CHAPTER 4

MODELLING & ANALYTICAL ASSESSMENT

4.1 INTRODUCTION

The industries using flammable gas such as LPG / Natural Gas / Hydrogen facilities were selected for this study. There were seven facilities selected. Three facilities handle LPG, two facilities handle hydrogen and the other two facilities handle Natural Gas.

Case Study 1: LPG storage and handling facility of automobile ancillary unit.

Case Study 2: Gaseous hydrogen storage and handling facility in a Thermal Power plant.

Case Study 3: LPG storage and handling facility in an automobile manufacturing plant.

Case Study 4: Liquid hydrogen storage and handling facility in a space research centre unit.

Case Study 5: LPG storage and distribution system in a high rise building, Oman.

Case Study 6: Natural gas gathering terminal and pipeline facility, Muscat, Oman.

Case Study 7: Natural gas station manifold and pipeline facility, Qatar.

4.2 LPG STORAGE AND HANDLING SYSTEM AT AUTOMOBILE ANCILLARY UNIT

4.2.1 INTRODUCTION

LPG is used in this automobile ancillary unit for various heating application purposes. The facility has 2 LPG bullets having a total capacity of 20 tons for various heat treatments of automobile components and parts.

4.2.2 PROCESS DESCRIPTION

The heat treatment plant uses LPG as a main fuel for heating purposes. LPG is used in boilers, furnaces and various heat treatment applications. The LPG is received through road tankers and unloaded in to two LPG bullets. The LPG is supplied to various sections of the plant through pipelines from the LPG bullet. The LPG bullet is operated at 4 bar and 28°C temperature. The LPG bullet storage yard consists of a road tanker unloading bay, unloading pipelines, hoses and associated valves and fittings. The LPG road tanker is unloaded using the LPG vapor method by pressurisation. The LPG vaporiser is installed downstream and supplies gas to the plant.

The following Table: 4.1 provides the details of the storage tank bullet and operating parameters which are used for modelling:

Table. 4.1: Operating parameter of LPG storage and handling facility case study-1

S.No	Parameters	site specific data
1	Material	LPG
2	Type of storage vessel	storage tank with horizontal bullet
3	Pressure	12.5 bar

4	Discharge Temperature	35°C
5	Internal Pipe	40 meter
6	Pipeline Size	50 mm
7	Mass / Volume	40 Ton
8	Air Temperature	37°C
9	Relative Humidity	74%
10	Piping details	4 Bends, 3 SRV's, 1 LPG vaporizer
11	Bund Size	10 * 15 m
12	Volume Inventory of material to discharge	Full tank / Leak or Hole size
13	Number of Excess Flow Valves	2
14	Number of Non-Return Valves	3
15	Number of Shut-Off Valves	4
16	Pipe Diameter	90 mm
17	Pipeline Size	40 meter
19	Location	non-urban
20	Elevation	0.8 m
21	Dispersion Concentration of Interest	10000 ppm
22	Flammable	Flammable / Toxic Chemical
23	Toxic	TLV / STEL values- Non toxic
24	Averaging time associated with Concentration	LFL/ UFL 2.8 /9.5 %
25	Status of Bund	Concrete Rectangle bund

.

The LPG bullet has provisioned safety and fire protection systems such as LPG detection and warning system, fire hydrants, automatic water monitor, bunded storage, static electricity holder, safety relief valve, burst disc, level indicator and flame retardant electrical appliances.

4.2.3 POSSIBLE SCENARIOS

Based on the hazard identification study, the following various incident scenarios are considered for this study as listed in Table. 4.2:

Table.4.2: Scenarios selected for analysis-case study 1

LPG unloading line leakage
LPG unloading line catastrophic failure
LPG bullet leakage
LPG bullet catastrophic failure
LPG vaporizer catastrophic failure

4.2.4 WEATHER CONDITIONS

The wind speeds, wind direction, relative humidity, solar radiation and outside temperatures are important parameters which may affect gas leaks. The meteorological data are collected from the meteorological station situated closest to the facility, and analysis is conducted mainly for weather classes such as 1.5 D, 1.5 F and 5 D cases.

4.2.5 RESULTS & DISCUSSIONS

Consequence analysis is carried out for all the identified scenarios. For example over-pressure effects from line rupture explosion of LPG during unloading is provided. The over-pressure from the explosion and heat radiation intensity from fire and explosion is considered as criteria for assessing the effects towards humans and structures. Figure 4.1, 4.2 and 4.3 are presented below.

From the figures we can see that the cloud may rise up to 2.5 m @ 10,000 ppm, and may reach 48 meters at a concentration of 20,000 ppm.

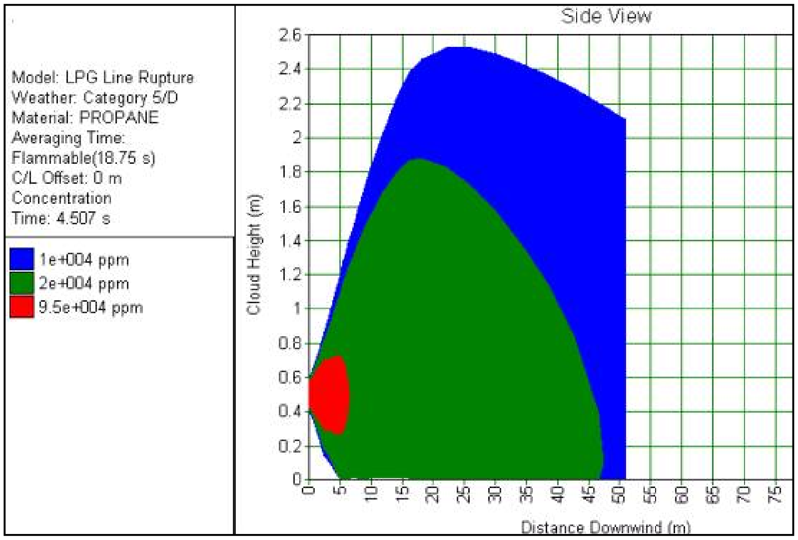


Figure.4.1 LPG Cloud height and dispersion in downwind direction.

Catastrophic LPG bullet failure under the weather condition class 5 D is analysed. A concentration level for LPG of 10,000 ppm and 20,000 ppm are shown in Figure. 4.2.

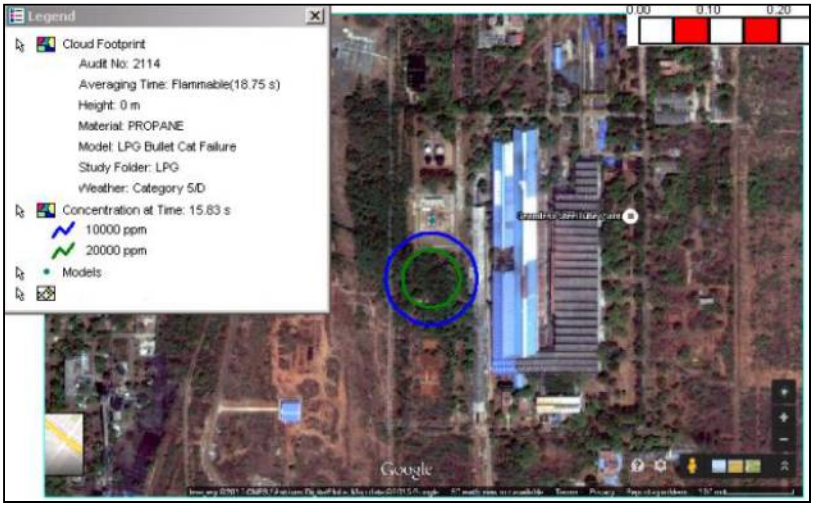


Figure.4.2 LPG concentration level contour on map.

LPG vaporizer catastrophic failure results shown 35kW/ m^2 reach up to the distance of 120 meter in a down wind direction.

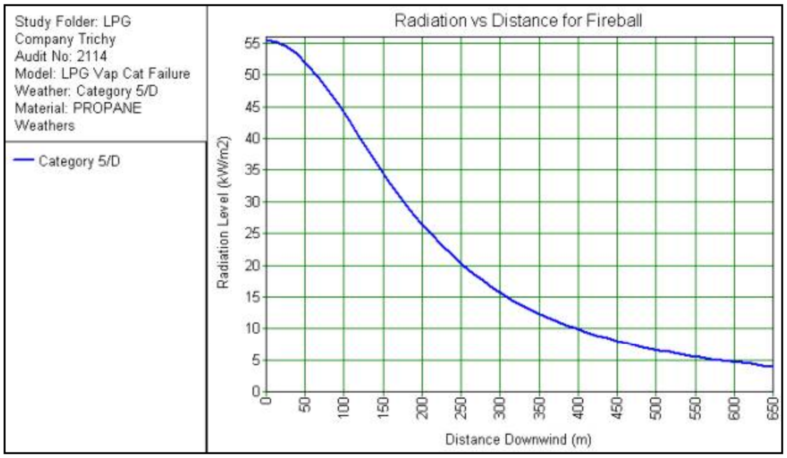


Figure.4.3: Radiation Heat intensity over downwind direction.

Table: 4.3 shows the over-pressure and distance affected while Table: 4.4 shows the radiation level due to fire/explosion of a tank.

Table.4.3: Over Pressure vs distance due to explosion

Overpressure	Unit	Maximum Distance (m)		
		Category 1.5/D	Category 5/D	Category 1.5/F
0.02068	Bar	1027.79	1045.74	1002.04
0.1379	Bar	311.667	335.557	311.605
0.2068	Bar	256.996	284.776	259.211

Table 4.4: Radiation intensity over distance

Scenario	Maximum distance affected by the radiation level (in meter)				
	4.0 kW/m^2	9.5 kW/m^2	12.5 kW/m^2	25.0 kW/m^2	37.5 kW/m^2
Catastrophic Failure of tank	550	400	350	200	120

From the consequence analysis it was found that Jet Fire, VCE and BLEVE are the potential scenarios. The frequency analysis for a leak and probability of ignition is used to find the overall outcome failure frequency. The consequence analysis results such as the over-pressure distance and radiation intensity is to be used for future planning of adjacent facilities if the catastrophic tank failure heat radiation intensity reaches 120-meter distance of 37.5 kW / m^2.

In such situations, an Emergency Preparedness Plan for the facility, on-site as well as off-site has to be developed and delivered to employees and public in the immediate area.

4.3 HYDROGEN STORAGE TANK & HANDLING FACILITY AT THERMAL POWER PLANT

4.3.1 INTRODUCTION

Hydrogen gas is a future energy source and used in industries for many applications. Many developing countries are using hydrogen as a fuel. It is used in power plants for the purpose of cooling generators. It is a clean energy but at the same can be expensive and highly flammable in nature.

4.3.2 PROCESS DESCRIPTION

The hydrogen gas is stored in cylinders with manifolds and filled in the cooling system. Hydrogen is filled during start up and make up as and when required. The major components of hydrogen handling systems are:

- Storage container;
- Hydrogen Holder or Manifold;
- Hydrogen piping system;
- Generator cooler.

Table 4.5 provides the input for consequence analysis and main equipment availability within the facility:

Table 4.5: Operating parameter of Gaseous hydrogen storage case study 2.

