Quantitative Risk Assessment (QRA)

For

Indian Oil Corporation Limited
LPG Bottling Plant Pondicherry

By

Ultra-Tech Environmental Consultancy

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DOCUMENT HISTORY

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Prepared By	***Reviewed By***	***Approved By***
Ms. S. Deepika Rani	*Mr. Suresh Joseph*	
Ultra-Tech Environmental Consultancy	***Ultra-Tech Environmental Consultancy***	***Indian Oil Corporation Limited***

ABBREVIATIONS

ALARP	As Low As Reasonably Practicable
CCTV	Closed Circuit Tele -Vision
ESD	Emergency Shut Down
ESDV	Emergency Shut Down Valve
HAZID	Hazard Identification
HSE	Health Safety & Environment
IOCL	Indian Oil Corporation Limited
IR	Individual Risk
LOC	Loss of Containment
LFL/LEL	Lower Flammability Limit / Lower Explosive Limit
LPG	Liquefied Petroleum Gas
P&ID	Piping and Instrument Diagram
QRA	Quantitative Risk Assessment
SOP	Standard Operating Procedure
SR	Societal Risk
TLFG	Tanker Lorry Filling Gantry
VCE	Vapour Cloud Explosion

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EXECUTIVE SUMMARY

M/s. Indian Oil Corporation Ltd. (IOCL) intended to conduct an extensive Quantitative risk assessment study for their expansion project of LPG Bottling Plant facilities at Pondicherryto assess the risk associated with loss of containment of the various process involved. This scope was awarded to Ultra – Tech Environmental Consultancy and accordingly they conducted the risk assessment study to provide a better understanding of the risk posed to the plant and surrounding population.

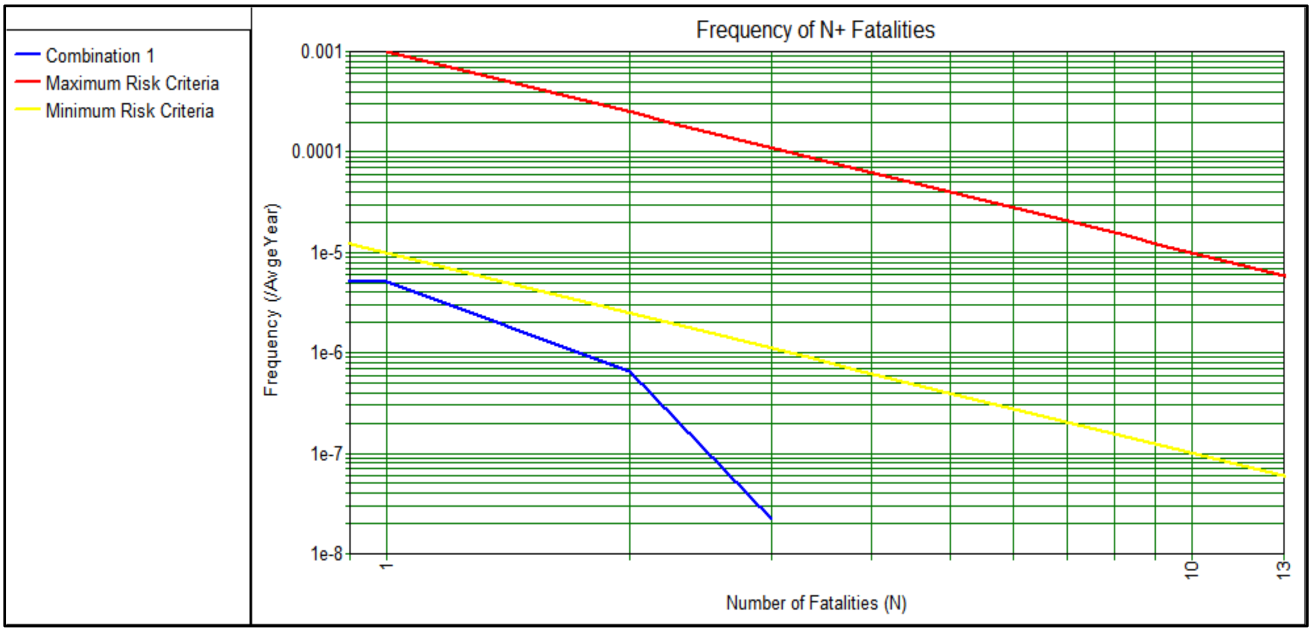
The consequences & Risk estimation modeling was conducted using PHASTRISK (Version 6.7) software developed by DNV GL. The IR output taken from PHASTRISK was found to fall in Acceptable region both in 1.5F and 5D weather conditions.

Overall Individual Risk at 1.5F& 5D weather condition;

Individual Risk is 6.20E-06 Per Avg Year

Societal Risk at 1.5F& 5D weather condition;

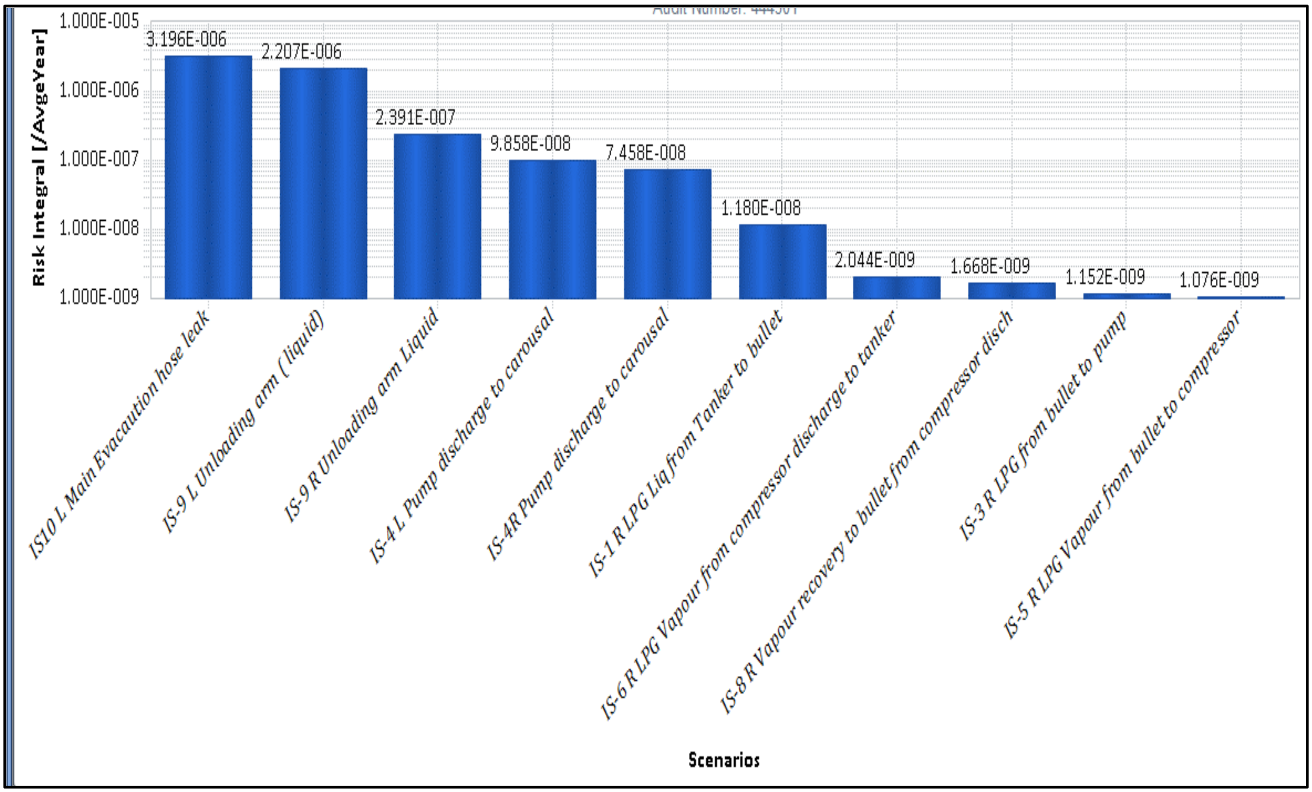
Societal Risk is 5.83E-06 Per Avg Year



Top Ten Risk Integrals

RECOMMENDATIONS

Based on the information provided to Ultra - Tech team and the outcome of the QRA report, it is



inferred that present risk levels posed by Pondicherry-LPG Bottling Plant is in Acceptable region.

As per Consequence analysis maximum damage is caused by rupture of LPG liquid line from road tanker to bullet. LFL contour travels up to 86mat 5D wind condition.

Some of the important suggested risk control measures are provided below:

1. Safety interlocks systems for pumps, compressors, bullets to be verified, counterchecked to make sure proper operation in the event of any failures
2. Gas detectors should be appropriately located, to identify the gas leaks as quick as possible
3. Ensure elimination of all the ignition sources by provision of flame proof electrical fittings as per hazardous area classification, and also by incorporating operational controls by prohibiting use of spark generating equipment such as mobile phone/camera. All the tools and tackles used in this area shall be spark proof.
4. LPG tankers shall be fitted with spark arrestors within gas farm.
5. Operation and maintenance personnel shall be adequately trained and qualified for unloading of LPG tankers and operation of the facility.
6. Operation checklist in local language and English to be provided near operation area
7. It is suggested to have regular patrolling with critical parameters logging in order to prevent untoward incidents
8. Procedures to verify the testing & inspection records of the LPG tanker at the entry gate shall be developed. Vehicle speed limit within the Gas farm shall be restricted to the maximum of 20 km/hr.
9. Pipeline corridors and unloading area shall be protected with adequate crash barrier to prevent any accidental impacts / Vehicle movement.
10. Temporary stoppers (wheel chock's) to the wheel must be provided for the tanker to prevent rolling or sudden movement of the tanker. Wooden stoppers shall be used to prevent generation of spark.
11. Unauthorized entry into the facility shall be prohibited. Entry and exit shall be strictly controlled

12. The TREM (Transport Emergency) card should be available in the LPG tanker so that in case of any spillage or leakage from the tanker during transit or on road suitable emergency aid becomes easier.

CHAPTER-1

INTRODUCTION

1.0 INTRODUCTION

M/s. Indian Oil Corporation Ltd. (IOCL) intended to conduct an extensive Quantitative risk assessment study for their LPG Bottling Plant facilities at Pondicherry to assess the risk associated with loss of containment of the various process involved. This scope was awarded to Ultra – Tech Environmental Consultancy and accordingly they conducted the risk assessment study to provide a better understanding of the risk posed to the plant and surrounding population. The consequences & Risk estimation modeling was conducted using PHASTRISK (Version 6.7) software developed by DNV GL.

1.1 Scope of Study

The scope of the QRA is given below:

- Identification of Hazards and Major Loss of Containment (LOC) events.
- Calculation of physical effects of accidental scenarios, which includes frequency analysis for incident scenarios leading to hazards to people and facilities (flammable gas, fire, and smoke and explosion overpressure hazards) and consequence analysis for the identified hazards covering impact on people and potential escalation.
- Damage limits identification and quantification of the risks and contour mapping on the plant layout.
- Risk contour mapping.
- Evaluation of risks against risk acceptable limit
- Risk reduction measures to prevent incident to control the accident
- Hazard mitigation recommendations based on QRA
- Provide consolidated conclusion on QRA of location

1.2 Facility Description

1.2.1 Geographic Location

IOCL is located 8km away from the Pondicherry city, near Villianur village which is located at distance of about 2km from the Terminal.

