5 & 3 psi overpressure blast waves may reach a distance of 155 m and 164 m respectively.
- Instrument tapping failure at Reject C4 Pump*:* From the consequence analysis, it was observed that LFL may reach a distance of 42 m from the source. The jet fire radiation intensities of 37.5 and 12.5 kW/m^2 may reach a distance of 37 m and 45 m respectively and may have a localized effect. The 5 & 3 psi overpressure blast waves may reach a distance of 50 m and 54 m respectively with localized effect.
- Large hole at Product Splitter bottom: From the event outcome analysis, it was observed that LFL distances may reach up to 112 m. The jet fire radiation intensities of 37.5 kW/m^2 and 12.5 kW/m^2 may reach a distance of 82 m and 100 m (@2F condition) respectively. The 5 & 3 psi overpressure blast waves may reach a distance of 131 m and 140 m respectively.

In addition to the above mentioned scenarios Instrument Tapping failure of product splitter heat pump Compressor, Propylene refrigerant compressor were also modeled and it is observed that hazardous affect zones from these scenarios are largely restricted to the unit depending upon the prevailing weather conditions at the time of release.

6.5.3 LPG RECOVERY UNIT

Scenarios of the LPG recovery unit have been modelled to identify hazard to the adjacent buildings. The composition and operating conditions used for modelling are for LPG mode of operation.

Figures 3.1 A to 3.7 C in Annexure II

- 20mm Leak in LP separator bottom outlet: From the consequence analysis, it is observed that LFL may reach a distance of 86 m from the source. The jet fire radiation intensities of 37.5 and 12.5 kW/m^2 may reach a distance of 40 m and 49 m respectively and may have a localized escalation. The 5 & 3 psi overpressure blast waves may reach a distance of 99 m and 107 m which may affect the existing control room and PDH unit partially.
- 20mm Leak in HP separator bottom outlet*:* From the incident outcome analysis, it is observed that LFL may be realized upto of 74 m from the source. The jet fire radiation intensities of 37.5 and 12.5 kW/m^2 may reach a distance of 43 m and 53 m respectively and may have a localized effect. The 5 & 3 psi overpressure blast waves may reach a distance of 87 m and 93 m and may possibly affect the existing control room and PDH unit partially.
- Large hole in LEF column bottom*:* From the consequence analysis, it is observed that LFL may reach a distance of 108 m from the source. The jet fire radiation intensities of 37.5 and 12.5 kW/m^2 may reach a distance of 86 m and 106 m respectively and may lead to escalation within the unit. The 5 & 3 psi overpressure blast waves may reach a distance of 124 m and 134 m and may possibly affect the existing control room and lab building and cooling tower on the south-eastern side.
- Instrument tapping failure at LEF Reflux Pumps*:* From analysis of consequence contours of this scenario, it is observed that LFL may reach a distance of 47 m from the source. The jet fire radiation intensities of 37.5 and 12.5 kW/m^2 may reach a distance of 40 m and 49 m respectively and may have a localized effect. The 5 & 3 psi overpressure blast waves effect distances may be realized at a maximum distance 51 m and 56 m from the source.
- Instrument tapping failure at LPG Product Pump*:* From the consequence analysis, it was observed that LFL may reach a distance of 34 m from the source. The jet fire

radiation intensities of 37.5 and 12.5 kW/m^2 may reach a distance of 36 m and 44 m respectively and may have a localized effect. The 5 & 3 psi overpressure blast waves may reach a distance of 39 m and 42 m respectively.

- <u>Instrument tapping failure at LPG column bottom line/NGL pump inlet</u>*:* From analysis of consequence contours of this scenario, it is observed that LFL may reach a distance of 80 m from the source. The jet fire radiation intensities of 37.5 and 12.5 kW/m^2 may reach a distance of 43 m and 54 m respectively and may lead to localized escalation. The Late pool fire radiation intensities of 12.5 kW/m^2 may be realized at a distance of 33 m from the source. The 5 & 3 psi overpressure blast waves effect distances may be realized at a maximum distance 100 m and 108 m from the source and may possibly affect the control room. The existing Lab building may be subjected to 3 psi overpressure blast waves.

  In addition Instrument Tapping Failure at Lean Gas Compressor discharge is modelled and found that the consequence effects are largely localized.

Note:

For LPG unit the following documents have been considered: PFD -3032-10-2-41-1001 Rev 0,3032-10-2-41-1002 Rev 0 Material Balance: 3032-02-10-MB-001 /002/003. Equipment Layout : 4602-10-16-43001 Rev C. However as conveyed by client only LPG mode was operational with modifications carried out for LPG cum C3 case. In the current study LPG mode of operation is considered.