S.No	Parameters	Site specific data
1	Material	Gaseous Hydrogen
2	Type of storage vessel	Cylinder skid
3	Pressure	3.4 bar
4	Discharge Temperature	34°C
5	Internal Pipe diameter	35 meter

6	Pipeline Size	50 mm
7	Mass / Volume	34 kg * 8 cylinder
8	Air Temperature	34
9	Relative Humidity	85%
10	Piping details	6 bends,
11	Bund Size	No bund
12	Volume Inventory of material to discharge	Cylinder skid and pipeline capacity
13	Number of Excess Flow Valves	Nil
14	Number of Non-Return Valves	3
15	Number of Shut-Off Valves	4
16	Pipe Diameter	50 mm
17	Pipeline length	15 m
19	Location	Coastal near sea
20	Elevation	1.5, 10, 30
21	Dispersion Concentration of Interest	50 % LEL
22	Flammable	Flammable / Toxic Chemical
23	Toxic	TLV / STEL values - Non Toxic
24	Averaging time associated with Concentration	LFL/ UFL 4 / 74%
25	Status of Bund	No bund

4.3.3 POSSIBLE SCENARIOS

Based on the hazard identification study, the following two scenarios are the maximum credible results and therefore selected for analyzing the risk during storage and handling of hydrogen:

a) Catastrophic failure of hydrogen cylinder ;

b) Catastrophic failure of Hydrogen manifold.

Fire and explosion with hazardous outcome cases are applicable for this storage facility. Hydrogen loading is carried out in a closed atmosphere in this facility, therefore VCE is one of the accident scenarios in case of hydrogen leak from the hydrogen holder [14].

4.3.4 WEATHER CONDITIONS

As this loading operation is carried out in a closed space/room, a neutral stability class (D) is selected and a wind speed of 3.0 m/s is assumed.

Table 4.6 illustrates the fire and explosion hazard for the two scenarios and the thermal radiation effect:

Table 4.6: vulnerable distances due to radiation from fire and explosion

Scenario	Maximum distance affected by the radiation level (in meter)		
	4.0 kW/m^2	12.5 kW/m^2	37.5 kW/m^2
Catastrophic Failure of Hydrogen Cylinder	24.7	15	8.8
Bursting of one hydrogen manifold	34.5	20.8	12.3

4.3.5 RESULTS AND DISCUSSION

From the study, two scenarios are selected for detailed consequence analysis - hydrogen cylinder catastrophic failure and cylinder manifold failure. The maximum heat radiation of 37.5 kW /m^2 intensity reach up to 12.3 meter and 8.8 meter for both cases respectively is selected.

4.4 LPG STORAGE AND HANDLING SYSTEM AT AUTOMOBILE PLANT

4.4.1 INTRODUCTION

This LPG storage facility is located at Hosur, India, and used in the automobile plant for various applications. It is one of the main fuels for heating, steam production, paint shop, ovens and furnace. LPG is the main fuel in this plant apart from furnace oil.

4.4.2 PROCESS DESCRIPTION

The capacity of each LPG bullet is approximately 9 tonnes. There are 3 bullets and 1 bullet is being used as a standby. From the LPG bullet, the LPG is fed to the vaporiser and distributed to all sections of the plant through pipelines on demand.

4.4.3 POSSIBLE SCENARIOS

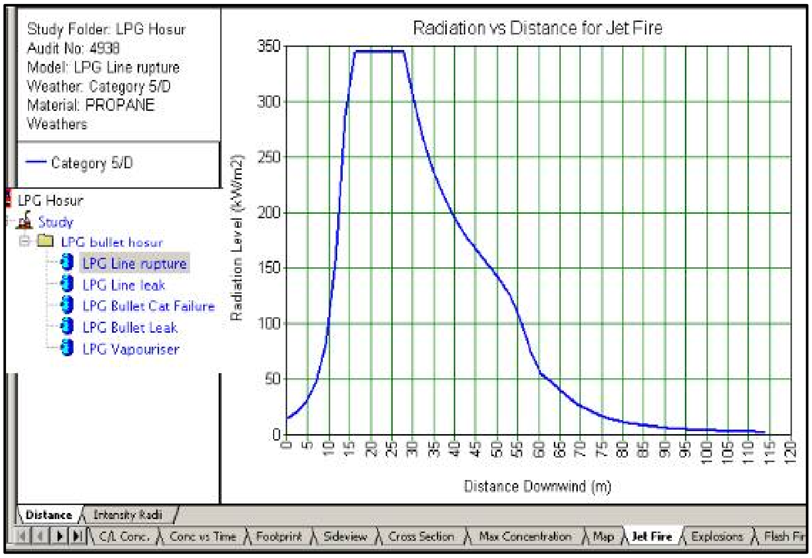
Based on the hazard identification study, different hazardous scenarios are identified and various initiating events and failures of piping and storage vessels are analysed. The consequence models such as Jet Fire, Flash Fire, BLEVE, UVCE and Frequency of Failure for various LPG system components are established in order to assess the risk and safety distances, which are assessed based on thermal radiation and over-pressure by fire or explosion. Based on the results of this analysis, the existing control measures are evaluated and recommendations are suggested for the facility to improve the safety and fire protection systems. Table 4.7 shows the input parameters and facility data of the LPG storage tank:

Table 4.7: Operating parameter of LPG storage tank case study 3

S.No	Parameters	Site specific data
1	Material	LPG
2	Type of storage vessel	Storage Bullet

3	Pressure	3 kgf / cm^2
4	Discharge Temperature	33^{0}C
5	Internal Pipe diameter	75 meter
6	Pipeline Size	50 mm and Vapour line 36 mm
7	Mass / Volume	9 tonne capacity- 3 no's
8	Air Temperature	35^{0}C
9	Relative Humidity	70%
10	Piping details	6 Bends, 3 SRV's, 4 valves
11	Bund Size	10* 12 Rectangular
12	Volume Inventory of material to discharge	Full tank / Leak or Hole size
13	Number of Excess Flow Valves	3
14	Number of Non-Return Valves	2
15	Number of Shut-Off Valves	4
16	Pipe Diameter	75 mm
17	Pipeline Size	120 meter
19	Location	Outdoor urban
20	Elevation	1.2 m
21	Dispersion Concentration	10000 ppm
22	Flammable	Flammable / Toxic Chemical
23	Toxic	TLV / STEL values-non toxic
24	Averaging time associated with Concentration	LFL/ UFL 2.8 / 9.5 %
25	Status of Bund	Concrete Rectangle bund

Figure 4.4, 4.5 and 4.6 show the various analysis results during the study. The graph shows an LPG line ruptured in a Jet fire, with the resulting radiation intensity. The heat radiation shown (115m distance) is in the downwind direction.



Study Folder: LPG Hosur
Audit No: 4938
Model: LPG Line rupture
Weather: Category 5/D
Material: PROPANE

Figure.4.4: Radiation over vulnerable distance

The heat intensity is mentioned as a contour in this figure for 4 kW/ m^2, 12.5 kW/ m^2, 37.5 kW/ m^2:

Intensity Radii for Jet Fire
Audit No: 4938
Material: PROPANE
Model: LPG Line rupture
Study Folder: LPG Hosur
Weather: Category 5/D

Figure.4.5: Radiation Intensity Contour for Jet Fire

As per figure 6.6, 20000 ppm may reach up to 110 meter in the downwind direction, and 10000 ppm may spread up to 225 meter in the downwind direction.

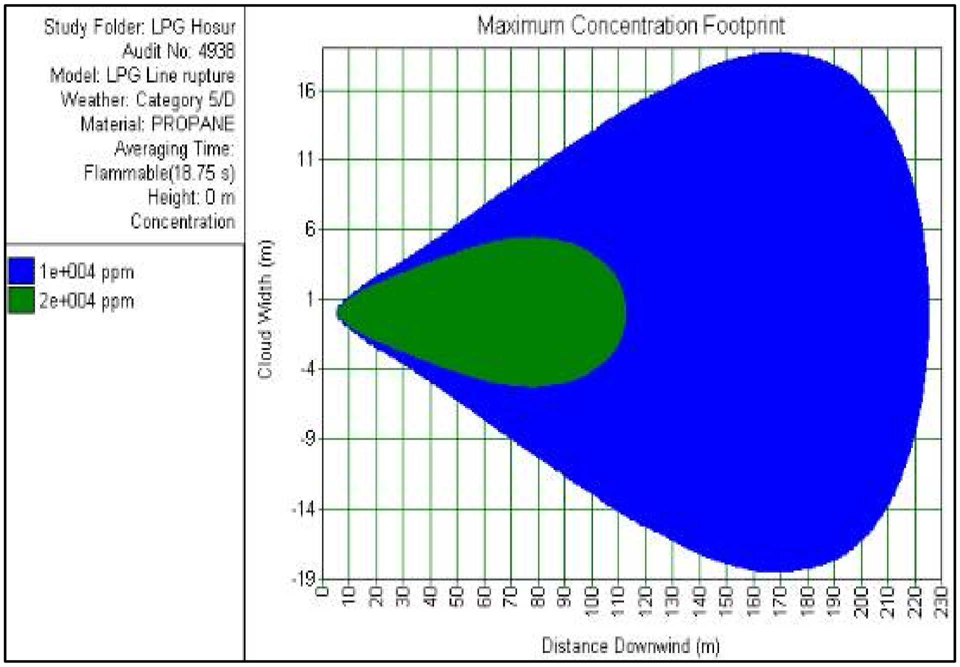


Figure.4.6: Maximum Concentration Foot Print

4.4.4 RESULTS AND DISCUSSION

From this study we can see that the concentration can reach up to 210 meters for LPG line rupture. The Figure 6.6 shows the contours of maximum concentration for jet fire in case of LPG line rupture.

4.5 LIQUID HYDROGEN STORAGE TANK & HANDLING FACILITY

4.5.1 INTRODUCTION

Liquid hydrogen and gaseous hydrogen are used for testing and qualification of various components and engines in test facilities for the national space program of India, located at Mahendragiri. Any interruption to the testing of these components would obviously cause a massive disruption to the program at a very high cost.

4.5.2 PROCESS DESCRIPTION

The test facility has one run tank in a test stand. Hydrogen is transferred by road tanker from a hydrogen plant. The hydrogen is then transferred to the run tank and distributed to the test components. The transfer method used is pressure difference using gaseous hydrogen.

A line diagram of a simplified hydrogen loading from a road tanker to the storage tank is shown in Figure 4.7. The road tanker is parked in the tanker parking area and the fill line and pressurisation line connected to the road tanker. The pressurisation line is connected from the gaseous hydrogen cylinder to the hydrogen road tanker. The fill line is connected from hydrogen road tankers to the hydrogen storage tank. The road tanker is pressurized up to 1.5 bar and the hydrogen is transferred from the road tanker to the storage tank.

The fill line and the storage tank both have safety systems to take care of over-pressure during the transfer operation.

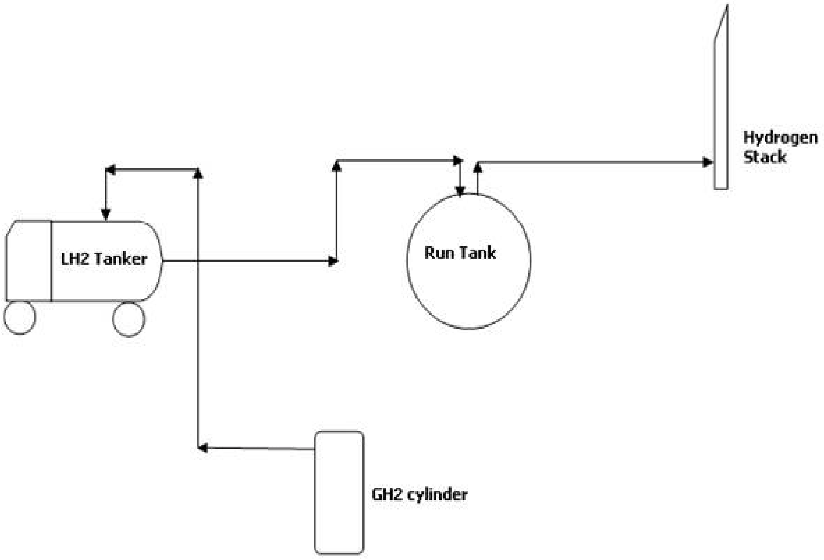


Figure. 4.7 Typical flow diagram of hydrogen from road tanker to storage tank.