1.2.2 Description of the Facility

The main operation of LPG Bottling Plant in Pondicherry is to receive bulk LPG, store into mounded storage vessels, bottle in cylinders and dispatch the same to distributors in Pondicherry and adjoining districts.

There are mainly two operations:

- Shed operation
- TLD (Tank Truck Decantation) operation

In TLD operation,the product i.e. LPG from tank truck is received and transferred into Mounded Storage Vessels andbottled in cylinders and dispatched in lorries to various consumers in Pondicherry.

The Bottling Plant hasexpanded their storage capacity to 900MT from 300MT.

1.3 Disclaimer

The advice rendered by consultants is in the nature of guidelines based on good engineering practices and generally accepted safety procedures and consultants do not accept any liability for the same. The recommendations shown in the report are advisory in nature and not binding on the parties involved viz. Ultra- Tech Environmental Consultancy and IOCL.

1.4 Acknowledgement

Ultra-Tech gratefully acknowledges the co-operation received from the management of IOCL during the study. Ultra-Tech in particular would like to thank their entire teamfor their support and help throughout the study.

CHAPTER -2
METHODOLOGY

2.0 QUANTITATIVE RISK ANALYSIS – METHODOLGY

2.1 An Overview

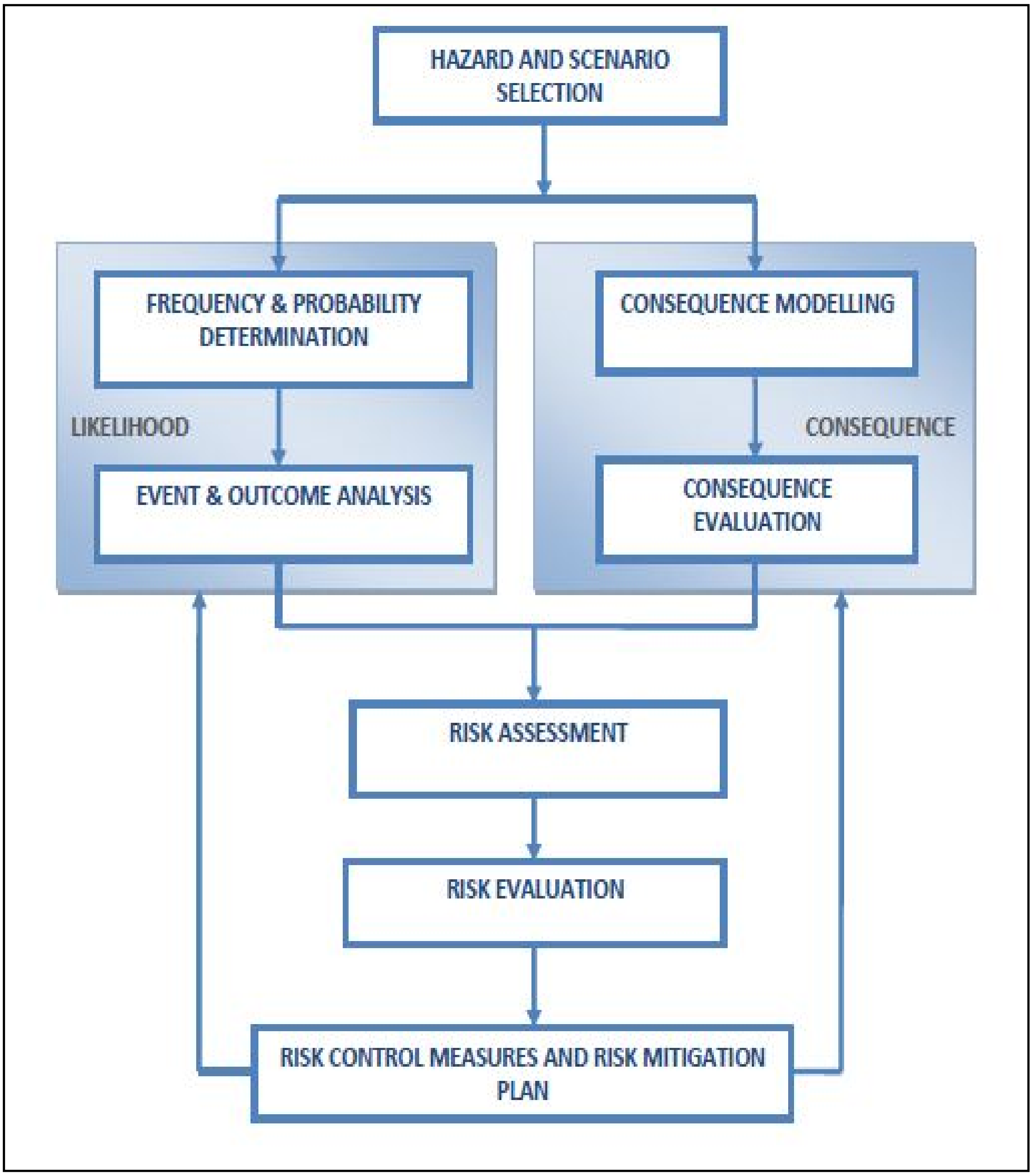
Risk Analysis is proven valuable as a management tool in assessing the overall safety performance of the Chemical Process Industry. Although management systems such as engineering codes, checklists, and reviews by experienced engineers have provided substantial safety assurances, major incidents involving numerous casualties, injuries and significant damage can occur - as illustrated by recent world-scale catastrophes. Risk Analysis techniques provide advanced quantitative means to supplement other hazard identification, analysis, assessment, control and management methods to identify the potential for such incidents and to evaluate control strategies.

The underlying basis of Risk Analysis is simple in concept. It offers methods to answer the following four questions:

1. What can go wrong?
2. What are the causes?
3. What are the consequences?
4. How likely is it?

This study tries to quantify the risks to rank them accordingly based on their severity and probability. The report should be used to understand the significance of existing control measures and to follow the measures continuously. Wherever possible the additional risk control measures should be adopted to bring down the risk levels. The methodology adopted for the QRA Study has been depicted in the Flow chart given below:

Figure 1 Methodology



2.2 Risk Assessment Procedure

Hazard identification and risk assessment involves a series of steps as follows:

Step 1: Identification of the Hazard

Based on consideration of factors such as the physical & chemical properties of the fluids being handled, the arrangement of equipment, operating & maintenance procedures and process conditions, external hazards such as third party interference, extreme environmental conditions, aircraft / helicopter crash should also be considered.

Step 2: Assessment of the Risk

Arising from the hazards and consideration of its tolerability to personnel, the facility and the environment, this involves the identification of initiating events, possible accident sequences, and likelihood of occurrence and assessment of the consequences. The acceptability of the estimated risk must then be judged based upon criteria appropriate to the particular situation.

Step 3: Elimination or Reduction of the Risk

Where this is deemed to be necessary, this involves identifying opportunities to reduce the likelihood and/or consequence of an accident.

Hazard Identification is a critical step in Risk Analysis. Many aids are available, including experience, engineering codes, checklists, detailed process knowledge, equipment failure experience, hazard index techniques, What-if Analysis, Hazard and Operability (HAZOP) Studies, Failure Mode and Effects Analysis (FMEA), and Preliminary Hazard Analysis (PHA). In this phase all potential incidents are identified and tabulated. Site visit and study of operations and documents like drawings, process write-up etc. are used for hazard identification.

Assessment of Risks

The assessment of risks is based on the consequences and likelihood. Consequence Estimation is the methodology used to determine the potential for damage or injury from specific incidents. A single incident (e.g. rupture of a pressurized flammable liquid tank) can have many distinct incident outcomes (e.g. Unconfined Vapour Cloud Explosion (UVCE), flash fire.

Likelihood assessment is the methodology used to estimate the frequency or probability of occurrence of an incident. Estimates may be obtained from historical incident data on failure frequencies or from failure sequence models, such as fault trees and event trees. In this study the historical data developed by software models and those collected by CPR18E – Committee for Prevention of Disasters, Netherlands (Edition: PGS 3, 2005) are used.

Risk Assessment combines the consequences and likelihood of all incident outcomes from all selected incidents to provide a measure of risk. The risks of all selected incidents are individually estimated and summed to give an overall measure of risk.

Risk-reduction measures include those to prevent incidents (i.e. reduce the likelihood of occurrence) to control incidents (i.e. limit the extent & duration of a hazardous event) and to mitigate the effects (i.e. reduce the consequences). Preventive measures, such as using inherently safer designs and ensuring asset integrity, should be used wherever practicable. In many cases, the measures to control and mitigate hazards and risks are simple and obvious and involve modifications to conform to standard practice. The general hierarchy of risk reducing measures is:

- Prevention (by distance or design)
- Detection (e.g. fire & gas, Leak detection)
- Control (e.g. emergency shutdown & controlled depressurization)
- Mitigation (e.g. firefighting and passive fire protection)
- Emergency response (in case safety barriers fail)

CHAPTER-3
INPUTS FOR QRA STUDY

3.0 RISK ASSESSMENT METHODOLOGY

3.1 Identificationof Hazards and Release scenarios

A technique commonly used to generate an incident list is to consider potential leaks and major releases from fractures of all process pipelines and vessels. This compilation includes all pipe work and vessels in direct communication, as these may share a significant inventory that cannot be isolated in an emergency. The following data were collected to envisage scenarios:

- Composition of materials stored in vessels / flowing through pipeline
- Inventory of materials stored in vessels
- Flow rate of materials passing through pipelines
- Vessels / Pipeline conditions (phase, temperature, pressure)
- Connecting piping and piping dimensions.

Accidental release of flammable liquids / gases can result in severe consequences. Delayed ignition of flammable gases can result in blast overpressures covering large areas. This may lead to extensive loss of life and property. In contrast, fires have localized consequences. Fires can be put out or contained in most cases; there are few mitigating actions one can take once a flammable gas or a vapour cloud gets released. Major accident hazards arise, therefore, consequent upon the release of flammable gases.

3.2 Factors for Identification of Hazrds

In any installation, main hazard arises due to loss of containment during handling of flammable liquids / gases. To formulate a structured approach to identification of hazards, an understanding of contributory factors is essential.

Blast over Pressures

Blast Overpressures depend upon the reactivity class of material and the amount of gas between two explosive limits. For example, MS once released and not ignited immediately is expected to give rise to a gas cloud. These gases in general have medium reactivity and in case of confinement of the gas cloud, on delayed ignition may result in an explosion and overpressures.

Operating Parameters

Potential gas release for the same material depends significantly on the operating conditions. The gases are likely to operate at atmospheric temperature (and hence high pressures). This operating range is enough to release a large amount of gas in case of a leak / rupture, therefore the pipeline leaks and ruptures need to be considered in the risk analysis calculations.

Inventory

Inventory Analysis is commonly used in understanding the relative hazards and short listing of release scenarios. Inventory plays an important role in regard to the potential hazard. Larger the inventory of a vessel or a system, larger is the quantity of potential release. A practice commonly used to generate an incident list is to consider potential leaks and major releases from fractures of pipelines and vessels/tanks containing sizable inventories.

Range of Incidents

Both the complexity of study and the number of incident outcome cases are affected by the range of initiating events and incidents covered. This not only reflects the inclusion of accidents and / or non-accident-initiated events, but also the size of those events. For instance, studies may evaluate one or more of the following:

- catastrophic failure of container
- large hole (large continuous release)
- smaller holes (continuous release)
- leaks at fittings or valves (small continuous release)

In general, quantitative studies do not include very small continuous releases or short duration small releases if past experience or preliminary consequence modeling shows that such releases do not contribute to the overall risk levels.

