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Quantitative Risk Assessment on hydrocarbon release

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ABSTRACT

Safety is the first priority in the chemical industry. Over the past thirty years, Industrial processes increasingly involve the use and manufacture of hydrocarbons having highly dangerous substances, particularly flammable, explosive and toxic gases. Inevitably, occasional escapes of gas occur, which create a potential hazard to the industrial plant, its employees, and people living nearby and risk to the environment. This paper explains how to overcome/control such type of potential hazards using Quantitative Risk Assessment technique taking a case study.

KEYWORDS: Health Safety, Risk Analysis, Hazards, Leakage and PHASTRisk.

INTRODUCTION

According to the Centre of Chemical Process Safety (CCPS) book , Quantitative Risk Analysis (QRA) is defines as the process of hazard identification followed by numerical evaluation of incident consequences and frequencies, and their combination into an overall measure of risk when applied to the chemical process industry [1]. Now, Risk assessment means comparing the risk analysis results to the risk criteria. This QRA Study follows UK-Health Safety & Environment (HSE) risk criteria as mentioned in Table 1.

Table 1: Acceptability Risk Criteria

Criteria	Individual Risk Per Annum(IRPA)
Unacceptable Risk	$>1.0 \times 10^{-3}$
Tolerable Risk (Subject to the implementation of mitigation measures to reduce to ALARP)	$>1.0 \times 10^{-5}$ and $<1.0 \times 10^{-3}$
Acceptability Risk	$<1.0 \times 10^{-5}$

In general, hydrocarbons such as ethane, propane and also liquefied gases have the potential to cause major hazards and in that LPG have still higher potential to cause catastrophic events. For example, on September 14th, 1997 an LPG vapour cloud explosion destroyed the facilities at HPCL Refinery Vishakhapatnam, India [2] and on July 26th, 1996 an LPG Boiling liquid vapour cloud explosion destroyed the facilities at Cactus, Reforma, Mexico [3]. These two accidents are only two examples of incidents with high number of fatalities inside the occupied buildings. CCPS provides a list of other serious incidents involving in process plants. There will always be a possibility of having an explosion when dealing with hydrocarbons. About 42% of largest losses in the hydrocarbon process industries, were caused by vapour cloud explosions [5]. Lenoir and Davenport [6] have presented a review of many major incidents involving vapour cloud explosions worldwide from 1921 to 1991. Hydrocarbon materials such as ethane, ethylene, propane and butane, which have been involved in the incidents indicated, have a greater potential for explosions. The impact of such explosions can be destructive, resulting in fatalities and large financial losses. Prevention of these explosions means prevention of risk in the process facility is not possible, but we can reduce/control the risk associated with the process facility by following risk mitigation steps. For that we have to know, what is the risk, How to identify the risk, impacts on people and surroundings, what are the mitigation measures. Quantitative Risk Assessment gives us a detailed result about risk associated with the process facility using software tools known as PHAST & PHASTRisk.

MATERIALS AND METHODS

Based on the quantitative risk assessment methodology Fig.1 describes a case study