4.5.3 POSSIBLE SCENARIO

Liquid hydrogen is a cryogenic fluid and gaseous hydrogen poses fire and explosion hazards. The following are the hazards/risks that are encountered during handling of these fluids. Pressure will rise rapidly in the pipelines and vessels which are not properly insulated. The consequences such as Jet Fire, Boiling Liquid and Expanding Vapour Cloud Explosion have been modelled.

Liquid and gaseous hydrogen will mix with air very quickly and therefore require very little energy to ignite. Hydrogen forms combustible/explosive mixtures with air or O_2 depending upon the confinement and ignition source. Obstructions like burr in the flow path in H_2 and O_2 systems may lead to localized heating and associated hazards like fire or explosion. The main hazards involved with hydrogen are Fire, Explosion, and Violent combustion reaction with oxygen.

Table 4.8: Operating parameter of Liquid H_2 storage tank case study 4

S.No	Parameters	Site specific data
1	Material	Liquid Hydrogen
2	Type of storage vessel	Cryogenic vessel
3	Pressure	70 bar
4	Discharge Temperature	28°K
5	Internal Pipe	15 meter
6	Pipeline Size	75 mm
7	Mass / Volume	4.5 Tonne, Road Tanker-6 Tonne
8	Air Temperature	22°C
9	Relative Humidity	80%
10	Piping details	6 Bends, 3 SRV's,
11	Bund Size	10 * 15 m
12	Volume Inventory of material to discharge	Full tank / Leak or Hole size
13	Number of Excess Flow Valves	Nil
14	Number of Non-Return Valves	3
15	Number of Shut-Off Valves	2
16	Pipe Diameter	75 mm
17	Pipeline Size	15 meter
19	Location	Test facility
20	Elevation	1.5 meter
21	Dispersion Concentration of Interest	20000

22	Flammable	Flammable / Toxic Chemical
23	Toxic	TLV / STEL values
24	Averaging time associated with Concentration	LFL/ UFL
25	Status of Bund	No Bund

A HAZID study, Critical Consequence Outcome Cases of a HAZOP study, Event Tree Analysis and hazardous properties of liquid hydrogen and gaseous hydrogen leak scenarios have been conceptualized. Based on all the hazard identification studies the following five scenarios are considered for further analysis. Hydrogen is highly flammable and explosive in nature. Leaks from pipelines and tanks lead to Jet Fire, VCE and BLEVE scenarios which have been considered for consequence analysis. The radiant heat from fire (kW/m^2) and radiant heat dose from BLEVE (kJ/m^2) and over-pressure [24] from explosions (bar) levels are evaluated to assess the level of injury to humans.

Scenario: Leak from the input liquid hydrogen line from the road tanker to the storage tank in the facility during loading operations.

Scenario: Leak from the liquid hydrogen storage tank; a hole in the run tank is considered.

Scenario: Leak from the liquid hydrogen storage tank; catastrophic failure of the storage tank.

Scenario: Leak from the gaseous hydrogen line from a gaseous hydrogen cylinder to the road tanker.

Scenario: Leak from the liquid hydrogen tank output line to the test equipment at the facility during testing operations.

4.5.4 METEOROLOGICAL CONDITION

The effect zones due to any accidental release of hydrogen will depend on many factors such as the quantity of material, phase of the hydrogen, atmospheric stability class, wind speed and direction etc. During summer the temperature reaches 37°C and winter average temperatures reach 25°C. The relative humidity varies between 70-85 % over summer and winter periods. The prevalent wind directions are West-East-North direction. All this information has been taken from the meteorological station installed at the site. The software considers the following three categories for analysis purposes - category 1.5 F, category 1.5 D, Category 5 D.

4.5.5 CALCULATION OF OVERPRESSURE AND FIRE BALL

The TNT equivalent method (as per US Army Material Command Regulations No.385-100), is followed in manual calculations to assess the safety distance from the different facilities. TNT equivalent is taken as 60 % of total weight of the hazardous materials handled.

The blast pressures at various distances is calculated by using the following equation:

P = 2.69 W 0.4 R –1.2

Where P - Max. Over pressure in kg/cm^2

W - TNT Equivalent in kg = 12342 kg

R - Distance in meters.

Peak over-pressure values at various distances of our interest are given below:

Barricaded Intra line distance = 0.556 kg /cm^2 (86 m)
Un-barricaded intra line distance = 0.242 kg /cm^2 (172 m)
Inhabitation distance = 0.092 kg /cm^2 (383 m)
Control Room distance = 0.285 kg /cm^2 (150 m)

In case of accidental mixing of the propellants, the fire ball diameter, its duration and blast pressure levels at various distances will be as follows:

Equivalent Fire ball diameter, D = 9.56 W 0.325

Where D - in feet (the standard error is 30%)

W - wt. of the oxidiser& fuel in lbs. = 20568.0 kg = 27646 lbs

D = 9.56 * 276460.325

= 265.45 ft. = 82 m

Hence, the maximum fire ball diameter will be 106 m.

From these calculations, the safety distances for other facilities and emergency evacuation of personnel from adjacent facilities are evaluated. This is implemented during hydrogen transfer operations due to the large inventory at the time of operation.

4.5.6 RESULTS AND DISCUSSION

Maximum concentration levels of hydrogen gas based on lower explosive limits (LFL) in 100% LFL and 50 % LFL are plotted in the footprint shown in Figure 4.8. The cloud width and distance are mentioned based on a downwind direction.

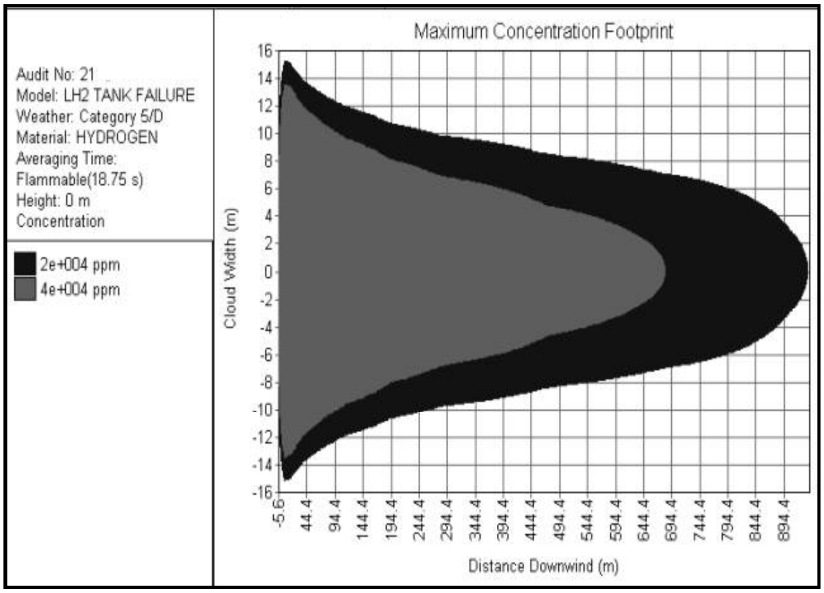


Figure 4.8. Maximum hydrogen concentration in ppm in downwind direction

Figure 4.9 shows the various heat radiation intensity levels around the hydrogen facility. The three contours represent the radiation levels 4 kW/m^2, 12.5 kW/m^2, and 37.5 kW/m^2 respectively.

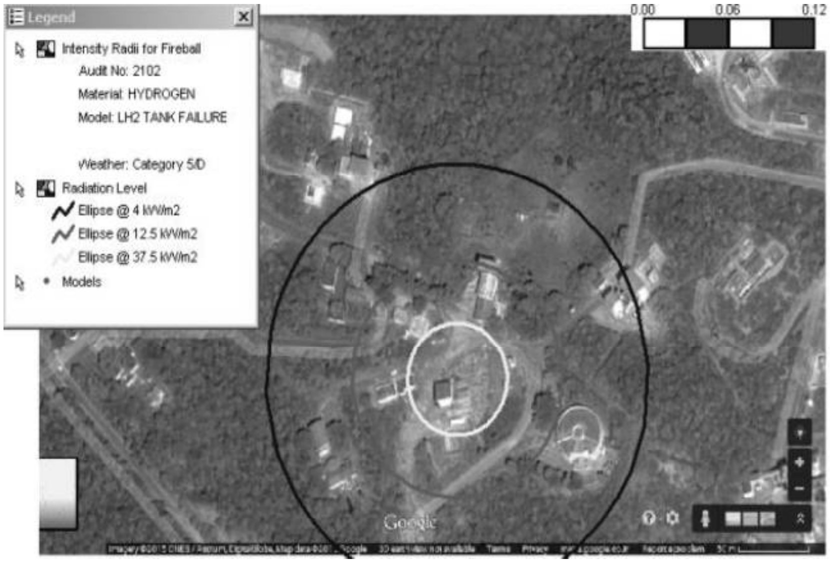


Figure 4.9. Radiation intensity contour for catastrophic failure

Table 4.9 indicates a 35 meter radius with a heat intensity maximum level and lower intensity of 4 kW/m^2 spread across a distance of 135 m. The study shows that the facility should have an evacuation zone of at least 97 m around the hydrogen storage facility during transfer operations, while structures around the facility at a distance of approximately 110 m distance may receive minor damage. This is used for further land use planning and providing additional protection for existing facilities.

Table 4.9: Radiation intensity with distance

Scenario	Maximum distance affected by the radiation level (in meter)				
	4.0 kW/m^2	9.5 kW/m^2	12.5 kW/m^2	25.0 kW/m^2	37.5 kW/m^2

Catastrophic Failure of liquid Hydrogen run tank	135 m	97 m	70 m	46 m	35 m

Over-Pressure from the hydrogen tank and catastrophic rupture is shown in Figure 4.10. The peak pressure is reached immediately after an explosion occurs and decreases over time and distance.

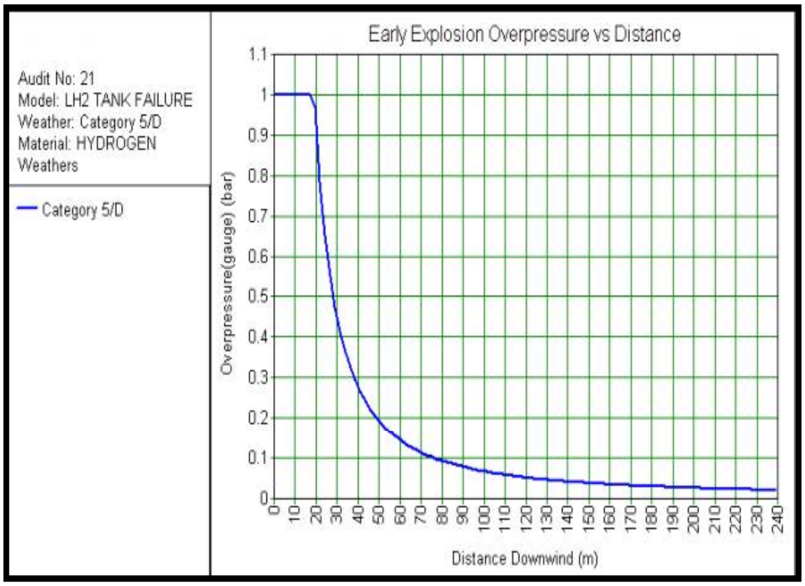


Figure 4.10 Over pressure with distance chart

Table 4.10 indicates the safe distances which the over-pressure of 1 psi to 14 psi require.