3.3 Selection Of Initiating Events And Incidents

The selection of initiating events and incidents should take into account the goals or objectives of the study and the data requirements. The data requirements increase significantly when non - accident - initiated events are included and when the number of release size increase. While the potential range of release sizes is tremendous, groupings are both appropriate and necessitated by data restrictions. The main reasons for including release sizes other than the catastrophic are to reduce the conservatism in an analysis and to better understand the relative contributions to risk of small versus large releases.

As per CPR 18 E guidelines & Reference Manual BEVI Risk Assessments Version 3.2 only the Loss of Containment (LOC) which is basically the release scenarios contributing to the individual and/ or societal risk are included in the QRA. LOCs of the installation are included only if the following conditions are fulfilled:

- Frequency of occurrence is equal to or greater than 10-8 and
- Lethal damage (1% probability) occurs outside the establishment's boundary or the transport route.

There may be number of accidents that may occur quite frequently, but due to proper control measures or fewer quantities of chemicals released, they are controlled effectively. A few examples are a leak from a gasket, pump or valve, release of a chemical from a vent or relief valve, and fire in a pump due to overheating. These accidents generally are controlled before they escalate by using control systems and monitoring devices – used because such piping and equipment are known to sometimes fail or malfunction, leading to problems.

On the other hand, there are less problematic areas / units that are generally ignore or not given due attention. Such LOCs are identified by studying the facilities and Event Tree Analysis etc. and accidents with less consequence are ignored. Some of the critical worst case scenarios identified by the Hazard Identification study are also assessed as per the guidelines of Environment Protection Agency.

3.4 Typesof Outcome Events

In this section of the report we describe the probabilities associated with the sequence of occurrences which must take place for the incident scenarios to produce hazardous effects and the modeling of their effects.

Considering the present case, the outcomes expected are

- Jet fires
- Vapour Cloud Explosion (VCE) and Flash Fire (FF)

Jet fires

Jet fire occurs when a pressurized release (of a flammable fluid) is ignited by any source. They tend to be localized in effect and are mainly of concern in establishing the potential for domino effects and employee safety zones rather than for community risks.

The jet fire model is based on the radiant fraction of total combustion energy, which is assumed to arise from a point slowly along the jet flame path. The jet dispersion model gives the jet flame length.

Vapour Cloud Explosion (VCE)

Vapour cloud explosion is the result of flammable materials in the atmosphere, a subsequent dispersion phase, and after some delay an ignition of the vapour cloud. Turbulence is the governing factor in blast generation, which could intensify combustion to the level that will result in an explosion. Obstacles in the path of vapour cloud or when the cloud finds a confined area, as under the bullets, often create turbulence. Insignificant level of confinement will result in a flash fire. The VCE will result in overpressures.

It may be noted that VCEs have been responsible for very serious accidents involving severe property damage and loss of lives. Vapour Cloud Explosions in the open area with respect to Pure Methane is virtually impossible due to their lower density.

3.5 Probabilities

3.5.1 Population Probabilities

It is necessary to know the population exposure in order to estimate the consequences and the risk resulting from an incident. The exposed population is often defined using a population density. Population densities are an important part of a QRA for several reasons. The most notable is that the density is typically used to determine the number of people affected by a given incident with a specific hazard area. Sometimes, population data are available in sketchy forms. In the absence of specific population data default categories can be used.

The population density can be averaged over the whole area that may be affected or the area can be subdivided into any number of segments with a separate population density for each individual segment. The population data for the outside population and inside population has been taken as provided by the local IOCL management.

3.5.2 Failure/Accident Probabilities

The failure data is taken from CPR 18E –Guidelines for Quantitative Risk Assessment, developed by the Committee for the Prevention of Disasters, Netherlands.

The failure frequency data and list of scenarios is given in Table No.3

3.5.3 Weather Probabilities

The following meteorological data is used for the study:

Wind Speed	: 1.5m/s and 5m/s
Atmospheric Temperature	: 30°C
Atmospheric Pressure	: 101.325 KN/m2
Humidity	: 74%
Surface roughness	: 0.02 m
Wind stability class	: F & D (1.5F & 5D)

Wind proportion in each direction with respect to each wind speed is calculated and tabulated below based on the wind rose chart of Pondicherry.

Table 1:Wind Proportion Details

wind speed m/s	0	>0.3	>1.6	>3.4	>5.5	>8	>10.8	>13.9	>17.2
N	0.00023	0.00468	0.01849	0.03801	0.01735	0.00171	0.00000	0.00000	0.00000
NNE	0.00023	0.00388	0.01963	0.04578	0.03174	0.00148	0.00000	0.00000	0.00000
NE	0.00011	0.00320	0.01416	0.03425	0.02237	0.00046	0.00000	0.00000	0.00000
ENE	0.00034	0.00445	0.01416	0.02215	0.00605	0.00000	0.00000	0.00000	0.00000
E	0.00000	0.00263	0.01176	0.01553	0.00263	0.00000	0.00000	0.00000	0.00000
ESE	0.00023	0.00377	0.01313	0.02340	0.01416	0.00000	0.00000	0.00000	0.00000
SE	0.00011	0.00342	0.01518	0.02808	0.02363	0.00011	0.00000	0.00000	0.00000
SSE	0.00000	0.00342	0.01781	0.03059	0.01210	0.00057	0.00000	0.00000	0.00000
S	0.00057	0.00594	0.02454	0.05183	0.02534	0.00171	0.00000	0.00000	0.00000
SSW	0.00011	0.00377	0.01975	0.04863	0.02568	0.00114	0.00000	0.00000	0.00000
SW	0.00023	0.00411	0.01712	0.05000	0.02637	0.00091	0.00000	0.00000	0.00000
WSW	0.00000	0.00308	0.01039	0.03527	0.03482	0.00240	0.00000	0.00000	0.00000
W	0.00034	0.00434	0.00731	0.01313	0.01176	0.00126	0.00000	0.00000	0.00000
WNW	0.00011	0.00217	0.00354	0.00354	0.00171	0.00023	0.00000	0.00000	0.00000
NW	0.00023	0.00297	0.00354	0.00046	0.00183	0.00091	0.00034	0.00011	0.00000
NNW	0.00000	0.00240	0.00559	0.00765	0.00400	0.00068	0.00000	0.00000	0.00000

Stability Class

The tendency of the atmosphere to resist or enhance vertical motion and thus turbulence is termed as stability. Stability is related to both the change of temperature with height (the lapse rate) driven by the boundary layer energy budget, and wind speed together with surface characteristics (roughness).

A neutral atmosphere neither enhances nor inhibits mechanical turbulence. An unstable atmosphere enhances turbulence, whereas a stable atmosphere inhibits mechanical turbulence.

Stability classes are defined for different meteorological situations, characterized by wind speed and solar radiation (during the day) and cloud cover during the night. The so called Pasquill-Turner stability classes' dispersion estimates include six (6) stability classes as below:

A – Very Unstable

B – Unstable

C – Slightly Unstable

D – Neutral

E – Stable

F – Very Stable

The typical stability classes for various wind speed and radiation levels during entire day are presented in table below:

Table 2Pasquill'sStability Class

Wind Speed (m/s)	Day : Solar Radiation			Night : cloud Cover		
	Strong	Moderate	Slight	Thinly < 40%	Moderate	Overcast > 80%
<2	A	A-B	B	-	-	D
2-3	A-B	B	C	E	F	D
3-5	B	B-C	C	D	E	D
5-6	C	C-D	D	D	D	D
>6	C	D	D	D	D	D

For the study purpose, and consistent with good industry practice, the following weather conditions have been considered:

- 1.5F - F stability class and wind speed of 1.5m/sec
- 5D - D stability class and wind speed of 5m/sec

3.5.4 Ignition Probabilites

For gas/ oil releases from the gas/ oil handling system, where a large percentage of rupture events may be due to third party damage, a relatively high probability of immediate ignition is generally used.

Delayed ignition takes other factors into account. Delayed ignition probabilities can also be determined as a function of the cloud area or the location. In general, as the size of the cloud increases, the probability of delayed ignition decreases. This is due to the likelihood that the cloud has already encountered an ignition source and ignited before dispersing over a larger area (i.e. the cloud reaches an ignition source relatively close to the point of origin).

For this study the ignition probabilities have been modified to suit the existing site conditions. The ignition probabilities inside enclosed areas shall be much higher than the open areas. It is because of the fact that there will be much more activities taking place and the possibility of ignition increases.

CHAPTER -4

SCENARIO SELECTION

4.0 SCENARIO SELECTION

4.1 Scenario Selection of QRA Study

This section documents the consequence-distance calculations, which have been computed for the accident release scenarios considered

In Risk Analysis studies contributions from low frequency - high outcome effect as well as high frequency - low outcome events are distinguished; the objective of the study is emergency planning, hence only holistic & conservative assumptions are used for obvious reasons. Hence though the outcomes may look pessimistic, the planning for emergency concept should be borne in mind whilst interpreting the results.

For this study rupture of LPG storage tank is not considered as it's a mounded storage so the possibility of rupture of tank is nearly impossible. Similarly rupture of Road tanker within the IOCL scope is not possible so it is not considered for the study.

For this study, Major Accident Events (MAE) or Loss ofcontainment (LOC) Scenarios were selected for modeling based on the HAZID/HAZOP discussions. Thediscussions were recorded using PHA PRO software and the register is attached as Annexure 2 & 3.

The below risk matrix was used for the HAZOP discussion.

		Risk				
Severity		1 Near Impossible	2 Unlikely	3 Notable Chance	4 Likely	5 Almost Certain
	1 Insignificant	1	2	3	4	5
	2 Minor Injuries	2	4	6	8	10
	3 Notable Injuries	3	6	9	12	15
	4 Major Injuries	4	8	12	16	20
	5 Death	5	10	15	20	25

The following are the LOC scenarios which were selected for modeling.

Table 3:List of Scenarios & Failure Frequency

S. No	Scenario	Description	Pressure, Bar	Temperature °C	Flow rate, m3/hr	Diameter in m	Length of Pipeline/ equipment m	Total Inventory m3	Calculated Failure Frequency
IS 1	**Leak**	LPG from Road tanker to Bullet	8	30	90	0.1016	125	1.327912311	2.50E-06
	Rupture				90	0.1016	125	4.0129012	3.75E-07
IS 2	**Leak**	LPG storage bullet (ROV upstream flange leak)	8	30	-	-	-	300	1.00E-07
IS 3	**Leak**	LPG from bullet to pump suction	8	30	48	0.1016	90	1.044299975	1.80E-06
	Rupture				48	0.1016	90	2.329288864	2.70E-07
IS 4	**Leak**	LPG pump dis to filling carousal	18	30	48	0.1016	90	1.201535531	1.80E-06
	Rupture				48	0.1016	90	2.329288864	2.70E-07
IS 5	**Leak**	LPG vapor from bullet to compressor inlet	8	40	255	0.1016	90	1.044299975	1.80E-06
	Rupture				255	0.1016	90	9.222622197	2.70E-07
IS 6	**Leak**	LPG vapor from compressor discharge to TLD	10	55	255	0.1016	50	0.454177813	1.00E-06
	Rupture				255	0.1016	50	8.898493813	1.50E-07
IS 7	**Leak**	Vapor recovery from	8	40	255	0.1016	50	0.720171591	1.00E-06

S. No	Scenario	Description	Pressure, Bar	Temperature °C	Flow rate, m3/hr	Diameter in m	Length of Pipeline/ equipment m	Total Inventory m3	Calculated Failure Frequency
	Rupture	tanker to compressor inlet			255	0.1016	50	8.898493813	1.50E-07
IS 8	**Leak**	LPG vapor from compressor discharge to bullet inlet	9	55	255	0.1016	41	0.376362927	8.20E-07
	Rupture				255	0.1016	41	8.825564927	1.23E-07
IS 9	**Leak**	Unloading arm	8	30	12	0.1016	2	0.33121753	8.76E-06
	Rupture				12	0.1016	2	0.416206419	8.76E-07
IS 10	**Leak**	Main evacuation hose leak	6	30	18	0.0381	1.5	0.005991737	6.57E-04

CHAPTER -5

CONSEQUENCE ANALYSIS

5.0 CONSEQUENCCE ANALYSIS

5.1 Consequence Calculations

In consequence analysis, use is made of a number of calculation models to estimate the physical effects of an accident (spill of hazardous material) and to predict the damage (lethality, injury, material destruction) of the effects.