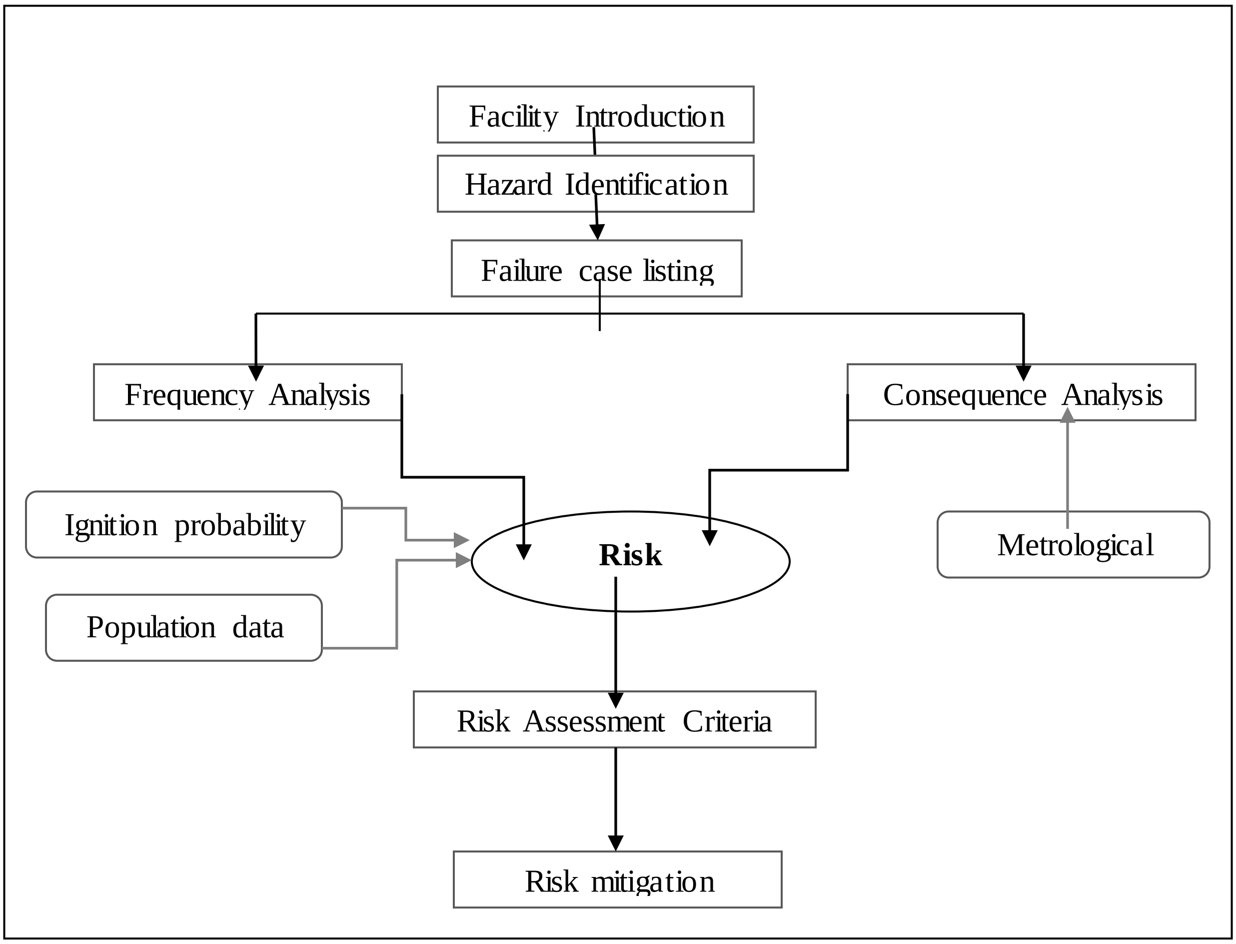

Figure 1: QRA methodology flow chart.

3. Case Study

This case study is to demonstrate the application of the proposed program. The case study is Liquefied Petroleum Gas (LPG) storage and transferring facility.

3.1. Facility introduction

LIQUEFIED PETROLEUM GAS STORAGE & TRANSFERRING facility, contains LPG, 50% Propane + 50% Butane. LPG is a flammable mixture of hydrocarbon gases. It is a mixture of Propane (C_3) and Butane (C_4) hydrocarbons that remain in gaseous state under atmospheric pressure and temperature.

This facility consists of LPG sphere and transferring pump connected with the associated pipelines and instruments as shown in Fig.2. LPG was received into the sphere from LPG Unit through a 6" line. The sphere is of 18m diameter, has a hold up volume as 3052m^3.The sphere was provided with a single nozzle at the bottom and it extends 3m outside the shadow of the sphere. So that any fire at the end of the nozzle does not impinge on the sphere. The sphere was provided with two safety valves, TG, PG, LG, LI and depressurized line. Sphere is designed for 55^{o}C and design pressure for 14.5 kg/cm^2 (g). The bottom nozzle was used for both dispatch and receptor of LPG. From the sphere LPG is pump through dispatch pump rail or road or pipeline transfers. A ROV was provided at the bottom nozzle, to isolate the sphere in case of emergency. LSHH was provided in the sphere to close the ROV-1 in case of very high level. Similarly at very low level LSLL was provided to trip the pump. The pump having the capacity of 100m^3/hr. and develops a differential head of 50 MLC.