6.5.4 OFFSITES

Figures 4.1 A to 4.4 C in Annexure II

- Instrument tapping failure at Propane Pump discharge*:* From the consequence analysis, it was observed that LFL may reach a distance of 43 m from the source. The jet fire radiation intensities of 32 and 8 kW/m^2 may reach a distance of 45 m and 58 m respectively and may have a localized effect. The 5 & 3 psi overpressure blast waves may reach a distance of 51 m and 55 m respectively.
- Instrument tapping failure at Propylene Pump discharge*:* From the consequence analysis, it was observed that LFL may reach a distance of 45 m from the source. The jet fire radiation intensities of 32 and 8 kW/m^2 may reach a distance of 45 m and 58 m respectively and may have a localized effect. The 5 & 3 psi overpressure blast waves may reach a distance of 51 m and 55 m respectively.
- Instrument tapping failure at metering area: From the consequence analysis, it was observed that LFL may reach a distance of 46 m from the source. The jet fire radiation intensities of 32 and 8 kW/m^2 may reach a distance of 44 m and 57 m respectively and may have a localized effect. The 5 & 3 psi overpressure blast waves may reach a distance of 51 m and 55 m respectively.
- Instrument tapping failure at H2 Bullet:. From the consequence analysis, it was observed that LFL may reach a distance of 48 m from the source. The jet fire radiation intensities of 32 and 8 kW/m^2 may reach a distance of 19 m and 23 m respectively and may have a localized effect. The 5 & 3 psi overpressure blast waves may reach a distance of 48 m and 51 m respectively.

7 OBSERVATIONS & RECOMMENDATIONS

The detailed consequence analysis of release of hydrocarbon in case of major credible scenarios are modeled in terms of release rate, dispersion and flammability which have been discussed in detail in the report. The Observations and recommendations arising out of the Rapid Risk analysis study for units under upcoming Usar Petrochemical project are summarized below:

PP Unit

- Instrument tapping failure at Propylene charge pump, it is observed that LFL may reach a distance of 46 m and may extend beyond the unit boundary. The jet fire radiation intensities of 37.5 and 12.5 kW/m^2 may be realized upto 45 and 55 m respectively. The 5 & 3 psi overpressure blast waves may reach a distance of 51 m and 55 m respectively. Similarly in case of Instrument tapping failure at Recycle pump discharge, it is observed that LFL may reach a distance of 46 m from the source. The jet fire radiation intensities of 37.5 and 12.5 kW/m^2 may be realized upto 45 and 54 m respectively. The 5 & 3 psi overpressure blast waves may reach a distance of 51 m and 55 m respectively. However the effects are observed to be largely restricted within the unit provided the equipments are suitably sited.

  Note: *Locating the extrusion and pellet handling section towards the western side ensures the hydrogen and hydrocarbon section is located at a maximum distance from truck parking area*.

PDH

- In case of high frequency failure scenarios in PDH unit such as Instrument tapping failure in Propane line at B/L, It is observed that LFL may reach a distance of 42 m and may cross the unit boundary. The jet fire radiation intensities of 37.5 and 12.5 kW/m2 may cause escalation within the unit. The 5 & 3 psi overpressure blast waves, if realized may have an effect zone of 50 m and 54 m respectively. Also in case of Instrument tapping failure at De-ethanizer bottom pump it was observed that LFL may reach a distance of 49 m from the source. The jet fire radiation intensities of 37.5 and 12.5 kW/m2 may reach a distance of 42 m and 51 m respectively with possible localized escalation. The 5 & 3 psi overpressure blast waves may reach a distance of 51 m and 56 m respectively.

  Similar effect distances are noticed in case of Instrument tapping failure at De-ethanizer feed dryer inlet line and Instrument tapping failure at Reject C4 Pump.

  Note: The loss of containment scenarios, equipment locations and conditions are indicative and need further assessment during detailing. It may also be noted that, there exists a possibility of other loss of containment scenarios, whose blast overpressure waves may effect the new control room based on the location of equipment in the unit and technology selected.

LPG unit

- From the high frequency failure scenarios such as Instrument tapping failure at LPG column bottom line/NGL pump inlet, it is observed that LFL may reach a distance of 80 m from the source. The jet fire radiation intensities of 37.5 and 12.5 kW/m^2 may lead to localized escalation. The Late pool fire radiation intensities of 12.5 kW/m^2 may be realized at a distance of 33 m from the source. The 5 psi overpressure blast wave may possibly affect the control room. The existing Lab building may be subjected to 3 psi overpressure blast waves.
  In case of a 20mm Leak in LP separator bottom outlet, it is observed that LFL may reach a distance of 86 m from the source. The jet fire radiation intensities of 37.5 and 12.5 kW/m^2 may lead to a localized escalation. The 5 & 3 psi overpressure blast waves may reach a distance of 99 m and 107 m which may affect the existing control room and PDH unit partially. Similar effects are noticed in case of 20mm Leak in HP separator bottom outlet.