Accidental release of flammable liquids / gases can result in severe consequences. Immediate ignition of the pressurized chemical will result in a jet flame. Delayed ignition of flammable vapors can result in blast overpressures covering large areas. This may lead to extensive loss of life and property. In contrast, fires have localized consequences. Fires can be put out or contained in most cases; there are few mitigating actions one can take once a vapour cloud gets released.

The calculations can roughly be divided in three major groups:

a) Determination of the source strength parameters;

b) Determination of the consequential effects;

c) Determination of the damage or damage distances.

The basic physical effect models consist of the following.

Source strength parameters

- Calculation of the outflow of liquid out of a vessel / Tank or a pipe, in case of rupture. Also Two-phase outflow can be calculated.
- Calculation, in case of liquid outflow, of the instantaneous flash evaporation and of the dimensions of the remaining liquid pool.
- Calculation of the evaporation rate, as a function of volatility of the material, pool dimensions and wind velocity.
- Source strength equals pump capacities, etc. in some cases.

Consequential effects

- Dispersion of gaseous material in the atmosphere as a function of source strength, relative density of the gas, weather conditions and topographical situation of the surrounding area.
- Intensity of heat radiation [in kW/ m2] due to a fire, as a function of the distance to the source.
- Energy of vapour cloud explosions [in N/m2], as a function of the distance to the distance of the exploding cloud.
- Concentration of gaseous material in the atmosphere, due to the dispersion of evaporated chemical. The latter can be either explosive or toxic.

It may be obvious, that the types of models that must be used in a specific risk study strongly depend upon the type of material involved:

- Gas, vapour, liquid, solid
- Inflammable, explosive, toxic, toxic combustion products
- Stored at high/low temperatures or pressure
- Controlled outflow (pump capacity) or catastrophic failure

5.2 Selection Of Damage Criteria

The damage criteria give the relation between the extents of the physical effects (exposure) and the effect of consequences. For assessing the effects on human being consequences are expressed in terms of injuries and the effects on equipment / property in terms of monetary loss.

The effect of consequences for release of toxic substances or fire can be categorized as

- Damage caused by heat radiation on material and people;
- Damage caused by explosion on structure and people;
- Damage caused by toxic exposure.

In Consequence Analysis studies, in principle three types of exposure to hazardous effects are distinguished:

1. Heat radiation due to fires. In this study, the concern is that of Jet fires and flash fires.
2. Explosions
3. Toxic effects, from toxic materials or toxic combustion products.

The knowledge about these relations depends strongly on the nature of the exposure. Following are the criteria selected for damage estimation:

Heat Radiation:

The effect of fire on a human being is in the form of burns. There are three categories of burn such as first degree, second degree and third degree burns. The consequences caused by exposure to heat radiation are a function of:

- The radiation energy onto the human body [kW/m^2];
- The exposure duration [sec];
- The protection of the skin tissue (clothed or naked body).

The limits for 1% of the exposed people to be killed due to heat radiation, and for second-degree burns are given in the table below:

Table 4:Effects Due to Incident Radiation Intensity

Incident Radiation (kW/m^2)	Type of Damage
0.7	Equivalent to Solar Radiation
1.6	No discomfort for long exposure
4.0	Sufficient to cause pain within 20 sec. Blistering of skin (first degree burns are likely)
9.5	Pain threshold reached after 8 sec. second degree burns after 20 sec.
12.5	Minimum energy required for piloted ignition of wood, melting plastic tubing's etc.

Incident Radiation (kW/m^2)	Type of Damage
37.5	Damage to process equipment's

The actual results would be less severe due to the various assumptions made in the models arising out of the flame geometry, emissivity, angle of incidence, view factor and others. The radiative output of the flame would be dependent upon the fire size, extent of mixing with air and the flame temperature. Some fraction of the radiation is absorbed by carbon dioxide and water vapour in the intervening atmosphere. Finally, the incident flux at an observer location would depend upon the radiation view factor, which is a function of the distance from the flame surface, the observer's orientation and the flame geometry.

Assumptions made for the study (As per the guidelines of CPR 18E Purple Book)

- The lethality of a jet fire is assumed to be 100% for the people who are caught in the flame. Outside the flame area, the lethality depends on the heat radiation distances.
- For the flash fires lethality is taken as 100% for all the people caught outdoors and for 10% who are indoors within the flammable cloud. No fatality has been assumed outside the flash fire area.

Overpressure:

Vapour cloud Explosion (VCE)

The assessment aims to determine the impact of overpressure in the event that a flammable gas cloud is ignited. The TNO multi energy model is used to model vapour cloud explosions.

A Vapour cloud Explosion (VCE) results when a flammable vapor is released, its mixture with air will form a flammable vapour cloud. If ignited, the flame speed may accelerate to high velocities and produce significant blast overexposure.

The damage effects due to 20mbar, 140mbar & 210mbar are reported in terms of distance from the overpressure source.

In case of vapour cloud explosion, two physical effects may occur:

- A flash fire over the whole length of the explosive gas cloud;
- A blast wave, with typical peak overpressures circular around ignition source.

For the blast wave, the lethality criterion is based on:

- A peak overpressure of 0.1bar will cause serious damage to 10% of the housing/structures.
- Falling fragments will kill one of each eight persons in the destroyed buildings.

The following damage criteria may be distinguished with respect to the peak overpressures resulting from a blast wave:

Table 5: Damage due to overpressure

Peak Overpressure	Damage Type	Description
0.30 bar	Heavy Damage	Major damage to plant equipment structure
0.10 bar	Moderate Damage	Repairable damage to plant equipment structure
0.03 bar	Significant Damage	Shattering of glass
0.01 bar	Minor Damage	Crack in glass

Assumptions for the study (As per the guidelines of CPR 18 E Purple Book)

- Overpressure more than 0.3bar corresponds approximately with 50% lethality.
- An overpressure above 0.2bar would result in 10% fatalities.
- An overpressure less than 0.1bar would not cause any fatalities to the public.
- 100% lethality is assumed for all people who are present within the cloud proper.

5.3 Consequence Results

Table 6: Consequence Results

Scenario. No	Description	Weather	Flash Fire	Jet Fire			Explosion		
			LFL	4 KW/M2	12.5 KW/M2	37.5 KW/M2	0.03 bar	0.1 bar	0.3 bar
IS1 L	LPG from Road tanker to Bullet	1.5 F	16.70	30.97	24.83	21.09	63.61	50.07	45.03
		5 D	11.77	27.39	20.85	16.95	38.23	27.77	23.88
IS1 R		1.5 F	86.75	96.75	76.89	65.00	286.50	225.42	202.68
		5 D	86.95	86.40	65.22	52.75	239.97	188.37	169.16
IS2 L	LPG storage bullet (ROV upstream flange leak)	1.5 F	0.957117	20.7347	9.60718	NR	NA	NA	NA
		5 D	1.38536	20.8607	12.4239	7.25855	NA	NA	NA
IS3 L	LPG from bullet to pump suction	1.5 F	17.15	31.62	25.35	21.53	64.16	50.30	45.15
		5 D	12.16	27.97	21.29	17.31	48.68	37.96	33.98
IS3 R		1.5 F	63.31	75.70	60.29	51.05	218.51	173.48	156.72
		5 D	57.71	67.47	51.04	41.35	175.64	137.99	123.98
IS4 L	LPG pump dis to filling carousal	1.5 F	21.27	36.86	29.53	25.09	79.62	62.63	56.31
		5 D	15.96	32.63	24.82	20.20	63.02	49.82	44.90
IS4 R		1.5 F	60.83	74.96	59.72	50.59	205.41	162.16	146.06

Scenario. No	Description	Weather	Flash Fire	Jet Fire			Explosion		
			LFL	4 KW/M2	12.5 KW/M2	37.5 KW/M2	0.03 bar	0.1 bar	0.3 bar
		5 D	55.81	66.76	50.53	40.97	174.05	137.32	123.64
IS5 L	LPG vapor from bullet to compressor inlet	1.5 F	3.77	6.55	NR	NR	NA	NA	NA
		5 D	3.28	6.42	NR	NR	NA	NA	NA
IS5 R		1.5 F	11.24	22.41	17.58	12.94	36.36	26.98	23.48
		5 D	9.03	22.81	18.85	15.16	34.19	26.05	23.02
IS6 L	LPG vapor from compressor discharge to TLD	1.5 F	4.04	7.28	NR	NR	NA	NA	NA
		5 D	3.52	7.17	NR	NR	NA	NA	NA
IS6 R		1.5 F	13.78	26.90	21.13	16.42	49.67	38.39	34.19
		5 D	11.17	27.31	22.52	18.53	37.02	27.26	23.62
IS7 L	Vapor recovery from tanker to compressor inlet	1.5 F	3.77	6.55	NR	NR	NA	NA	NA
		5 D	3.28	6.42	NR	NR	NA	NA	NA
IS7 R		1.5 F	10.44	21.22	16.68	11.98	35.31	26.53	23.26
		5 D	8.53	21.55	17.81	14.07	23.43	15.73	12.86
IS8 L	LPG vapor from compressor discharge to bullet inlet	1.5 F	3.84	6.81	NR	NR	NA	NA	NA
		5 D	3.36	6.66	NR	NR	NA	NA	NA

Scenario. No	Description	Weather	Flash Fire	Jet Fire			Explosion		
			LFL	4 KW/M2	12.5 KW/M2	37.5 KW/M2	0.03 bar	0.1 bar	0.3 bar
IS8 R		1.5 F	13.71	26.79	21.04	16.34	49.58	38.35	34.17
		5 D	11.11	24.20	22.43	18.46	36.93	27.22	23.61
IS9 L	Unloading arm	1.5 F	16.70	30.97	24.83	21.09	63.61	50.07	45.03
		5 D	11.77	27.39	20.85	16.95	38.22	27.77	23.88
IS9 R		1.5 F	19.80	34.66	27.77	23.59	77.72	61.82	55.90
		5 D	14.33	30.69	23.34	18.98	51.22	39.05	34.52
IS10 L	Main evacuation hose leak	1.5 F	1.04	NR	NR	NR	12.03	5.13	2.56
		5 D	0.96	NR	NR	NR	12.03	5.13	2.56

Legend:

NA➔ Not Applicable

NR ➔ Not Reached

Impact Analysis:

As highlighted in table above, the maximum damage distance reached for Flash Fire is for cases IS-1, LPG from Road tanker to Bulletrupture at 5D weather condition. The maximum damage distance for Flash Fire is 87m (LFL).