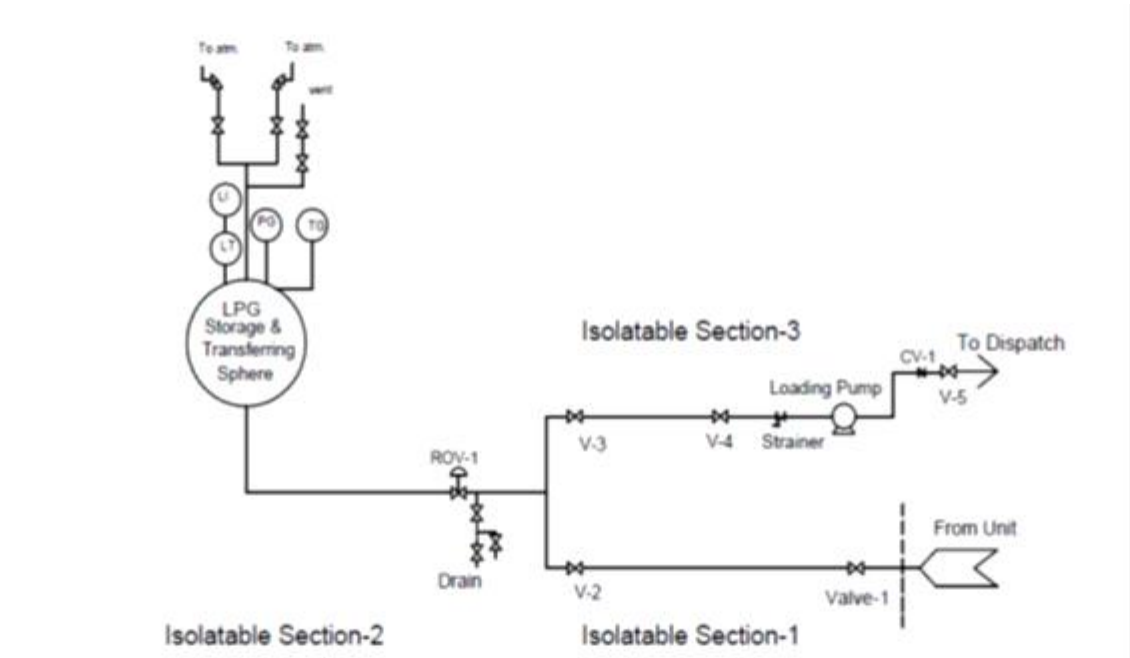

Figure 2: LPG Storage and Transferring Facility Layout.

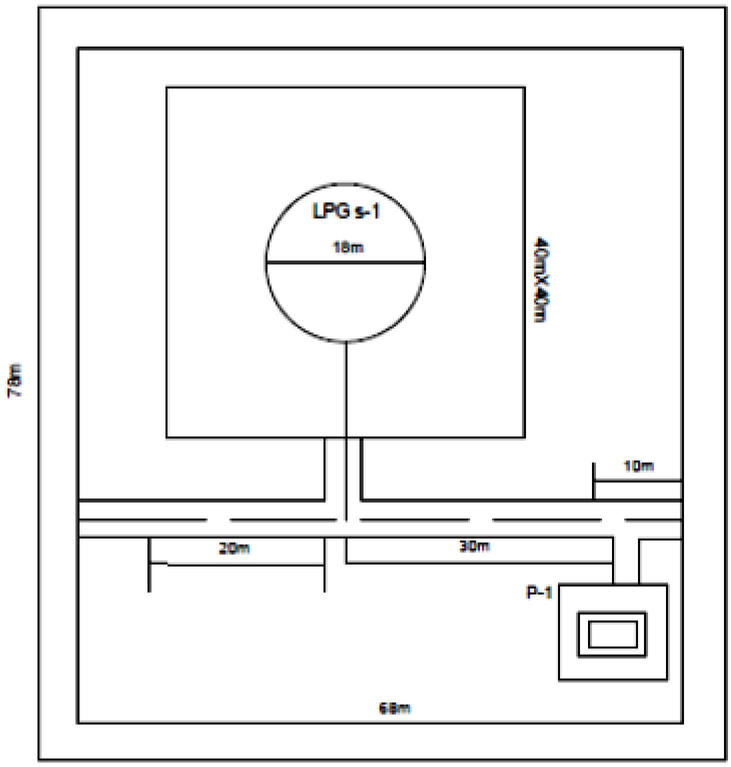

Figure 3: LPG Storage & Transferring Plotplan.