Hence based on the above consequences, following are recommended:

- *Provide adequate number of gas detectors (H_2 &/HC) at suitable locations within unit (PDH/PP/LPG) for early leak detection. Also philosophy for quick isolation (through ROV's) for vessels and columns containing inventories of C4/C5 and lighters should be developed for PDH/PP plants as a part of good safety design practice.*
- *In PP unit, it is suggested locate the extrusion and pellet handling sections towards the western side for enhanced safety.*
- *It is advisable to consider blast resistant construction of new MCR.*
- *It is suggested to relocate the existing lab building to a safe location beyond the explosion effects based on scenarios arising out of LPG unit.*
- *Ensure LPG control room is of blast resistant construction (or) explore integration of the same with New MCR.*

In case of low frequency high consequence credible failure scenarios in PDH unit such as:

- Large hole at Product Splitter bottom, it is observed that LFL distances may reach up to 112 m. The jet fire radiation intensities of 37.5 kW/m2 and 12.5 kW/m2 may reach a distance of 82 m and 100 m (@2F condition) respectively. The 5 & 3 psi overpressure blast waves may reach a distance of 131 m and 140 m respectively and may affect new MCR and existing MCR depending on the location of equipment in the unit. Similarly in case of large hole at de-ethanizer reflux drum bottom, it is observed that LFL distances may be realized up to 131 m and may affect MCR, control room and LPG recovery unit depending on the location of the equipment. The jet fire radiation intensities of 37.5 & 12.5 kW/m2 may reach a distance of 78 m and 95 m respectively (@2F condition). The 5 & 3 psi overpressure blast waves may reach a distance of 155 m and 164 m respectively.

In case of low frequency high consequence credible failure scenarios in PP unit such as:

- Large hole at Propylene dryer bottom: it is observed that LFL distance of 157 m may reach SRR, warehouse and PDH plant. The jet fire radiation intensities of 37.5 and 12.5 kW/m^2 may be realized upto 103 and 125m respectively @ 2F condition. The 5 & 3 psi overpressure blast waves may reach a distance of 178 m and 188 m and may affect SRR, Sub Station, PDH unit and warehouse depending on the location of equipment.

Based on the above consequence, following are recommended:

- *Include these scenarios outcomes as an input to the Disaster Management Plan (DMP) & Emergency Response Plan (ERP).*

OFFSITES

In case of high frequency failure scenarios in Offsites such as:

Instrument tapping failure at Propane Pump discharge it is observed that LFL may reach a distance of 43 m from the source. The jet fire radiation intensities of 32 and 8 kW/m^2 may reach a distance of 45 m and 58 m respectively and may have a localized effect. The 5 & 3 psi overpressure blast waves may reach a distance of 51 m and 55 m respectively. Similar effect distances are noticed in case of Instrument tapping failure at Propylene Pump discharge and Instrument tapping failure at metering area.

In case of Instrument tapping failure at H2 Bullet, it was observed that LFL may reach a distance of 48 m from the source. The jet fire radiation intensities of 32 and 8 kW/m^2 may reach a distance of 19 m and 23 m respectively and may affect the adjacent bullet. The 5 & 3 psi overpressure blast waves may reach a distance of 48 m and 51 m respectively.

Based on the above consequence, following are recommended:

- *Provide gas and optical flame detectors at pump houses, metering station and H2 bullet area for quick detection and early action in loss of containment.*
- *Consider fireproofing of H2 bullet for jet fire hazards.*

GENERAL RECOMMENDATIONS

a) Recommendations for Construction Safety during execution of the Project

- ✓ *Proper material movement path within the project shall be identified.*
- ✓ *Detailed HSE Plan & HSE Philosophy to be developed by contractors during construction phase of the project, in line with client's safety requirements.*

b) Safety Recommendations

- ✓ *In order to prevent secondary incident arising from any failure scenario, it is recommended that sprinklers and other protective devices provided are regularly checked to ensure these are functional.*
- ✓ *Mock drills to be organized at organization level to ensure preparation of the personnel's working in the plant for handling any hazardous situation.*
- ✓ *For positively pressurized buildings, Hydrocarbon gas detectors need to be placed at suction duct of HVAC. HVAC to be tripped automatically in event of the detection of any Hydrocarbon material by the detector.*

c) 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:

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

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 strongly recommended to consider minimization of the traffic movement within the facility.*
- ✓ *Classifying equipment and instruments in flammable zone helps in ignition control.*

e) 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 crosswind from flammable releases.*

- ✓ *Provide sign boards marking emergency/safe roads to be taken during any exigencies.*

f) Preventive Maintenance for Critical Equipment

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

a. *For all critical HC handling pumps like High head pumps, 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.*

g) Others

- ✓ *Recommended to use portable HC detector during sampling and maintenance etc.*
- ✓ *Ensure operator cabins/change rooms are not located inside/near to plant area.*
- ✓ *Chlorine toners are to be substituted with lesser hazardous substances for disinfection of cooling water.*

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/Flash Fire zone) 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.

9 REFERENCES

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