Table 4.10: Over pressure with distance from point of explosion

Scenario	Maximum distance affected by the over pressure wave in meter				
	1 psi (6894 N/m^2)	2 psi (13789 N/m^2)	4 psi (27578 N/m^2)	7 psi (48263 N/m^2)	14 psi (96526 N/m^2)
Failure of liquid Hydrogen tank	110 m	60 m	40 m	28 m	18 m

The worst case scenario is selected and over-pressure and radiation intensity are calculated based on software models and manual calculations [71]. Based on the radiation contour and over-pressure developed from the hydrogen tank explosion, an evacuation zone of up to 97.5 m is required.

4.6 LPG STORAGE AND HANDLING SYSTEM IN HIGH RISE APARTMENT BUILDING. OMAN

4.6.1 INTRODUCTION

LPG is a common fuel used in industries and as well as for domestic purposes. LPG is stored in ‘bullets’ and small cylinders for commercial and domestic purposes. In recent developments, LPG is stored in bulk quantities in high rise apartments and supplied directly to individual homes.

4.6.2 PROCESS DESCRIPTION

LPG is stored in this building mainly for domestic (cooking and heating) purposes. The LPG is stored in an underground storage tank of the apartment building. The LPG supply lines are connected from the storage tank to individual apartments in the building.

Figure.4.11 LPG gas unloading operation of the apartment

The supply lines are laid through the vertical shaft of the building and each floor has output lines connected to individual apartments. A separate flow meter and LPG leak detector is fitted in each individual dwelling. The individual dwelling owner uses the LPG fuel depending upon their requirement, and pays as per the meter reading. Figure 4.11 and 4.12 show the typical flow diagram and LPG unloading operation to the underground tank from the road tanker.

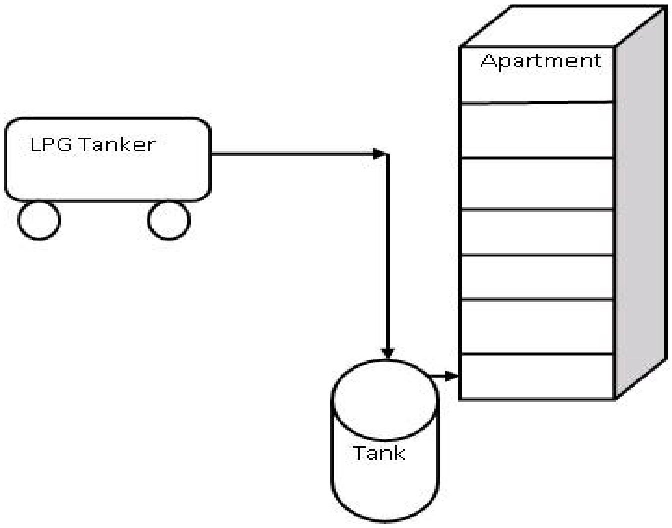


Figure.4.12 Line diagram of LPG unloading operations

LPG in the underground storage tank is filled by the LPG supplier from a road tanker and is unloaded to the storage tank periodically when required. This study considers the inventory of the road tanker for assessment.

For this LPG handling system in the high rise apartment building, hazard identification is carried out based on checklist, hazard and an operability study. For each LPG leak various incident outcomes are derived by event tree techniques. Four scenarios (listed below) are considered.

4.6.3 WEATHER CONDITIONS AND OTHER ASSUMPTIONS

Surface roughness : 0.1

Release source : 1.5 m (case 1-outdoor pipeline rupture)

: 12 m (case 2-Indoor pipeline rupture)

Atmospheric stability class : 5D and 2F

Discharge coefficient : 0.7 (Two phase)

Pipeline dispersion / release : 10 min

Solar radiation : 1 kW /M^2

LFL criteria : 40 and 50 and 100 %

Thermal Radiation criteria : 6.0, 12.5, 25, 37.5 kW / M^2

Over pressure radius : 0.02, 0.04, 0.08, 0.17, 0.26, 0.5 bar

Weather Data:

Atmospheric temperature : 38°C

Humidity : 74 %

Wind speed : 5 km / hr. (Day) and 2 km / hr. (Night) & North East

Unloading pipeline hose size : 75 mm and 12 meter length.

The following Table 4.11 shows the LPG tank source data and other process parameters used for this study.

Table 4.11: Operating parameter of LPG tank.

S No.	Parameters	site specific data
1	Material	LPG
2	Type of storage vessel	LPG bullet- Vertical tank
3	Pressure	3 bar
4	Discharge Temperature	45°C
5	Internal Pipe	12 meter

6	Pipeline Size	50 mm, vapor line 36 mm
7	Mass / Volume	3.5 tonne
8	Air Temperature	22°C
9	Relative Humidity	72%
10	Piping details	4 Bends, 2 SRV's, 3 valves
11	Bund Size	2.5 * 2.5 m and depth 6 m.
12	Volume Inventory of material to discharge	Full tank / Leak or Hole size
13	Number of Excess Flow Valves	3
14	Number of Non-Return Valves	2
15	Number of Shut-Off Valves	2
16	Pipe Diameter	50 mm
17	Pipeline Size	35 meter
19	Location	Indoor –Dimensions
20	Elevation	1.2 m
21	Dispersion Concentration of Interest	10000 ppm
22	Flammable	Flammable / Toxic Chemical
23	Toxic	TLV / STEL values
24	Averaging time associated with Concentration	LFL/ UFL 2.8 / 9.5 %
25	Status of Bund	Vertical bund

4.6.4 POSSIBLE SCENARIOS

The leakage of LPG may be from a tanker, unloading pipeline, underground tank or distribution supply line. The availability of an ignition source, timing of ignition and metrological conditions such as wind speed, direction, day or night time also influence the dispersion and affects the consequences:

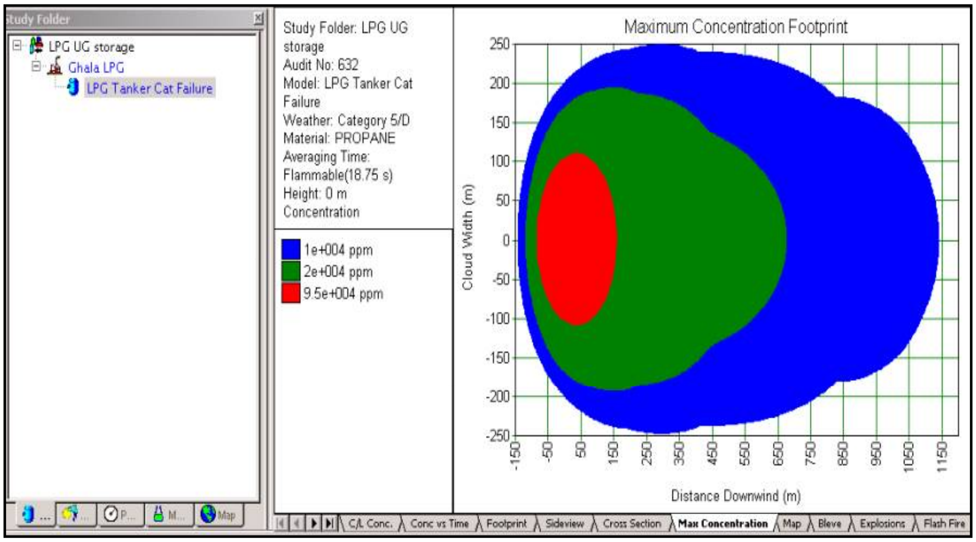
1. Catastrophic LPG Tanker failure;
2. Unloading Hose Line rupture;
3. LPG distribution Supply line rupture –Indoor;
4. Catastrophic underground tank failure.

In general, the following are the different consequences and outcome cases that may occur:

- Jet Fire
- Pool Fire
- Flash Fire
- VCE / BLEVE

4.6.5 RESULTS & DISCUSSION

From the analysis the LPG tanker car failure releases the LPG up to 1150 meters. Due to the fire ball, the radiation level reaches 49 kW/m^2. The intensity of the fire ball radiation is felt near the main highway if the wind direction is on that side. The various graphs are shown in Figures 4.13, 4.14, 4.15 and 4.16 respectively.

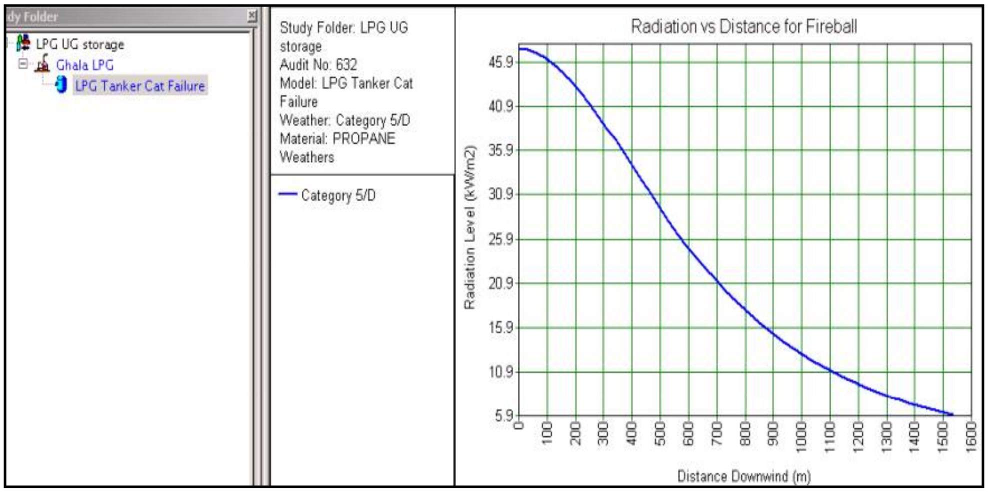


Study Folder: LPG UG storage
Audit No: 632
Model: LPG Tanker Cat Failure
Weather: Category 5/D
Material: PROPANE
Averaging Time: Flammable(18.75 s)
Height: 0 m
Concentration

🟦 1e+004 ppm
🟩 2e+004 ppm
🟥 9.5e+004 ppm

Figure.4.13 Maximum gas concentration of LPG tanker failure

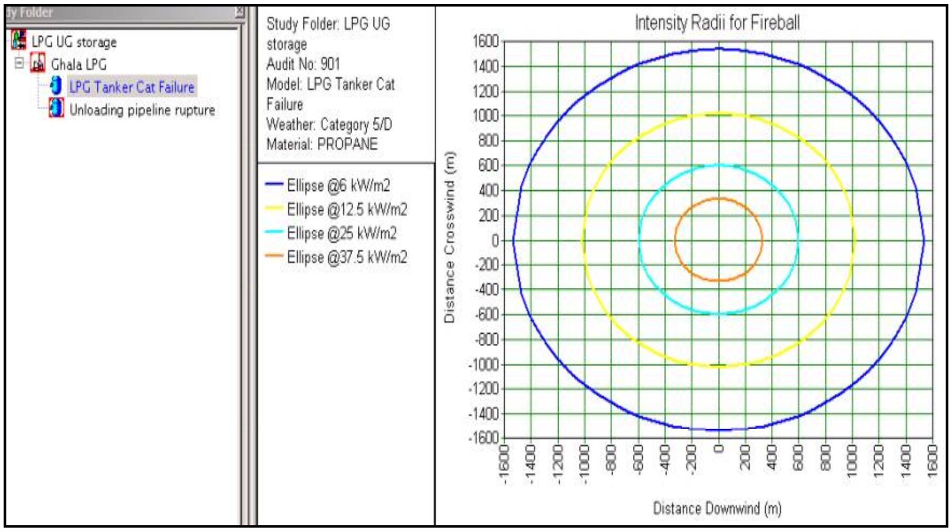
From Fig 4.13 we can see that the maximum gas concentration reaches 95,000ppm around 150 meters in both directions of downwind and upwind, with a flammablility range chance of flash fire.