3.1.1 Input data for Risk Analysis

The conditions related to the facility that is input for the risk analysis, i.e., the parameters that are generic to each release scenario. The following information was presented in subsequent sections [6]:

1. Meteorological data (atmospheric parameters and wind data) (Table 2)
2. Population (Table 3)
3. Ignition Sources (Table 4,5 & 6)

Table 2: Weather Conditions

Wind Speed	Pasquill Stability
2	F
5	D

Table 3: Population Data on LPG Site Location

On site Location	Manning Pattern	
	Day	Night
Total Staff	25	15

Table 4: Atmospheric Parameters

Parameter	Average value considered for study
Ambient temperature (°C)	30
Relative Humidity (%)	70%
Sola Radiation Flux (KW/m²)	0.7

Table 5: Wind Probability

Wind direction	North	North East	East	South East	South	South West	West	North West
Day	5	5	8	13	5	6	24	15
Night	9	12	21	15	5	7	16	14

Table 6: Ignition Probability data for industrial LPG plant

Release Rate (Kg/s)	Ignition Probability
0.1	0.0010
0.2	0.0010
0.5	0.0011
1	0.0012
2	0.0026
5	0.0073
10	0.0162

3.2. Hazard Identification

Hazard identified for the LPG facility was release of LPG. This has the potential to cause harm to entire facility and people inside the terminal. If the release of inventory was large amount then it may cause severe problems to the public and environment also.

3.3. Failure case listing

When calculating the risk presented by a large facility or process, the analysis can be divided into area or sections, that sections are called isolatable sections.

LPG processing facility was divided into three isolatable sections as;

1. Input Piping form Unit to LPG Sphere
2. Output piping from sphere to Loading Pump and
3. Discharge pipeline from Pump to dispatch

As per Oil & Gas Procedures, The following representative leak sizes was considered for this study:

- Small release through 5mm equivalent hole, representative of 1 to 10mm hole sizes.
- Medium release through 30 mm hole, representative of 10 to 50 mm hole sizes.

- Full bore release at pipeline diameter, representative of releases larger than 100 mm, including full bore rupture and
- Catastrophic rupture for LPG Sphere.

To estimate the consequences of process release, the failure cases are developed based on the inventory released, process conditions, atmospheric conditions and release orientation. (Table 7)

Table7: Selected failure scenarios

S.No.	Failure case Description	Failure Scenario	Pipeline Size(inch)	Operating Pressure(Bar)	Operating Temperature
1.	Input Pipe line from Refinery to LPG sphere	Small	6	6	20
		Medium			
		FBR			
2.	LPG Sphere	Small	-	6	20
		Medium			
		Cat. Rapture			
3.	LPG Discharge pump Seal failure	Small	-	6	20
		Medium			
		Full Bore Rapture			

3.4. Frequency analysis

In this section the failure frequencies taken for assessment of the overall risk posed by the selected failure scenarios on the surroundings were discussed as shown in Table 8.

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Table 8: Process Release Frequencies

Isolatable Section S. No	Equipment Involved	Equipment Failure Frequencies respective Hole Sizes						
		Small (mm)	Medium (mm)	Large/FBR (mm)	Quantity/meter Per Year			
					Quantity	Small (mm)	Medium (mm)	Large/FBR (mm)
1. Input Piping From Unit to LPG Sphere	Input Process Piping-6"	5.80E-5	7.40E-6	7.60E-6	30	1.74E-3	2.22E-4	2.28E-4
	Manual Valves	1.00E-4	1.80E-5	1.10E-5	2	2.00E-4	3.60E-5	2.20E-5
	Flanges	9.10E-5	1.10E-5	8.50E-6	3	2.73E-4	3.30E-5	2.55E-5
Total Frequency						**2.21E-3**	**2.91E-4**	**2.76E-4**
2. LPG Sphere	Process Piping-6"	5.80E-5	7.40E-6	7.60E-6	20	1.16E-3	1.48E-4	1.52E-4
	Actuated valves	5.10E-4	6.60E-5	3.30E-5	3	1.53E-3	1.98E-4	9.90E-5
	Manual valves	1.0E-4	1.80E-5	1.10E-5	4	4.00E-4	7.20E-5	4.40E-5
	LPG Sphere	3.5E-5	7.10E-6	4.30E-6	1	3.50E-5	7.10E-6	4.30E-6
	Instruments	5.0E-4	6.50E-5	0	4	2.00E-3	2.60E-4	0
	Flanges	9.10E-5	1.10E-5	8.50E-6	14	1.27E-3	1.54E-4	1.19E-4
Total Frequency						**6.40E-3**	**8.39E-4**	**4.18E-4**