The maximum damage distance reached for Jet Fire is for IS-1, LPG from Road tanker to Bulletrupture at 1.5F weather condition. First degree burns can be experiences up to a distance of 97m (4Kw/m2), second degree burns (piloted ignition of wood, etc.) can be experienced up to a distance of 77m (12.5Kw/m2); 99% fatality (damage to process equipment) can be experienced up to a distance of 65 m.

As highlighted in table above, the maximum damage distance reached is for the case IS-1, LPG from Road tanker to Bulletrupture at 1.5 F weather condition. 10% of window glasses are broken up to a distance of 287m, repairable damage to building and houses can be experienced up to a distance of 225 m and Heavy machines (3000 lb.) in industrial building suffered little damage, steel frame building and pulled away from foundations can be experienced up to a distance of 203 m.

5.4 Frequency Analysis

Frequency estimates have been obtained from historical incident data on failure frequencies and from failure sequence models (event trees). In this study the historical data available in international renowned databases will be used.

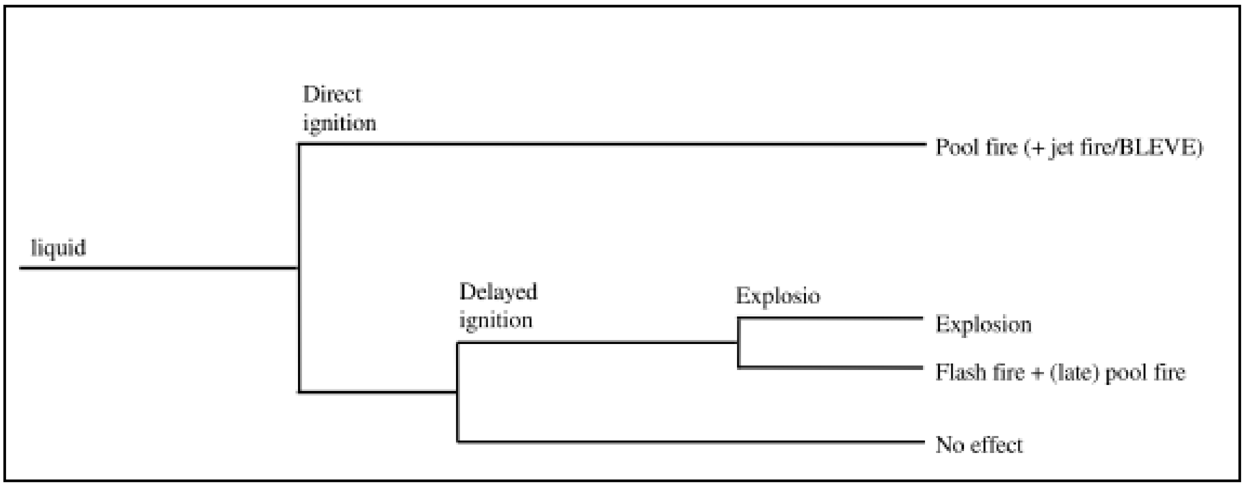
Reference Manual Bevi Risk Assessments version 3.2

CPR 18E – Committee for Prevention of Disasters, Netherlands

The scenario list and frequencies are available in Table No. 3

Event tree analysis

A release can result in several possible outcomes or scenarios (fire, explosions, unignited release etc.). This is because the actual outcome depends on other events that may or may not occur following the initial release. Event tree analysis is used to identify potential outcomes of a release and to quantify the risk associated with each of these outcomes.



The above event tree is used for calculating the event frequencies and the probabilities are defined in below:

1. <u>Immediate Ignition Probability</u>

Release Rate	Immediate Ignition Probability (for Low / Medium Reactive Chemicals)	Delayed Ignition Probability
< 10 kg/sec	0.02	0.01
10 to 100 kg/sec	0.04	0.05
> 100 kg/sec	0.08	0.1

The above table from Bevi manual & CPR 18E is used for ignition probability.

2. <u>Explosion Probability</u>

In the sequence of events, following the ignition of a free gas cloud, an incident occurs demonstrating characteristics of both a flash fire and an explosion. This is modeled as two separate events: as a pure flash fire and a pure explosion. The fraction that is modeled as an explosion, F explosion, is equal to 0.4.

The leak detection and shutdown systems are classified as Automatic, Semi-automatic & Manual systems based on the leak detection facilities.

CHAPTER -6

RISK ANALYSIS

6.0 RISK ANALYSIS

6.1 Risk Concept

Risk in general is defined as a measure of potential economic loss or human injury in terms of the probability of the loss or injury occurring and magnitude of the loss or injury if it occurs. Risk thus comprises of two variables; magnitude of consequences and the probability of occurrence. The results of Risk Analysis are often reproduced as Individual and groups risks and are defined as below.

Individual Risk is the probability of death occurring as a result of accidents at a plant, installation or a transport route expressed as a function of the distance from such an activity. It is the frequency at which an individual or an individual within a group may be expected to sustain a given level of harm (typically death) from the realization of specific hazards.

Such a risk actually exists only when a person is permanently at that spot (out of doors). The Individual results are based on the occupancy factor for different category of personnel at that particular location.

Individual Risk = Location Specific Individual risk * Occupancy factor

Whereas, Location Specific Individual Risk corresponds to the level of damage at a particular location or area.

The exposure of an individual is related to:

- The likelihood of occurrence of an event involving a release and Ignition of hydrocarbon,
- The vulnerability of the person to the event,
- The proportion of time the person will be exposed to the event (which is termed 'occupancy' in the QRA terminology).

The second definition of risk involves the concept of the summation of risk from events involving many fatalities within specific population groups. This definition is focused on the risk to society rather than to a specific individual and is termed **'Societal Risk'**. In relation to the process operations we can identify specific groups of people who work on or live close to the installation; for example, communities living or working close to the plant.

6.2 Risk Estimation

6.3 Individual Risk

The Individual Risk (IR) measure, expresses the risk exposure to any Individual who is continuously present in a particular area for the whole year. The risk exposure is calculated for all relevant hazards and summed to give the overall risks for the installation. The IR output from PHASTRISK is shown below:

Overall Individual Risk at 1.5F& 5D weather condition;

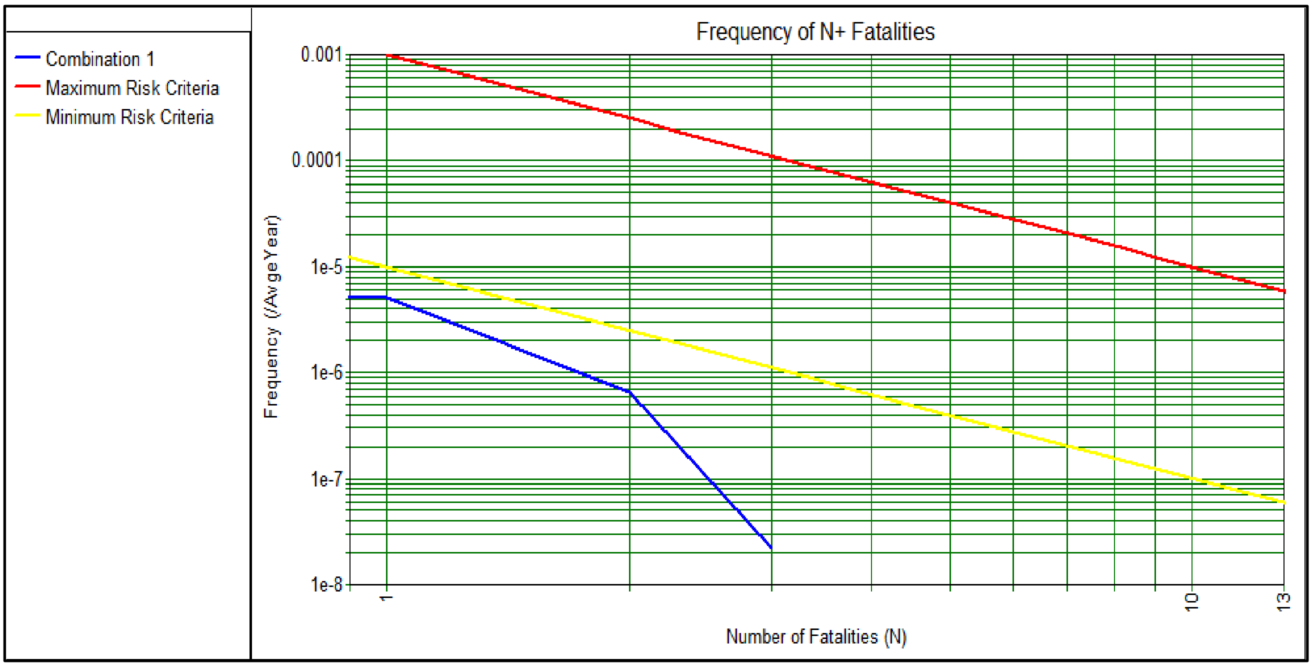
Individual Risk is 6.20E-06Per Avg Year

6.4 Societal Risk

The SR output from PHASTRISK for LPG Bottling Plant, Pondicherry is shown below:

Societal Risk at 1.5F& 5D weather condition;

Societal Risk is 5.83E-06Per Avg Year



Individual and Societal risk of each scenarios is given below in the table

Table 7 Individual and Societal Risk of each scenarios

Scenarios		Individual Risk per Avg year	Societal Risk per Avg year
IS1 L -10 mm	LPG from Road tanker to Bullet	Negligible	Negligible
IS1 Rupture		7.51E-09	1.17E-08
IS2 L -10 mm	LPG storage bullet (ROV upstream flange leak)	Negligible	Negligible
IS3 L -10 mm	LPG from bullet to pump suction	Negligible	Negligible
IS3 Rupture		6.45E-10	1.15E-09
IS4 L -10 mm	LPG pump dis to filling carousal	1.13E-07	9.85E-08
IS4 Rupture		7.96E-08	7.45E-08
IS5 L -10 mm	LPG vapor from bullet to compressor inlet	1.64E-17	1.74E-15
IS5 Rupture		1.99E-09	1.07E-09

Scenarios		Individual Risk per Avg year	Societal Risk per Avg year
IS6 L -10 mm	LPG vapor from compressor discharge to TLD	5.68E-12	8.12E-13
IS6 Rupture		2.91E-09	2.04E-09
IS7 L -10 mm	Vapor recovery from tanker to compressor inlet	3.79E-15	1.45E-14
IS7 Rupture		9.91E-10	4.74E-10
IS8 L -10 mm	LPG vapor from compressor discharge to bullet inlet	1.19E-13	1.47E-13
IS8 Rupture		2.38E-09	1.66E-09
IS9 L -10 mm	Unloading arm	2.58E-06	2.20E-06
IS9 Rupture		2.74E-07	2.39E-07
IS10 L -3 mm	Main evacuation hose leak	3.25E-06	3.19E-06

6.5 Risk Acceptance Criteria

In India, there is yet to define Risk Acceptance Criteria. However, in IS 15656 – Code of Practice for Hazard Identification and Risk Analysis, the risk criteria adopted in some countries are shown. Extracts for the same is presented below:

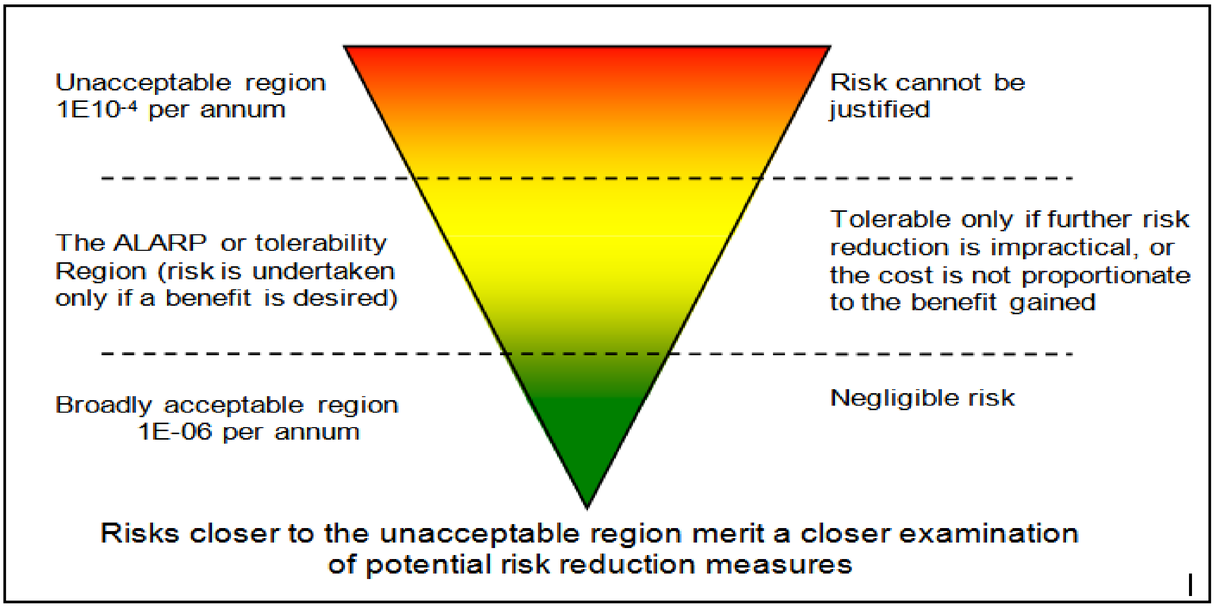
Table 8: Risk Criteria

Authority and Application	Maximum Tolerable Risk (per year)	Negligible Risk (per year)
VROM, The Netherlands (New)	1.0E-6	1.0E-8
VROM, The Netherlands (existing)	1.0E-5	1.0E-8
HSE, UK (existing-hazardous industry)	1.0E-4	1.0E-6
HSE, UK (New nuclear power station)	1.0E-5	1.0E-6
HSE, UK (Substance transport)	1.0E-4	1.0E-6
HSE, UK (New housing near plants)	3.0E-6	3.0E-7
Hong Kong Government (New plants)	1.0E-5	Not used

6.6 ALARP

To achieve the above risk acceptance criteria, ALARP principle was followed while suggesting risk reduction recommendations.

Figure 2 ALARP



As per the risk acceptance criteria, the risk (IR) of IOCL, Pondicherry LPG Bottling Plant falls in Acceptableregion.

CHAPTER -7
RECOMMENDATIONS

7.0 RECOMMENDATIONS

Based on the outcome of the QRA report, it is inferred that present risk levels posed by Pondicherry LPG Bottling Plant is in ALARP region.

And as per Consequence analysis maximum damage is caused by rupture of LPG pipeline from road tanker to bullet. LFL contour travels up to 86 m at 5D wind condition.

Some of the important suggested risk control measures are provided below:

1. Safety interlocks systems for pumps, compressors, bullets to be verified, counterchecked to make sure proper operation in the event of any failures
2. Gas detectors should be appropriately located, to identify the gas leaks as quick as possible
3. Ensure elimination of all the ignition sources by provision of flame proof electrical fittings as per hazardous area classification, and also by incorporating operational controls by prohibiting use of spark generating equipment such as mobile phone/camera. All the tools and tackles used in this area shall be spark proof.
4. LPG tankers shall be fitted with spark arrestors within gas farm.
5. Operation and maintenance personnel shall be adequately trained and qualified for unloading of LPG tankers and operation of the facility.
6. Operation checklist in local language and English to be provided near operation area
7. It is suggested to have regular patrolling with critical parameters logging in order to prevent untoward incidents
8. Procedures to verify the testing & inspection records of the LPG tanker at the entry gate shall be developed. Vehicle speed limit within the Gas farm shall be restricted to the maximum of 20 km/hr.
9. Pipeline corridors and unloading area shall be protected with adequate crash barrier to prevent any accidental impacts / Vehicle movement.
10. Temporary stoppers (wheel chock’s) to the wheel must be provided for the tanker to prevent rolling or sudden movement of the tanker. Wooden stoppers shall be used to prevent generation of spark.
11. Unauthorized entry into the facility shall be prohibited. Entry and exit shall be strictly controlled

The TREM (Transport Emergency) card should be available in the LPG tanker so that in case of any spillage or leakage from the tanker during transit or on road suitable emergency aid becomes easier.

CHAPTER -8
REFFERENCE

8.0 REFERENCE

1 Reference Manual Bevi Risk Assessments version 3.2 , Netherlands

2 CPR 18E – Committee for Prevention of Disasters, Netherlands

3 A guide to Chemical Process Quantitative Risk Analysis – Centre for Chemical Process Safety DNV GL, PHAST-RISK (Safeti), Version 6.7,

4 http://www.dnv.com/services/software/products/safeti/safeti/index.asp

5 Buncefield Major Incident Investigation Board, "The Buncefield Incident 11 December 2005, The Final Report of the Major Incident Investigation Board", December 2008

6 Census 2011

ANNEXURE – 1

CONSEQUENCE CONTOURS

FLASH FIRE PROFILES AT 1.5F WEATHER CONDITON

IS 1 R LPG Liquidfrom road tanker to Bullet.

IS 4R LPG pumpdischargeto fillingcarousal

IS5 R LPG vapor from bullet to compresor inlet

IS6 R LPG vapor from compressor discharge to TLD

IS9 R Unloading arm

ANNEXURE – 2

HAZOP

Node 1:LPG pump from bullet to carousal

Cause	Consequence	Safeguards	Risk Ranking			Recommendation	Residual Risk		
			L	C	R		L	C	R
Deviation: No/less flow									
1. No level in the mounded bullets	1.Pump damage 2. Operation interruption	1. Pump trips in low pressure 2. Magnetic level indication 3. Rochester Level indication	2	1	2	1. Consider providing low level alarm provision in Rochester			
2. Inadvertent closing of manual block valve	1.Pump damage 2. Operation interruption	1. Pump trips in low pressure 2. SOP is available	3	1	3	2. Ensure SOP's is followed using a checklist			
3.Inadvertant closing of liquid ROV	1.Pump damage 2. Operation interruption	1. Pump trips in low pressure 2. Valve open/close indication at pump house	3	2	6	3. Periodical maintenance of the valve 4. Explore the possibility of configuring audible alarm at the pump house for ROV indication panel	2	2	4

Cause	Consequence	Safeguards	Risk Ranking			Recommendation	Residual Risk		
			L	C	R		L	C	R
4. Failure of utility air supply	1. ROV closure 2. Pump damage 3. Operation interruption	1. Pump trips in low pressure 2. Valve open/close indication at pump house	3	2	6	4. Explore the possibility of configuring audible alarm at the pump house for ROV indication panel 5. Consider providing UPS for air compressor	2	2	4
5.Inadvertant closing of manual block valve in suction line	1.Pump damage 2. Operation interruption	1. Pump trips in low pressure 2. SOP is available	3	2	6	2. Ensure SOP's is followed using a checklist	2	2	4
6. Choking of pump suction strainer	1.Pump damage 2. Operation interruption	1. Pump trips in low pressure 2. Quarterly cleaning schedule is available	2	2	4	6. Consider periodical logging of parameters like suction pressure and motor amps			
7.Inadvertant opening of vent valve	1. Possible fire and explosion 2. Pump damage 3. Operation interruption	1. Pump trips in low pressure 2. SOP is available	2	3	6	7. Consider removing the handle from the valve and secure with a chain for safety	1	3	3

Cause	Consequence	Safeguards	Risk Ranking			Recommendation	Residual Risk		
			L	C	R		L	C	R
8. Pump seal failure	1. Possible fire and explosion 2. Pump damage 3. Operation interruption	1. Pump trips in low pressure 2. Pump Seal failure trip available	2	3	6	8. Consider providing GMS (Gas monitoring system) trip provision to actuate ESD	2	2	4
9.Inadvertant closing of manual block valve in discharge line	1.Pump damage 2. Operation interruption	1. Pump trips in high pressure 2. SOP is available	2	2	4	2. Ensure SOP's is followed using a checklist			
10.Choking of strainer upstream of carousal	1.Operation interruption	1. Bypass is available 2.Pump trips in high pressure 3.Quarterly cleaning schedule is available	2	2	4				
11. Carousal inlet block valve close	1.Operation interruption	1.Pump trips in high pressure 2. SOP is available	2	2	4	9. Consider providing SOP and instruction boards in local language			

Cause	Consequence	Safeguards	Risk Ranking			Recommendation	Residual Risk		
			L	C	R		L	C	R
12. PAV (Pop Action Valve) failure	1. Possible fire and explosion 2. Operation interruption	1. Periodical maintenance (Yearly)	2	2	4				
13. Suction Line flange leak	1. Possible fire and explosion 2. Operation interruption	1. Pump trips in low pressure 2. GMS is available to alert the operator 3. Work permit system available for maintenance activities	2	3	6	10. Provision for operation clearance for critical activities in the plant	2	2	4
14. Discharge Line flange leak	1. Possible fire and explosion 2. Operation interruption	1. Pump trips in low pressure in the discharge line 2. GMS is available to alert the operator 3. Work permit system available for maintenance activities	2	3	6	10. Provision for operation clearance for critical activities in the plant	2	2	4

Cause	Consequence	Safeguards	Risk Ranking			Recommendation	Residual Risk		
			L	C	R		L	C	R
15. Standby pump NRV passing	1. Discharge line pressure reduction 2. Operation interruption	1. Suction discharge pressure indication available	3	1	3	6. Consider periodical logging of parameters like suction pressure and motor amps			
Deviation: High pressure									
1. High pressure in the mounded bullets	1. Possible pipeline leak/rupture	1. Compressor high discharge trip is available 2. High level alarm is available on mounded bullets 3. Level indication is provided to prevent overfilling of the bullets 4. PAV is available to limit the pressure 5. Return line DP valve 6. Pump high discharge pressure	2	2	4				

Cause	Consequence	Safeguards	Risk Ranking			Recommendation	Residual Risk		
			L	C	R		L	C	R
		trip							
2. Simultaneous operation of both the LPG pumps	1. Possible pipeline leak/rupture	1. PAV is available to limit the pressure 2. Return line DP valve 3. Pump high discharge pressure trip	3	1	3	11. Ensure the availability of SOP			
3. Return line DP valve failure	1. Possible pressurization of the upstream pipeline leading to leak/rupture	1. PAV is available to limit the pressure 2. Pump high discharge pressure trip 3. Manual bypass for DP valve	3	1	3				