Study Folder: LPG UG storage
Audit No: 632
Model: LPG Tanker Cat Failure
Weather: Category 5/D
Material: PROPANE
Weathers

Figure.4.14 Radiation distance due to Fire Ball

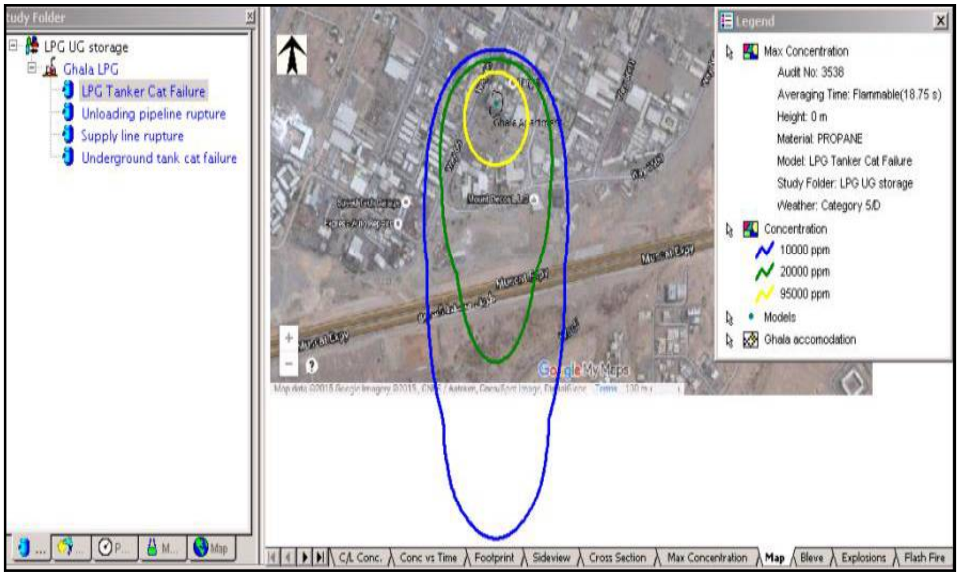
The radiation intensity heat flux reaches above 35 kW / m^2 intially, and upto 350 meters in the downwind direction.



Study Folder: LPG UG storage
Audit No: 901
Model: LPG Tanker Cat Failure
Weather: Category 5/D
Material: PROPANE

Figure.4.15 Radiation Intensity due to fire ball

The Fire ball radiation intensity is shown to reach a 300 meter distance for the scenario results in the LPG storage tank catstrophic failure and BLEVE.



Max Concentration
Audit No: 3538
Averaging Time: Flammable(18.75 s)
Height: 0 m
Material: PROPANE
Model: LPG Tanker Cat Failure
Study Folder: LPG UG storage
Weather: Category 5/D

Concentration
10000 ppm
20000 ppm
95000 ppm
Models
Ghala accomodation

Figure.4.16 Maximum concentration contour

The 95,000 ppm reaches in a downwind direction as shown in Figure 4.16. The surrounding buildings must be considered for the development of a risk management plan.

4.7 NATURAL GAS PIPELINE AND HANDING SYSTEM

4.7.1 INTRODUCTION

Natural gas is used worldwide for various applications. Natural gas consists mainly of methane and small amounts of other gases such as ethane, propane and butane. Natural gas is a clean and eco friendly fuel and its usage is increasing globally. Natural gas covers 20% of energy consumption in Europe, and many countries use natural gas as a fuel for transportation and feedstock in the chemical and petrochemical industries.

4.7.2 PROCESS DESCRIPTION

Natural gas (associated gas from well and flash gas from compressor) is produced at the production station, and is compressed and pumped into the export gas pipeline. During the process the gas is dehydrated in dehydration units, and dew is directed to a refrigeration unit. One soar gas pipeline exports the gas from the pumping station to a gathering station.

The associated gas produced in a power station has H_2S levels of approximately ~500 ppmv and is compressed. The high H_2S flashed gas contains H_2S ~20,000 ppmv from storage tanks and is currently flared through a Gas Recovery Compressor (GRC) to avoid contaminating the gas system with high H_2S gas levels.

Associated gas from the power station, and flash gas from the gas recovery compressor, are received to the new booster compressors at a pressure of 280 kPa (g) and compressed to 7500 kPa (g) pressure. The gas is further dehydrated and dew directed to the glycol injection and dew pointing units before being sent to the gathering station. There will be three new booster compressors with one working and one on standby during an initial period. After the initial period, two compressors will be running and one will be in standby. Similarly, there will be two trains of gas dehydration and dew pointing units. Initially, one train will be under operation, with a second train being initialised after some time. The conditioned gas will be routed via new pipelines to the gathering station.

The typical flow diagram of natural gas station and pipelines are shown in Figure 4.17. Fault Tree and Event Tree techniques [83] are used for hazard analysis. Fault Tree is used to identify the various basic events that lead to an accident, while Event Tree Analysis [54] is used to find different accident scenarios from an initiating event [42]. But neither technique provides a value for estimates or evaluates the frequency of failure. Although the frequency of release from wells, inter unit piping, compressors and the number of incidents are low, in order to generate the more reliable value, a confidence interval is used to obtain the release frequency [21].

Figures 4.1 a, 4.1 b and 4.1 c show a qualitative fault tree analysis of a natural gas leak from a natural gas gathering station which may contribute for leaks. (Enclosed in **Appendix- 4**).

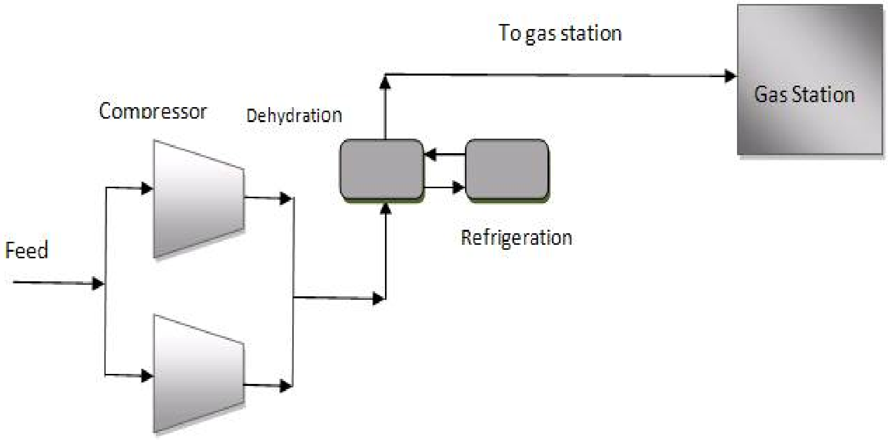


Figure.4.17 Typical Line diagram of Natural gas pipeline system

The following Table: 4.12 shows the key components and equipment available in the natural gas gathering station and associated pipeline network. This list is used to identify the various potential hazardous events and associated failures.

Table 4.12: Equipment and component List

S.No	Equipment	Equipment number
1	Suction scrubber	24281
2	Booster compressor 1st Stage	2463-1
3	Booster compressor 2nd Stage	2463-2
4	Booster compressor 3rd Stage	2463-3
5	Booster compressor 4th Stage	2463-4
6	1st Stage cooler	24101
7	2nd stage suction cooler	24284
8	2nd stage cooler	24104
9	3rd stage suction scrubber	24287
10	3rd stage cooler	24107
11	4th stage suction scrubber	24290
12	4th stage cooler	24110
13	Inlet gas Knock out drum	24193
14	Glycol contractor top	2455-1
15	Glycol contractor bottom	2455-2
16	Cold recovery exchanger	24121
17	Chiller	24123
18	LT Separator	24203
19	Glycol regenerator	24300
20	Glycol Flash vessel	24199
21	Lean / Rich Glycol Exchanger	24117
22	Glycol Booster pump	24183-1
23	Glycol Transfer pump	24183-2
	Glycol cooler	24119

24		
25	Tie-in Up to flares	24225-01
26	Pipeline from gathering station	55555
27	Condensate separator	36224
28	Scrapper receiver	36145

One of the transmission methods for natural gas is through pipelines either in NG or LNG forms. Transmission pipelines are laid across country or in between busy cities or a network of super high ways [88]. Corrosion, mechanical failure, damage during excavation, natural hazards and some other unknown factors are contributing factors for accidents involving natural gas pipelines [44]. The leakage of natural gas from pipelines results in fire, explosion and toxic gas dispersion which can bring serious loss to the immediate environment.

4.7.3 POSSIBLE SCENARIOS

From the HAZID & HAZOP study the following are the four major hazardous accident scenarios that have been identified for further risk assessment.

Scenario 1 - Loss of containment of hydrocarbon from Gas compression in the gathering station;

Scenario 2 – Loss of containment of H_2S from Gas Compression in the gathering station.

Scenario 3 - Loss of containment of hydrocarbon from the pipeline.

Scenario 4 – Loss of containment of H_2S from the pipeline.

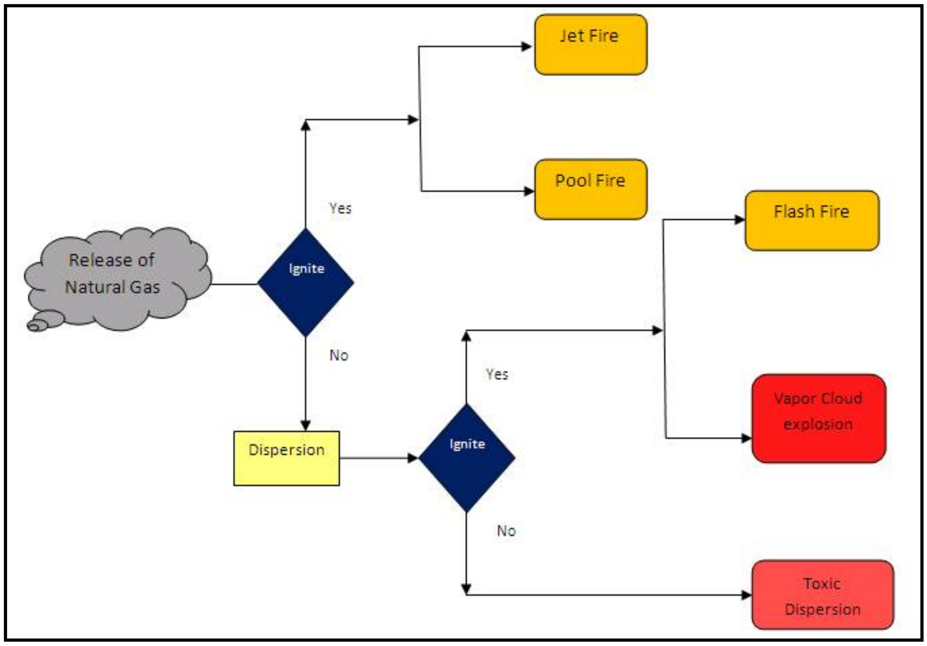
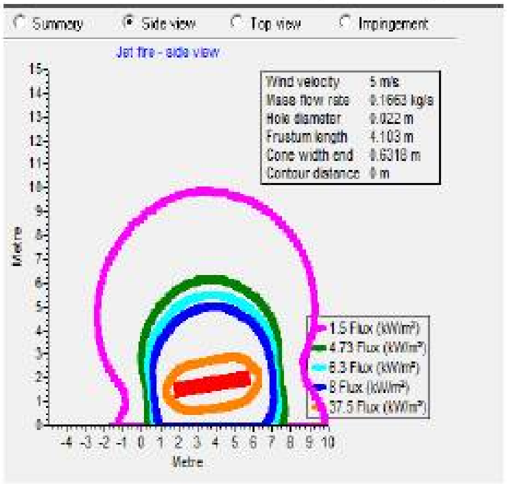


Figure.4.18: Event Tree showing different outcomes of NG pipeline

Figure 5.1a and 5.1b shows the various event outcomes that may occur when any natural gas leaks from any of the above scenairos and its calcualtions. (Enclosed in **Appendix-5**).