3.LPG Loading Pump	Process Piping-6"	5.80E-5	7.40E-6	7.60E-6	20	1.16E-3	1.48E-4	1.52E-4
	Manual Valve	1.00E-4	1.80E-5	1.10E-5	4	4.00E-4	7.20E-5	4.40E-5
	Loading Pump	6.9E-3	5.9E-4	1.40E-4	1	6.90E-3	5.90E-4	1.40E-4
	Process Piping-2"	1.28E-4	2.7E-5	0	10	1.28E-3	2.70E-4	0
	Flanges	9.10E-5	1.10E-5	8.50E-6	13	1.18E-3	1.40E-4	1.11E-4
Total Frequency						**1.09E-2**	**1.22E-3**	**4.47E-4**

3.5. Consequence analysis

For the selected failure cases mentioned above these are the consequences occurred using PHAST software in two wind directions. Graphical representation of consequences is mentioned below for isolatable section-1 as shown in Table 9 and Fig.4. It is not possible to display consequence results of three scenarios which have been selected, so that one isolatable section having small release was provided. For medium leak or any isolatable sections using frequency data & PHAST v 6.7 software [7] the remaining consequence results can also be obtained.

Table 9: Consequence Results From PHAST

S.No	Description	Accident Scenario	Event outcome	Impact criteria	Consequence Distance(m) respective weather Conditions	
					F 2m/s	D 5m/s
1.	I/p piping from unit to LPG facility	Small	Flash Fire	LFL	6.697	5.43
			Jet Fire	4 Kw/m^2	15.51	14.08
				12.5 Kw/m^2	12.26	10.67
				37.5 Kw/m^2	10.219	8.55
			Late explosion	0.1 bar	14.3	NR
				0.2 bar	12.79	NR
				0.3 bar	12.18	NR
				0.01 bar	35.205	NR

Isolatable Section-1: For Small Leak

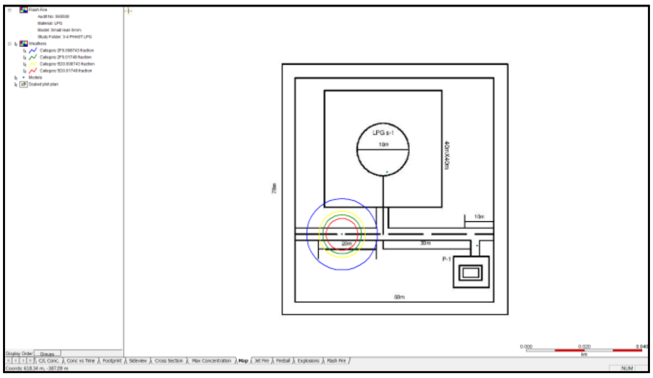

Figure 4: Flash Fire Contours.

Flash hazard would cover 5.4 to 6.7 m

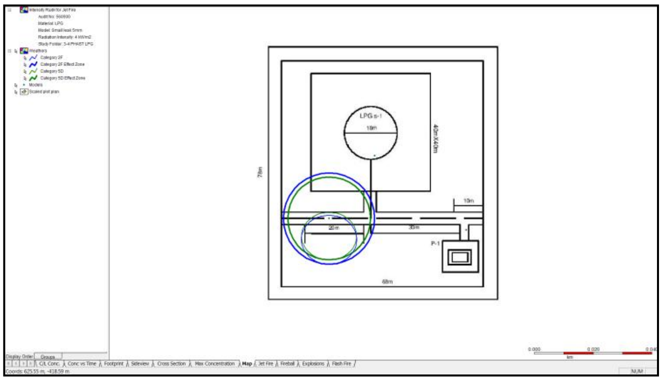

Figure 5: Jet fire Contour.

Thermal hazard distances of 37.5 k/m² radiation intensity due to jet fire would covers 8.5 m to 10 m. 12.5 k/m² radiation intensity would cover a distance of 10.6 to 12.3 m and 4 kw/m² radiation intensity would cover 14.1 to 15.51 m.