Cause	Consequence	Safeguards	Risk Ranking			Recommendation	Residual Risk		
			L	C	R		L	C	R
4. Pump discharge NRV stuck closed	1. Possible Pump seal failure	1. Pump trips in high pressure 2. Pump Seal failure trip available 3. PAV is available to limit the pressure	2	3	6	8. Consider providing GMS (Gas monitoring system) trip provision to actuate ESD	2	2	4
Deviation: Reverse/Misdirected flow									
1. Standby pump NRV passing	1. Discharge line pressure reduction 2. Operation interruption	1. Suction discharge pressure indication available	3	1	3	6. Consider periodical logging of parameters like suction pressure and motor amps			
2. LPG return line directed to other bullet which is not in line with pump suction due to main header NRV passing	1. Increase in level in the bullet	1. Level indications are available 2. High level (HL) alarm is available	1	2	2				
Deviation: Low temperature									
1. No significant cause can be identified									

Cause	Consequence	Safeguards	Risk Ranking			Recommendation	Residual Risk		
			L	C	R		L	C	R
Deviation: High temperature									
1. External fire	1. Possible damage to equipment in the facility	1. Fire protection system is available 2. ETB (Emergency trip button) is available	1	5	5	12. Ensure periodical emergency drills conducted	1	4	4
2. Internal fire due to static electricity or lightening	1. Possible damage to equipment in the facility	1. Fire protection system is available 2. ETB (Emergency trip button) is available 3. Earthing protection checks is available	1	5	5	12. Ensure periodical emergency drills conducted	1	4	4
3. Fire due to LPG leak	1. Possible damage to equipment in the facility	1. Fire protection system is available 2. ETB (Emergency trip button) is available 3. GMS is available	1	5	5	12. Ensure periodical emergency drills conducted	1	4	4
Deviation: Maintenance hazard									

Cause	Consequence	Safeguards	Risk Ranking			Recommendation	Residual Risk		
			L	C	R		L	C	R
1. Usage of non-standard material	1. Possible leak leading to fire/explosion	1. Job safety analysis (JSA) is available 2. Material quality check is available 3.Critical operations carried under Supervision. 4. Work permit Is available	2	4	8	13. Completion checklist to be implemented	1	4	4
2. Improper labor supply by the contractor	1. Possible leak leading to fire/explosion	1. Job safety analysis (JSA) is available 2.Critical operations carried under Supervision. 3. Work permit Is available	2	4	8	14. Similar job experience record to be checked by the contractor included in the tender/work order clause	1	4	4

Node 2 : LPG compressor, from 1. Mounded bullets to filling shed 2. TLD to mounded Bullet

Cause	Consequence	Safeguards	Risk Ranking			Recommendation	Residual Risk		
			L	C	R		L	C	R
Deviation: No/less flow									
1. Inadvertent closure of manual block valves	1.Damage to the compressor 2.Operation interruption	1.Compressor Low suction pressure trip is available 2. SOP is available	2	2	4	2. Ensure SOP's is followed using a checklist			
2.Inadvertant closing of vapour ROV	1.Compressor damage 2. Operation interruption	1. Compressor trips in low pressure 2. Valve open/close indication at pump house	3	2	6	3. Periodical maintenance of the valve 4. Explore the possibility of configuring audible alarm at the pump house for ROV indication panel	2	2	4
3. Failure of utility air supply	1. ROV closure 2. Compressor damage 3. Operation interruption	1. Compressor trips in low pressure 2. Valve open/close indication at pump house	3	2	6	4. Explore the possibility of configuring audible alarm at the pump house for ROV indication panel 5. Consider providing UPS for air compressor	2	2	4
4. Suction strainer choke	1.Damage to the compressor	1.Compressor Low suction pressure trip is available	2	2	4				

Cause	Consequence	Safeguards	Risk Ranking			Recommendation	Residual Risk		
			L	C	R		L	C	R
	2.Operation interruption	2. Regular checking is available 3. Stand by compressor is available							
5. Suction Line flange leak	1. Possible fire and explosion 2. Operation interruption	1. Compressor trips in low pressure 2. GMS is available to alert the operator 3. Work permit system available for maintenance activities	2	3	6	10. Provision for operation clearance for critical activities in the plant	2	2	4
6. Discharge Line flange leak	1. Possible fire and explosion 2. Operation interruption	1. Compressor trips in low pressure 2. GMS is available to alert the operator 3. Work permit system available formaintenance activities	2	3	6	10. Provision for operation clearance for critical activities in the plant	2	2	4

Cause	Consequence	Safeguards	Risk Ranking			Recommendation	Residual Risk		
			L	C	R		L	C	R
7. Compressor seal failure	1. Possible fire and explosion 2. Operation interruption	1. GMS is available to alert the operator 2. Pressure indicator (PI) is available to assist the operator 3. Continuous monitoring is available 4. Annual maintenance contract (AMC) is available 5. Periodical logging and inspection available	2	2	4				
8. NRV stuck close in the compressor discharge line	1. Possible pressurization of upstream 2. Operation interruption	1.Compressor high discharge pressure trip is available 2.Compressor high discharge temp. trip is available	2	2	4				
9. Inadvertent opening of Suction/discharge Knock Out drum drain valve	1. Possible fire and explosion 2. Operation interruption	1. Double block valves 2. End blind is provided	2	2	4	13. Completion checklist to be implemented			
10. Low pressure in TLD	No significant consequences	1.Compressor low suction pressure trip is available	2	2	4				

Cause	Consequence	Safeguards	Risk Ranking			Recommendation	Residual Risk		
			L	C	R		L	C	R
Deviation: More flow									
1. Simultaneous operation of both the LPG compressor	1. Possible pipeline leak/rupture	1. Safety relief valve (SRV) is available 2. Pump high discharge pressure trip 3.Compressor high discharge temp. trip is available 4. Continuous monitoring available	3	1	3	11. Ensure the availability of SOP			
Deviation: Reverse/Misdirected flow									
1. Liquid flow from evacuation vessel	1. Compressor damage 2. Seal failure	1. Suction Knock drum high level trip 2. Evacuation vessel changeover 3. Audible alarm is available	2	2	4	11. Ensure the availability of SOP			
Deviation: Low temp									
No causes could be identified									
Deviation: High temp									
1. External fire	1. Possible damage to	1. Fire protection system is available	1	5	5	12. Ensure periodical emergency drills conducted	1	4	4

Cause	Consequence	Safeguards	Risk Ranking			Recommendation	Residual Risk		
			L	C	R		L	C	R
	equipment in the facility	2. ETB (Emergency trip button) is available							
2. Internal fire due to static electricity or lightening	1. Possible damage to equipment in the facility	1. Fire protection system is available 2. ETB (Emergency trip button) is available 3. Earthing protection checks is available	1	5	5	12. Ensure periodical emergency drills conducted	1	4	4
3. Fire due to LPG leak	1. Possible damage to equipment in the facility	1. Fire protection system is available 2. ETB (Emergency trip button) is available 3. GMS is available	1	5	5	12. Ensure periodical emergency drills conducted	1	4	4
4. Failure of cooling water supply	1. Possible damage to equipment in the facility	1. Cooling water low pressure trip is available 2. Continuous monitoring	2	2	4	12. Ensure periodical emergency drills conducted	1	4	4

Node 3 : Mounded bullets

Cause	Consequence	Safeguards	Risk Ranking			Recommendation	Residual Risk		
			L	C	R		L	C	R
Deviation: No/less level									
1. Faulty Level indication	1. Possible pump damage 2. Operation interruption	1. Two different level indicators available 2. Trained operator is available 3. Cross checking of the level indications carried out daily	2	2	4				
2. Leakage of pipeline upstream of ROV	1. Possible fire/explosion	1. GMS is available 2. Periodical NDT of pipeline and vessels is available 3. Periodical hydro testing of pipeline and vessels is available 4. Fire protection system available	1	5	5	10. Provision for operation clearance for critical activities in the plant			

Cause	Consequence	Safeguards	Risk Ranking			Recommendation	Residual Risk		
			L	C	R		L	C	R
3. Inadvertent opening of drain valve	1. Possible fire/explosion	1. GMS is available 2. Fire protection system available 3. Double block with end blind is available 4. Operation will be carried out under supervision 5. Lock out is available	1	5	5	10. Provision for operation clearance for critical activities in the plant			
Deviation: More level									
1. Faulty Level indication/Human error	1. Operation interruption	1. Two different level indicators available 2. Trained operator is available 3. Cross checking of the level indications carried out daily 4. High level alarm is available	2	2	4				
Deviation: High temperature									

Cause	Consequence	Safeguards	Risk Ranking			Recommendation	Residual Risk		
			L	C	R		L	C	R
1. External fire	1. Possible damage to bullet in the facility	1. Fire protection system is available 2. ETB (Emergency trip button) is available	1	5	5	12. Ensure periodical emergency drills conducted	1	4	4
Deviation: High Pressure									
1. High level in the bullets	1. Possible leaks	1. Two different level indicators available 2. Trained operator is available 3. Cross checking of the level indications carried out daily 4. High level alarm is available 5. Pressure indication available 6. SRV is available	1	3	3				

Cause	Consequence	Safeguards	Risk Ranking			Recommendation	Residual Risk		
			L	C	R		L	C	R
2. Compressor high discharge pressure	1. Possible leaks	1. Trained operator is available 2. Pressure indication available 3. SRV is available 4. Compressor high discharge pressure alarm is available	1	3	3				

ANNEXURE – 3

SIMOPS

Simops have been carried out to know the hazards araising during simultaneous operations that take place in the LPG bottling plant and Simops risk matrix is attached. Below table specifies about the activities that should be stopped during operation activities and activities that should be controlled during operation activities.

CONSTRUCTION ACTIVITIES	OPERATION ACTIVITIES
Activities that should be stopped during operation	
survey works, including marking, barricading	1. Emergency drill 2. Plant start up 3. Plant shutdown 4. Real time emergency 5. Pressure testing 6. Activity on emergency utilities 7. Critical equipment switchovers
vehicle entry	1. Emergency drill 2. Plant start up 3. Plant shutdown 4. Real time emergency 5. Pressure testing 6. Activity on emergency utilities 7. Critical equipment switchovers
Excavation	1. Emergency drill 2. Plant start up 3. Plant shutdown 4. Real time emergency

CONSTRUCTION ACTIVITIES	OPERATION ACTIVITIES
	5. Pressure testing 6. Activity on emergency utilities 7. Critical equipment switchovers
Excavation (confined space)	1. Emergency drill 2. Plant start up 3. Plant shutdown 4. Real time emergency 5. Pressure testing 6. Activity on emergency utilities 7. Critical equipment switchovers
civil works (COLD)in confined space	1. Emergency drill 2. Plant start up 3. Plant shutdown 4. Real time emergency 5. Pressure testing 6. Activity on emergency utilities 7. Critical equipment switchovers
Hot Work in confined space	1. venting 2. Draining 3. Flushing 4. Emergency drill 5. Plant start up 6. Plant shutdown 7. Real time emergency 8. Pressure testing

CONSTRUCTION ACTIVITIES	OPERATION ACTIVITIES
	9. Activity on emergency utilities 10. Critical equipment switchovers
Hot work	1. venting 2. Draining 3. Flushing 4. Emergency drill 5. Plant start up 6. Plant shutdown 7. Real time emergency 8. Pressure testing 9. Activity on emergency utilities 10. Critical equipment switchovers
structural installation	1. Emergency drill 2. Plant start up 3. Plant shutdown 4. Real time emergency 5. Pressure testing 6. Activity on emergency utilities 7. Critical equipment switchovers
Concrete pouring	1. Emergency drill 2. Plant start up 3. Plant shutdown 4. Real time emergency 5. Pressure testing 6. Activity on emergency utilities