4.7.4 RESULTS & DISCUSSION

Based on the analysis, the Jet Fire radiation intensity reaches up to 8 meter for 1.5 kW/m^2. These values help us in deciding the layout of the equipment and operational rooms at site. The hydrogen sulphide gas dispersion is modelled for two wind speeds with 300 ppm reaching a 3 meter distance from the leak source. Based on the output, protective clothing and emergecny prepadnress should be planned accordinlgy. The following figure shows the output analysis of Jet Fire.



Wind velocity	5 m/s
Mass flow rate	0.1663 kg/s
Hole diameter	0.022 m
Frustum length	4.103 m
Cone width end	0.6318 m
Contour distance	0 m

Figure.4.19: Jet fire side view feed to stage scrubber

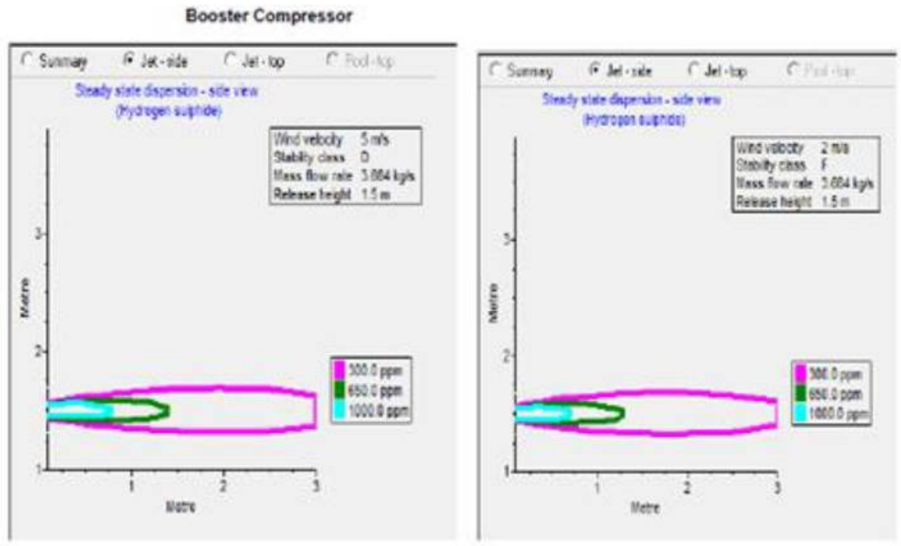
Jet fires have a high flame temperature producing high thermal radiation up to 300 kW/m^2. The immediate damage will apply either in the source area, or to adjacent equipment and structures of the terminal depending on the duration of the fire. The pressures in the process equipment range from 3.1 bar to 68 bar. Such high pressure releases, when ignited, are capable of generating significant Jet Fire flames and heat fluxes of greater than 37.5kW/m^2.

TOXIC GAS DISPERSION

Materials handled at the gas gathering station contain H_2S. The impact of H_2S dispersion, in terms of the percentage of fatalities over a period of time based on exposure, is defined by distance with the following toxic concentrations assumed for calculating the toxic risks:

- LC1 – 650 ppm H_2S;
- LC50 – 1000 ppm H_2S;
- LC100 – 1320 ppm H_2S.

The H_2S toxic dispersion does not have a significant impact. The maximum downwind dispersion distance of up to 650 ppm H_2S does not exceed 5 m. Therefore, the risk contribution from toxic gas dispersion is considered to be negligible. Fig 6.20 shows the H_2S toxic cloud distribution for wind speeds of 5 m/s and 2 m/s.



Wind velocity 5 m/s
Stability class D
Mass flow rate 3.884 kg/s
Release height 1.5 m

Wind velocity 2 m/s
Stability class F
Mass flow rate 3.884 kg/s
Release height 1.5 m

Figure.4.20: Hydrogen sulphide gas dispersion from compressor

This study reveals that we can expect a pipeline with a full bore leak to have a maximum lower flammability limit distance of 55 m. Release containment and suppression systems, fire containment and suppression systems, explosion relief, containment and suppression systems are the possible measures suggested as control and mitigation for accident prevention by previous researchers [72].

It is recommended that to install flammable and toxic gas detection systems around the refrigeration unit and air inlet close to the centralised air conditioning unit.

4.8 NATURAL GAS MANIFOLD & TRANSFER STATION

4.8.1 INTRODUCTION

LNG and condensates are extracted from the well heads offshore and transferred to gas stations onshore. The LNG gas manifold and transfer station receive gas, and transfer this to the storgae tanks of different companies. LNG is a clean fuel and its usage is increasing worldwide in industry replacing other fossil fuels. The contamiation such as H_2S is removed and put into flare.

4.8.2 PROCESS DESCRIPTION

The manifold stations in Ras laffan are used to transfer gas from one station to another. Currently three manifold stations (A1, A2 and V) are located in Ras laffan and will include five additional stations (A21, A3, A4, A5 and 72-SBV0) due to further expansion.

Station V is a large station setup to control the other manifold stations. Although the other stations are unmanned, station V is manned by a supervisor and three operators. This manifold station contains a gas compression system in order to receive three multistage ethane gas at low pressure.

4.8.3 POSSIBLE SCENARIOS

From the HAZID study, a total of 34 flammable gas release scenarios and 2 scenarios of toxic gas relase were indetified.

The consequences of each of the identified fire, explosion or toxic events associated with each of the identified isolatable sections, were calculated. The consequence analysis of the release of hydrocarbons and other hazardous material releases start with modeling of the discharge rates for different hole sizes in process equipment and pipelines. This enables us to analyse the discharge effects when hole sizes develop. Furthermore, the size and the shape of flammable and toxic gas clouds from releases in the atmosphere are modeled as well as the flame and radiation field of the releases which are ignited and burn as Jet Fires, Pool Fires, Flash Fires or BLEVE, also known as a Fire Ball.

4.8.4 Parts Count Approach Method (PCAM):

The frequency assessment involves the quantification of failure frequencies by combining the component failure rate data with parts count approach method. (PCAM). The assessment is only concerned with component failures which result in loss of containment leading to the identified hazards (i.e. leaks due to loss of containment).

Gas stations and associated piping are considered for this parts counts approach and nodes are calculated the number of equipment, piping and instruments are collected based on process flow schematic diagram and site visit survey.

4.8.5 WEATHER CONDITIONS

The consequences of released hazardous material are largely dependent on the prevailing weather conditions (e.g. wind, temperature and humidity).

The following ambient weather conditions were assumed:

- Average Ambient Temperature: 34°C
- Relative Humidity: 60 %
- Solar Radiation: 986 W/m^2

By applying location specific wind rose data, wind direction was incorporated to the analysis. The following stability wind-speed categories were used for two weather conditions representing day and night:

- D Stability, 5 m/s wind speed
- F Stability, 2 m/s wind speed

4.8.6 RESULTS & DISCUSSION

An event tree describes the way an incident develops through steps that need to be taken to come to a specific outcome (such as a pool fire or a flash fire). For this study, typical event trees where provided for pipelines and storage tanks. Potential risk driver scenarios from 5 gas manifold station contributing towards the risk are illustrated in Risk Contours Figure 4.21.

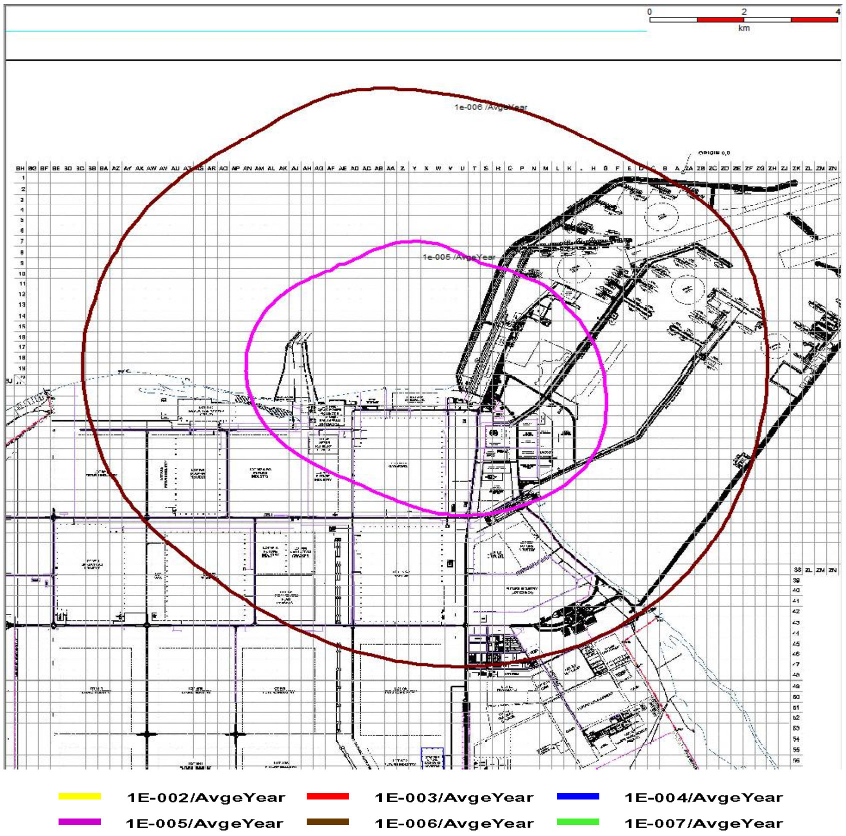


Figure 4.21 Individual Outdoor Risk Contours

A risk analysis was performed by summing up the results of the frequency analysis and the results from the consequence analysis with defined occupancy and derived ignition source.

Table 4.13: LOC Scenario and Risk level

S.No	LOC Scenario	Risk Integral / year
1	Condensate from Offshore to 72 station	9.23×10^{-03}
2	Gas from Offshore to 72 station	8.86×10^{-04}
3	Condensate from Offshore to 72 station	3.80×10^{-06}
4	Gas from offshore to 72-SBV-0 station	3.27×10^{-06}
5	Gas from AKG to ESDV 007 at Station 1	3.04×10^{-06}
6	Gas from ESDV 001 at Station5 to ESDV 002	2.28×10^{-07}
7	Gas from Train III & IV to ESDV 002 at Station 4	1.51×10^{-07}
8	Gas from Train I & II to ESDV 001 at Station 4	1.51×10^{-07}
9	Gas from E-2 Pipeline to Ethane Manifold at Station 4	3.17×10^{-08}
10	Gas from E-1 Pipeline to Ethane Manifold at Station 4	3.17×10^{-08}

The risk evaluation was carried out using the available population information and the major hazard events identified.

4.9 FREQUENCY ESTIMATION

The frequency of hazardous event scenarios depend upon many factors such as basic failure frequency of pipelines, valves, components, storage tanks, design, construction, maintenance, ignition probability and weather conditions. Failure frequency data for cylinders, piping, valves, connections and other components are taken from either historic data or standard failure databases [36].

4.9.1 FAULT TREE / EVENT TREE ESTIMATION

If the historical or generic data base failure frequency is not available, frequency is assessed [35] by either Fault Tree or Event Tree model software. There are very few software models that use a combination of the two techniques.

Simple spread sheet models are often used to assess the frequency throughout the Oil and Gas industry. Event Tree Analysis is used [47] to identify the various incident outcomes in the cross country pipeline safety assessment. Event Tree Analysis [78] is a formal technique used for accident investigation and risk assessment. It is very useful to find the possible accident scenarios and final outcomes based on severity.