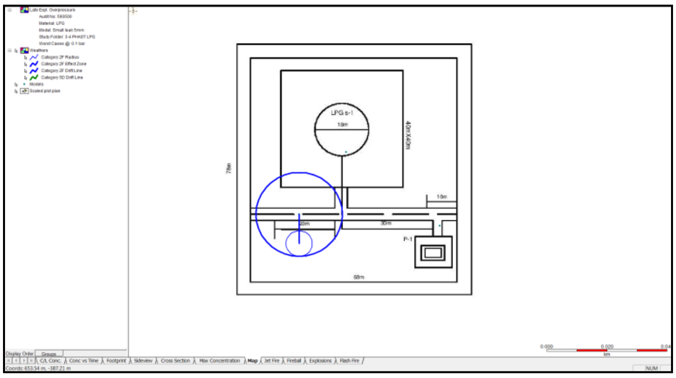

Figure 6: Late Explosion Contour.

Late Explosion Hazards for 0.1 bars would covers a distance of 14.3 m, 0.2 bars covers 12.79 m, 0.3bar covers 12 m and 0.01 bar covers 35 m respective to 2 m/s F wind direction. For 5 m/s wind direction explosion hazard is not reachable for a given set of pressures.

RESULTS & DISSCUSSION

Results from consequence analysis & Frequency analysis were used for input data to risk analysis. Total risk associated with the LPG facility is the combination of Individual risk & Scoial risk.Total risk contour given by the PHASTRisk v 6.7 [7] software is given below.

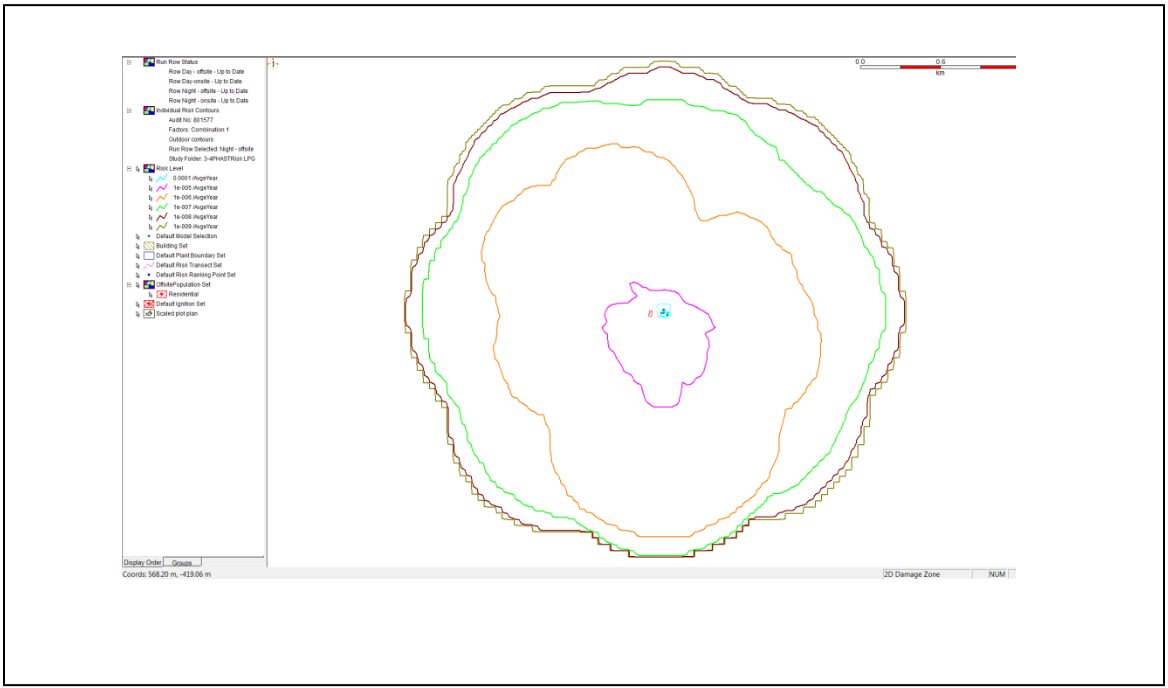

Figure 7: Individual Risk Contour for LPG Facility.