CONSTRUCTION ACTIVITIES	OPERATION ACTIVITIES
	7. Critical equipment switchovers
critical lifting operations	1. venting 2. Draining 3. Flushing 4. Emergency drill 5. Plant start up 6. Plant shutdown 7. Real time emergency 8. Pressure testing 9. Activity on emergency utilities 10. Critical equipment switchovers
routine lifting crane operations	1. venting 2. Draining 3. Flushing 4. Emergency drill 5. Plant start up 6. Plant shutdown 7. Real time emergency 8. Pressure testing 9. Activity on emergency utilities 10. Critical equipment switchovers
Miscellaneous cold work	1. Emergency drill 2. Plant start up 3. Plant shutdown 4. Real time emergency

CONSTRUCTION ACTIVITIES	OPERATION ACTIVITIES
	5. Pressure testing 6. Activity on emergency utilities 7. Critical equipment switchovers
Scaffolding (erection/dismantling)	1. Emergency drill 2. Plant start up 3. Plant shutdown 4. Real time emergency 5. Pressure testing 6. Activity on emergency utilities 7. Critical equipment switchovers
Activity on Emergency / Utility Systems	1. venting 2. Draining 3. Flushing 4. Hot work 5. Emergency drill 6. Plant start up 7. Plant shutdown 8. Real time emergency 9. Pressure testing 10. Activity on emergency utilities 11. Critical equipment switchovers
cable layout	1. Emergency drill 2. Plant start up 3. Plant shutdown 4. Real time emergency

CONSTRUCTION ACTIVITIES	OPERATION ACTIVITIES
	5. Pressure testing 6. Activity on emergency utilities 7. Critical equipment switchovers
Painting	1. Emergency drill 2. Plant start up 3. Plant shutdown 4. Real time emergency 5. Pressure testing 6. Activity on emergency utilities 7. Critical equipment switchovers
Pressure testing	1. Emergency drill 2. Plant start up 3. Plant shutdown 4. Real time emergency 5. Pressure testing 6. Activity on emergency utilities 7. Critical equipment switchovers
Pre commissioning - Line Blowing / Flushing/ Drying	1. Emergency drill 2. Plant start up 3. Plant shutdown 4. Real time emergency 5. Pressure testing 6. Activity on emergency utilities 7. Critical equipment switchovers

CONSTRUCTION ACTIVITIES	OPERATION ACTIVITIES
Reinstatement of pipeline with hydrocarbons	1. Hot work 2. Emergency drill 3. Plant start up 4. Plant shutdown 5. Real time emergency 6. Pressure testing 7. Activity on emergency utilities 8. Critical equipment switchovers
Radiography	1. Emergency drill 2. Plant start up 3. Plant shutdown 4. Real time emergency 5. Pressure testing 6. Activity on emergency utilities 7. Critical equipment switchovers
Activities to be controlled during operation activities	
survey works, including marking, barricading	8. Venting 9. Draining 10. Flushing 11. Shutdown purging 12. Crane operation/vehicle movement 13. Maintenance inspection 14. Shutdown periods 15. radiography

CONSTRUCTION ACTIVITIES	OPERATION ACTIVITIES
vehicle entry	8. unloading tankers 9. loading cylinders 10. Venting 11. Draining 12. Flushing 13. Shutdown purging 14. Crane operation/vehicle movement 15. Maintenance inspection 16. Shutdown periods 17. radiography
Excavation	1. Venting 2. Draining 3. Flushing 4. Shutdown purging 5. Crane operation/vehicle movement 6. Maintenance inspection 7. Shutdown periods 8. radiography
Excavation (confined space)	1. unloading tankers 2. loading cylinders 3. Venting 4. Draining 5. Flushing 6. Startup purging 7. Shutdown purging

CONSTRUCTION ACTIVITIES	OPERATION ACTIVITIES
	8. Crane operation/vehicle movement 9. Maintenance inspection 10. Shutdown periods 11. radiography
civil works (COLD)in confined space	1. unloading tankers 2. loading cylinders 3. Venting 4. Draining 5. Flushing 6. Startup purging 7. Shutdown purging 8. Crane operation/vehicle movement 9. Maintenance inspection 10. Shutdown periods 11. radiography
Hot Work in confined space	1. unloading tankers 2. loading cylinders 3. Startup purging 4. Shutdown purging 5. Crane operation/vehicle movement 6. Maintenance inspection 7. Shutdown periods 8. radiography
Hot work	1. unloading tankers

CONSTRUCTION ACTIVITIES	OPERATION ACTIVITIES
	2. loading cylinders 3. Startup purging 4. Shutdown purging 5. Crane operation/vehicle movement 6. Maintenance inspection 7. Shutdown periods 8. radiography
structural installation	1. venting 2. draining 3. flushing 4. Shutdown purging 5. Crane operation/vehicle movement 6. Maintenance inspection 7. Shutdown periods 8. radiography
Concrete pouring	1. venting 2. draining 3. flushing 4. Shutdown purging 5. Crane operation/vehicle movement 6. Maintenance inspection 7. Shutdown periods

CONSTRUCTION ACTIVITIES	OPERATION ACTIVITIES
	8. radiography
critical lifting operations	1. unloading tankers 2. loading cylinders 3. Shutdown purging 4. Crane operation/vehicle movement 5. Maintenance inspection 6. Shutdown periods 7. radiography
routine lifting crane operations	1. unloading tankers 2. loading cylinders 3. Shutdown purging 4. Crane operation/vehicle movement 5. Maintenance inspection 6. Shutdown periods 7. radiography
Miscellaneous cold work	1. venting 2. draining 3. flushing 4. Shutdown purging 5. Maintenance inspection 6. Shutdown periods 7. radiography

CONSTRUCTION ACTIVITIES	OPERATION ACTIVITIES
Scaffolding (erection/dismantling)	1. venting 2. draining 3. flushing 4. Shutdown purging 5. Crane operation/vehicle movement 6. Maintenance inspection 7. Shutdown periods 8. radiography
Activity on Emergency / Utility Systems	1. unloading tankers 2. loading cylinders 3. cold work 4. Startup purging 5. Shutdown purging 6. Crane operation/vehicle movement 7. Maintenance inspection 8. Shutdown periods 9. radiography
cable layout	8. venting 9. draining 10. flushing 11. Shutdown purging 12. Crane operation/vehicle movement

CONSTRUCTION ACTIVITIES	OPERATION ACTIVITIES
	13. Maintenance inspection 14. Shutdown periods 15. radiography
Painting	8. venting 9. draining 10. flushing 11. Shutdown purging 12. Crane operation/vehicle movement 13. Maintenance inspection 14. Shutdown periods 15. radiography
Pressure testing	8. unloading tankers 9. loading cylinders 10. Venting 11. Draining 12. Flushing 13. Hot work 14. Cold work 15. Startup purging 16. Shutdown purging 17. Crane operation/vehicle movement 18. Isolation/de isolation 19. Confined space entry 20. Maintenance inspection

CONSTRUCTION ACTIVITIES	OPERATION ACTIVITIES
	21. Shutdown periods 22. Operational checkup rounds 23. Radiography 24. Civil works
Pre commissioning - Line Blowing / Flushing/ Drying	1. unloading tankers 2. loading cylinders 3. Venting 4. Draining 5. Flushing 6. Hot work 7. Cold work 8. Startup purging 9. Shutdown purging 10. Crane operation/vehicle movement 11. Isolation/de isolation 12. Confined space entry 13. Maintenance inspection 14. Shutdown periods 15. Operational checkup rounds 16. Radiography 17. Civil works
Reinstatement of pipeline with hydrocarbons	1. unloading tankers 2. loading cylinders 3. Venting 4. Draining

CONSTRUCTION ACTIVITIES	OPERATION ACTIVITIES
	5. Flushing 6. Cold work 7. Startup purging 8. Shutdown purging 9. Crane operation/vehicle movement 10. Isolation/de isolation 11. Confined space entry 12. Maintenance inspection 13. Shutdown periods 14. Operational checkup rounds 15. Radiography 16. Civil works
Radiography	1. unloading tankers 2. loading cylinders 3. Venting 4. Draining 5. Flushing 6. Hot work 7. Cold work 8. Startup purging 9. Shutdown purging 10. Crane operation/vehicle movement 11. Isolation/de isolation 12. Confined space entry 13. Maintenance inspection

CONSTRUCTION ACTIVITIES	OPERATION ACTIVITIES
	14. Shutdown periods 15. Operational checkup rounds 16. Radiography 17. Civil works

SIMOPS RISK MATRIX

SIMOPS Activity Matrix	**Operation Activities**	unloading tankers	loading cylinders	Venting	Draining	Flushing	Hot work	cold work	startup Purging	shutdown purging	Crane Operation / Vehicle	Isolation /deisolation	Confined space entry	Maintenance / Inspection	Emergency Drill	plant start up (in progress)	plant shutdown (in progress)	shutdown periods	Operational round/ Patrolling	Real time Emergency	Pressure testing	Radiography	Civil Works	activity on emergency utility systems	critical equipment switchovers	simultaneous activities' to be	prohibited simultaneous activities
Construction Activities																											
survey works, including marking, barricading																										8	7
vehicle entry																										10	7
Excavation																										8	7
Excavation (confined space)																										11	7

SIMOPS Activity Matrix	Operation Activities	unloading tankers	loading cylinders	Venting	Draining	Flushing	Hot work	cold work	startup Purging	shutdown purging	Crane Operation / Vehicle	Isolation /deisolation	Confined space entry	Maintenance / Inspection	Emergency Drill	plant start up (in progress)	plant shutdown (in progress)	shutdown periods	Operational round/ Patrolling	Real time Emergency	Pressure testing	Radiography	Civil Works	activity on emergency utility systems	critical equipment switchovers	simultaneous activities' to be	prohibited simultaneous activities
civil works (COLD)in confined space																										11	7
Hot Work in confined space																										8	10
Hot work																										8	10
structural installation																										8	7
Concrete pouring																										8	7
critical lifting operations																										7	10
routine lifting crane operations																										7	10
Miscellaneous cold work																										7	7
Scaffolding (erection/dismantling)																										8	7
Activity on Emergency / Utility Systems																										9	11

SIMOPS Activity Matrix	**Operation Activities**	unloading tankers	loading cylinders	Venting	Draining	Flushing	Hot work	cold work	startup Purging	shutdown purging	Crane Operation / Vehicle	Isolation /deisolation	Confined space entry	Maintenance / Inspection	Emergency Drill	plant start up (in progress)	plant shutdown (in progress)	shutdown periods	Operational round/ Patrolling	Real time Emergency	Pressure testing	Radiography	Civil Works	activity on emergency utility systems	critical equipment switchovers	simultaneous activities' to be	prohibited simultaneous activities
cable layout																										8	7
Painting																										8	7
Pressure testing																										17	7
Pre commissioning - Line Blowing / Flushing/ Drying																										17	7
Reinstatement of pipeline with hydrocarbons																										13	8
Radiography																										17	7

Key	
SIMOPS ACTIVITY Prohibited/ only one operation is permitted	**N**
Authorized with Restrictions	**AWR**
Operation Activity permissible under SIMOPS procedures	**Y**