4.10 PARTS COUNT APPROACH METHOD (PCAM)

Quantitative risk assessments consider accidental releases of process materials due to loss of containment incidents. In the absence of local failure rate data, the likelihood of loss of containment is determined using historical failure rate data for standard plant components (e.g. pumps, valves, flanges etc.). The frequency assessment involves the quantification of failure frequencies by combining the component failure rate data with the Parts Count Approach Method. (PCAM).

The assessment is only concerned with component failures which result in loss of containment leading to the identified hazards (i.e. leaks due to loss of containment).

Failure frequencies are derived based on the Parts Count Approach in modern quantitative risk assessment studies. The total number of piping components and sizes of particular Oil and Gas facilities are calculated. Usually a 10 % margin is considered for the total pipeline length by risk analysts. Once the base frequency is selected from a generic database it is used in the Parts Count Approach method in order to arrive a total scenario frequency specific to the particular facility. So it is very important that a thorough and systematic parts count is calculated for the particular isopleths of the facility being studied.

Parts count of equipment, piping, pipelines, flanges, valves and instrument connections are estimated based on the P&ID diagram of the particular isopleth of the facility. Then the total failure frequency is derived from the combination of basic generic frequency and individual number of components and parts. Risk analysts divide the study facility into different isopleths and calculate the inventory with the help of process flow diagrams or process and instrumentation diagrams. Based on the pipe size, length of the pipeline and equipment, the components and instrumented connections are assessed.

Once the base failure rates and equipment counts are summarised then the total frequency is calculated for that particular isopleth. By assessing the frequency with this Part Count Approach, the failure frequency for that particular facility can be derived, even though the base failure frequency is assumed from generic databases.

The Leak Frequency also considers the severity of the leak such as minor, small, medium, large, and full or rupture of diameter. The detailed Parts Count Approach method is presented in using a Natural Gas storage facility as a case study to assess total leak frequency.

Once the Total Release Frequency is calculated it should be multiplied by other conditional probabilities to obtain the accident scenario frequency. Weather condition probability, wind direction probability, time slot probability, ignition probability should be considered in order to derive the total accident scenario frequency.

LEAK SIZE

The risk assessment considers a range of representative leak severities by defining a set of discrete failure hole sizes (expressed in terms of equivalent hole diameters). The selected hole sizes are intended to be representative of the full range of failures that could occur, ranging from relatively small leaks up to catastrophic failures. These are shown in **Table 4.14.**

Table 4.14: Leak hole sizes

Size	Range
Minor	2 mm
Small	7 mm
Medium	22 mm
Large	77 mm
Rupture	150 and above

4.10.1 PCAM FOR NATURAL GAS GATHERING STATION AND PIPELINE

Gas stations and associated piping are considered for this parts counts approach. Nodes are calculated based on the number of equipment, piping and instruments shown in process flow schematic diagrams and site visit surveys.

Table 4.15 shows the various components and equipment considered for assessing the frequencies.

Table 4.15: Equipment list for assessing frequency

S.No	Equipment	Equipment number
1	Suction scrubber	V-24281
2	Booster compressor 1st Stage	k-2463
3	Booster compressor 2nd Stage	k-2463
4	Booster compressor 3rd Stage	k-2463
5	Booster compressor 4th Stage	k-2463

6	1st Stage cooler	E-24101
7	2nd stage suction cooler	E-24284
8	2nd stage cooler	E-24104
9	3rd stage suction scrubber	V-24287
10	3rd stage cooler	V-24107
11	4th stage suction scrubber	V-24290
12	4th stage cooler	E-24110
13	Inlet gas Knock out drum	V-24193
14	Glycol contractor top	C-2455
15	Glycol contractor bottom	C-2455
16	Cold recovery exchanger	E-24121
17	Chiller	E-24123
18	LT Separator	V-24203
19	Glycol regenerator	V-24204
20	Glycol Flash vessel	V-24199
21	Lean / Rich Glycol Exchanger	E-24117
22	Glycol Booster pump	P-24183
23	Glycol Transfer pump	P-24183
24	Glycol cooler	E-24119
25	Tie-in up to flares	24225-01
26	Pipeline from station 1 to station 2	PL-01
27	Condensate separator	V-36224
28	Scrapper receiver	A-36145

In case of a leakage in the process equipment or pipelines, flammable or toxic compounds can be released into the atmosphere. This can occur in the form of a gasket failure in a flanged joint, a bleeding valve left open inadvertently, failure of a pipeline or any of other sources of leakage.

The frequency of occurrence of such an event is based on the probability of a scenario and the presence of constraints that influence the development of the event. Therefore, base failure frequency data for all the piping components was derived from any generic or historical databases. E&P forum QRA data sheets and OGP data sheets are used to identify the generic failure frequencies of the key important equipment in the facility. The detailed generic frequency for various assumed leak hole sizes are enclosed in **Appendix 6**.

These leak frequencies are derived based on the parts count approach, where parts shown on the P&ID have been counted and combined with base failure frequencies. The Parts Count Analysis was performed for the defined isolatable section. Thereby, the total number of piping components (e.g. valves, reducers) was counted in each isolatable section for the various leak sizes and the base failure frequency for each piping component was derived from the OGP data sheets process release frequencies. The total failure frequency for each isolatable section was calculated by combining the total number of piping components and base failure frequencies. The detailed parts count analysis results of frequency is presented in Table at **Appendix 7**.

Figure 4.22 shows the leak contribution of equipment and size of the leak.

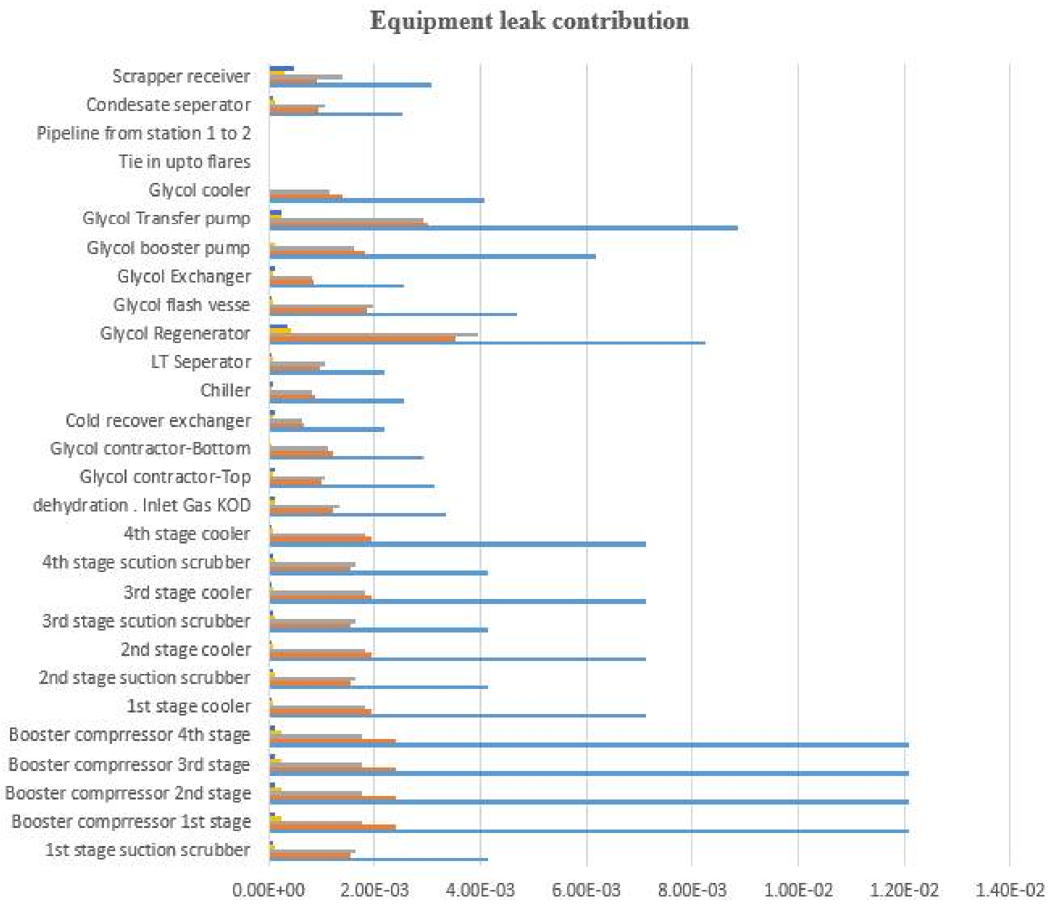


Figure 4.22: Equipment leak size contribution.

The data shows that the leaks are from all hole sizes, where the frequency is dominated by small leaks such as 2 mm.

4.11 BAYESIAN NETWORK METHOD

INTRODUCTION

Equipment failure or component failure rates are the main input for the risk analysis studies. Failure data needs to be established for the specific plant so that the risk assessment values are reliable in nature [59]. Plant specific failure data and generic data available from the historical databases are used for the risk analysis. Generic data are available and used by analysts for the study. But the question is how reliable is the data and how the risk values assessed are to be validated? This Bayesian model approach uses generic data as a prior and plant specific data as evidence to obtain posterior frequency.

The Bayesian Network is used to find the posterior failure probability of safety systems which is applied in Event Tree Analysis and combined with the Bow-tie approach [2].

4.11.1 EQUIPMENT LIST AND THEIR BOUNDARIES

A description of the equipment and its boundary is very important as it indicates up to what boundary the equipment may operate. The change of the boundary influences the failure rate, so schematic diagrams are drawn for all equipment and their boundaries.

FAILURE

The degradation of equipment or item not able to perform its required function is called failure of the equipment or item.

EQUIPMENT LIST

Figure 4.23 to 4.29 are illustrate the boundary of the equipment unit. It includes the specification of subunits or maintenance units that are part of the equipment units.

- Pump
- Pressure vessel
- Pipeline
- Piping
- Compressor system
- Heat Exchanger
- Flange Joint
- Manual Valve

- Actuated Valve
- Instrumented connection

EQUIPMENT BOUNDARY

This incorporates the particular equipment and its subsystem that are able to perform an intended function. The boundary includes certain parts of the system only. Based on failure cause analysis the limit is described.

PUMP

The boundary defines parts associated with the generic item that are considered to be essential for its function or sold by the manufacturer as part of the item. The pump implies general service and including fire service pumps. The motor, inlet valve, outlet valve and strainer are not considered in the boundary of the pump system. Figure 4.23 shows the pump and its boundary limit.

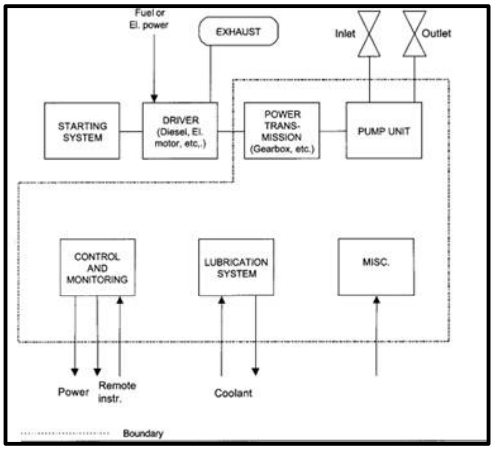


Figure 4.23: Pump

COMPRESSOR

The compressor boundary system is shown in Figure 4.24. The driver, inlet valve and outlet valve are not considered as a part of the system.

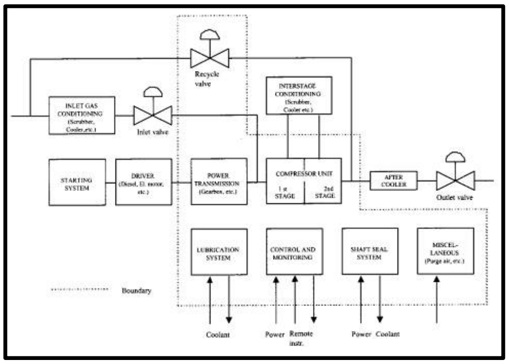


Figure 4.24: Compressor

All stages of the compressor are considered as a single unit.