The Maximum LSIR contour of 10^{-4} per year (cyan colour) is observed near the pump house and LPG storage sphere. This is in ALARP region. The whole LPG Terminal comes under the LSIR level (pink colour) of 10^{-5} per year which is in ALARP region. The LSIR contours of 10^{-5} per year (pink colour) which is mostly outside the plant boundary (Fig.7 & 8).

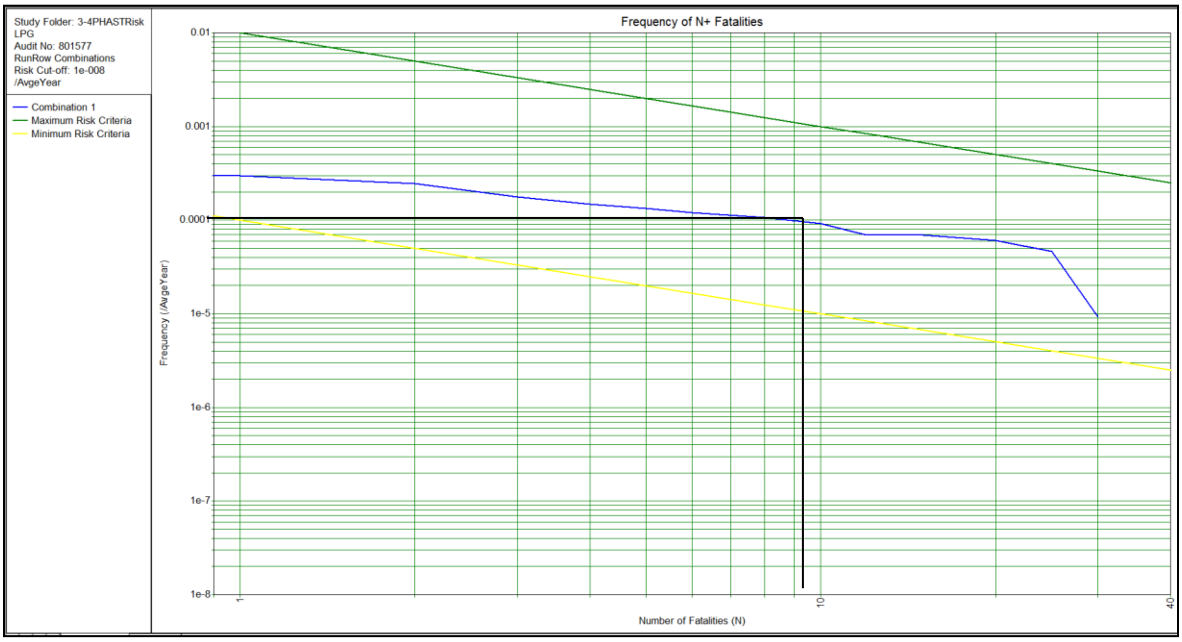

Figure 8: Combined F-N Curve for LPG Storage Facility.

From the Risk analysis results we know that risk in LPG facility is 2 X 10^{-4}. After comparison with the acceptance criteria, it seems that, the risk associated with the LPG facility is in tolerable region. This region is called (As Low As Reasonably Practicable) ALARP.

CONCLUSION

The individual risk level to public outside the plant boundary is in Acceptable region. Onsite societal risk when compared to the HSE UK risk criteria falls within the ALARP region. Offsite societal risk when compared to the HSE UK risk criteria falls within the ALARP region.
The following general risk prevention and mitigation measures are insisted to ensure desired level of safety to personnel and assets.

RECOMMENDATIONS

- The area shall be protected with fire water system and fixed monitors. For fire fighting equipment and appliances, it is recommended to use OISD GDN 144 Guidelines on fire fighting equipment and appliances in petroleum industry.
- Provision of siren / public address system to alert the personnel's working in the plant.
- Meticulous maintenance schedule, risk based inspections may be planned to avoid breakdown of critical safety equipment within the LPG Plant leading to hazardous events.
- Liquid level in the vessel shall not exceed the permissible limits. Filling shall not exceed safe permissible filling ratio.
- Vessel shall be inspected daily for any LPG leakage and corrective action taken.
- All gauges, viz. High level alarm, measuring gauges, pressure gauges, temperature gauges should be kept in operating condition at all times and be checked daily.

- LPG spheres having fire proofing should be periodically checked for cracks, bulging and suspected areas are further inspected for presence of corrosion etc. and corrective steps taken.

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