HEAT EXCHANGER

The inlet, outlet, pressure relief valve and drain valve are specifically excluded. Calibration valves and instrumental valves are included in the pressure boundary. Figure 4.25 shows the heat exchanger and its boundary limit.

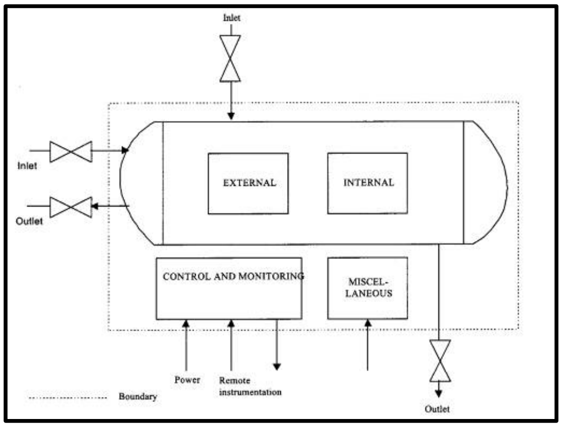


Figure 4.25: Heat exchanger

PRESSURE VESSEL

The inlet, outlet, pressure relief valve and drain valve are specifically excluded. Calibration valves and instrument valves are included in the form of a pressure boundary. Figure 4.26 shows the pressure vessel and its boundary limit.

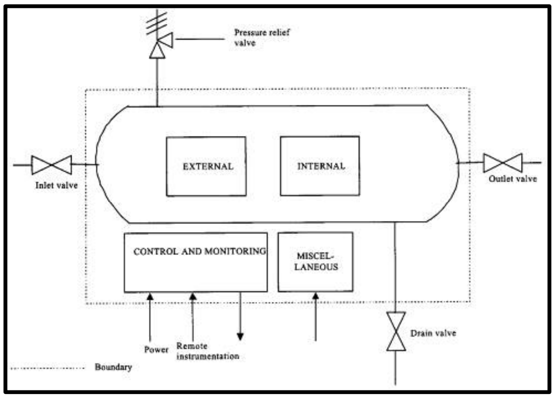


Figure 4.26: Pressure vessel

VALVE

The valve consists of the housing and the actuator. A valve includes the complete assembly of the connector attached to the piping. Solenoid valves are included within the boundary. Figure 4.27 shows the valve and its boundary limit.

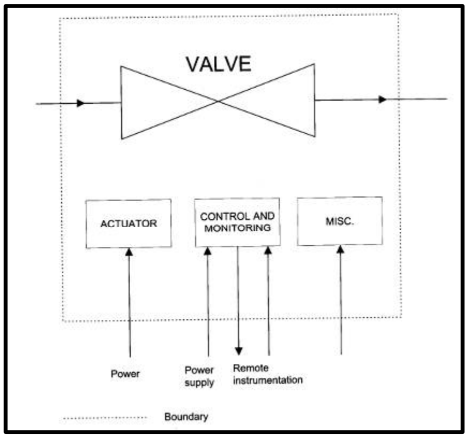


Figure 4.27: Valve

PIPING CONNECTION (FLANGE JOINT)

Figure 4.28 shows the piping connection boundary. It includes the flanges and gasket.

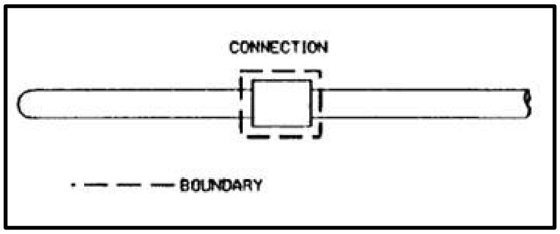


Figure 4.28: Flange joint

PIPING SYSTEM-LINED PIPE STRAIGHT SECTIONS

Figure 4.29 shows the piping in between two connections or considered as in between two shutdown valves.

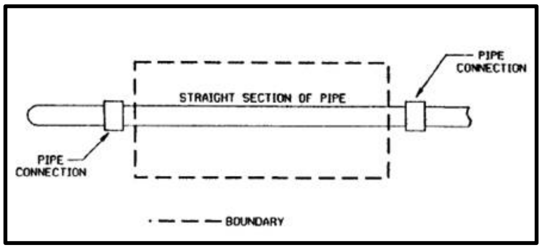


Figure 4.29: Piping system line joint

PRESSURE SAFETY RELIEF VALVE

Figure 4.30 has shown the pressure safety relief valve and its boundary limit which consists of the spring loaded sub system.

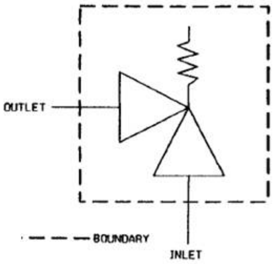


Figure 4.30: Safety relief valve

4.11.2 FAILURE FREQUENCY OF NATURAL GAS COMPRESSION & ASSOCIATED PIPELINE -BAYESIAN

Bayesian theorem is the basic tool for assigning probabilities to hypothesis combining prior data as well as experimental data. Bayesian updating is used to reduce uncertainty and imprecision of failure data in the risk analysis [55]. By updating historical failure data with plant specific data, it is able to provide more accurate data that is more reliable than historical data and plant specific data alone [51].

HISTORIC / GENERIC DATA

Historic failure databases have large numbers of failure occurrences and have a wide range of component types. These data are conservative in nature. These components from different companies have different maintenance policies, test frequencies and different operating processes and environmental conditions. But as the same time, these data are more widely accepted in the international community.

PLANT-SPECIFIC DATA

These data represent the plant/facility of study, and provide further credibility to the risk analysis. It is not possible to collect all the components or initiating events data address for reliability. For example, the lack of data may be interpreted by some analysts as ‘never failed’. Although this may be true in very few cases, the truth is more likely that those components may never have failed within the window or time period being taken in to consideration. Another well-known problem is that only a limited amount of plant specific data will be available for the plant. Therefore it is better to combine plant-specific data with historical data to improve accuracy and achieve a more realistic prediction.

Table (**Appendix 8**) includes plant specific data which is used to calculate the plant specific failure rate. With little plant specific evidence or data, one has to apply a Bayesian update technique to get as much information as possible from the data. The Bayesian update technique changes the generic uncertainty distribution into a posterior distribution by incorporating the plant specific data.

Bayesian update process procedure:

$$f(\lambda|E) = \frac{f(\lambda)\ f(E|\lambda)}{\int_0^\infty f(\lambda)\ f(E|\lambda)\ d\lambda}$$

Here,

f (λ) - Prior distribution rate values, i.e., generic historic data base values.

F (EIλ) - Likelihood function distribution

(Probability that E observed given value of λ)

F (λIE) - Posterior distribution.

Figure 4.31 shows the typical Bayesian Network model in graphical display.

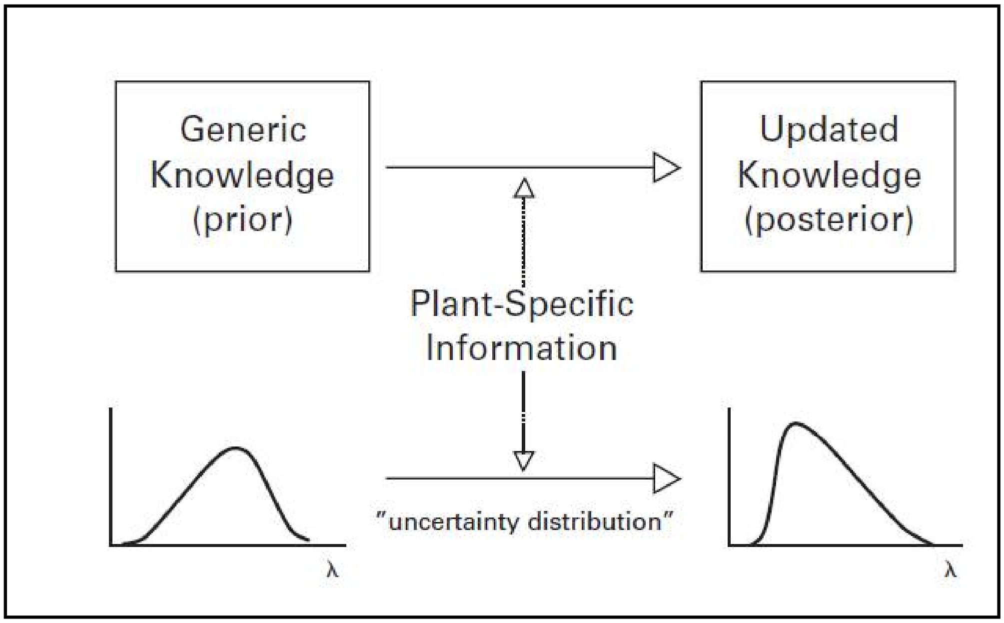


Figure 4.31: Bayesian Network graphical model

1) Prior distribution is considered as gamma distribution based on mean and variance. The α and β are therefore estimated thus:

$\alpha_{prior}=ɥ^2/\sigma^2$ ………………………. Equation 1

and $\beta_{prior}=\sigma^2/ɥ$ ………………………. Equation 2

Here, α – is Shape parameter

β- Is scale parameter in Gamma distribution.

σ- Logarithmic standard deviation.

ɥ - Mean value

The following are the steps in the update process:

2) Likelihood function

From the plant specific database the likelihood function x- number of failures occurred ''t'' period and is calculated as

λ= Failure rate = x/t………Equation 3.

3) Estimation of posterior α', and β'

$\alpha_{post} = x + \alpha_{prior}$ ………………………...Equation 4.

and $\beta_{post} = t + \beta_{prior}$………………………..Equation 5.

4) Estimation of posterior mean and variance.

Mean $_{post}$ $ɥ' = \alpha_{post} / \beta_{post}$……………….. …….Equation 6.

and Variance $= \alpha_{post} / (\beta_{post})^2$……………...Equation 7.

Bayesian update incorporates the degree of belief from generic data and information from plant collected data. The prior belief referred to as 'prior distribution' aims to discover or define the distribution of historical data.

Appendix 9 explains how the calculation uses generic data to calculate the posterior mean for the natural gas pipeline failure case study example is given.

Then the specific plant or industry data is used to update the prior distribution. Bayesian estimation can give credible estimates directly from posterior distribution. The frequency rate is based on time and demand type. The initiating failure frequency is time based and follows the gamma distribution. So in this study the Gamma distribution follows prior distribution and it makes the posterior distribution the same distribution. How close they are to the posterior mean provides verification. Based on the calculations the failure frequency using Bayesian network technique combined with generic failure frequency is tabulated in **Appendix 10**. The **Appendix 11** is an example of Bayesian network spread sheets which used to estimate the failure frequency.

4.12 PARTS COUNT APPROACH METHOD (PACM) COMBINED WITH BAYESIAN NETWORK

The Parts Count Approach Method is used basic frequency from generic or historical databases to evaluate the total failure frequency of the particular part of the facility. In order to overcome the limitations of generic or historical database, the Bayesian Network is combined with PCAM which is used to develop the updated failure frequency for risk computation.

This means that the frequency assessments derived from the plant specific data of failures, as well as the number of components to the particular facility, are appropriately calculated. So the final hazardous accident scenario frequency becomes more suitable and reliable for assessing risk compared to the conventional method. Few components and parts are selected in this work to estimate the failure frequency and are listed in the **Appendix 12**.