Quantitative Risk Assessment of LPG Bottling Plant

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ABSTRACT

With the development of industries and increase in population the need of LPG has accelerated in recent years. In order to provide an overview of the potential risks in LPG bottling plant, there is the high probability of accidents during handling & storage; various hazards are faced during storage and transportation. As we know LPG is a highly flammable gas, so there are many possibilities of hazards, like explosion, fire, which may results in minor or major or fatality, due to this there is loss of man-power and money will also occur. So a great concern is needed to minimize the occurrence of these hazards and for this purpose it is very necessary to analyse the risk associated in usage and handling of liquefied petroleum gas. Risk assessment is a legal requirement for every chemical and petrochemical industry. It is a formalised method for calculating individual, environmental, employee and public risk levels for comparison with regulatory risk criteria. In this paper we have carried out a careful examination of what could cause harm to people so that we can weigh up whether we have taken enough precautions or should do more.

Key Words: Quantitative Risk Assessment, LPG, Hazards Substances

I INTRODUCTION

The "risk" is the product of consequence and probability of each scenario. The risk for each scenario can be combined by specific areas or for the whole facility to obtain desired risk profiles. Risk assessment is a process where the results of a risk analysis are used to make decisions, either through a risk ranking of hazard reduction strategies or through comparison to target risk levels and cost-benefit analysis [1].Quantitative Risk Assessment is a well-defined procedure to be applied in order to calculate the degree of safety of a plant [2]. It is a systematic procedure for describing and quantifying the risk associated with Hazardous substances, processes, action or event.QRA may be a requirement of applicable legislation and/or internal company governance to show that risks are identified and controlled to an acceptable level [4&5].The criteria for risk acceptability may be defined by local regulations or company / investor policy. Typically, a QRA can be defined as the formal and systematic approach of identifying potentially hazardous events, estimating the likelihood and consequences of those events, and expressing the results as risk to people, the environment or the business. Quantitative Risk Assessment of the plant includes identification of various credible and non-credible failure scenarios and consequences of those scenarios leading to various phenomena like dispersion, pool fire, jet fire, and unconfined vapour cloud explosion etc.[11] Frequency of the failure cases, magnitude of hazards and hazard distances have also been dealt with. QRA helps in

(a) Forecasting any unwanted hazardous situation
(b) Estimating damage potential of such situation
(c) Modify existing facilities to extend their operational life
(d) Results of QRA not only increase safety but also improve cost effectiveness and subsequent savings.

II OBJECTIVE

Main objective of this study is to identify, quantify and assess the risk from the facility from the storage and handling of chemical products and to identify, quantify and assess the risk to nearby facilities / installations and suggestion of recommendations in order to reduce the risk to human life, assets, environment and business interruptions to as low as reasonably practicable.

III METHODOLOGY

An inherent property of a substance, agent, source of energy or situation having the potential to cause undesirable consequences. When LPG is released from a storage vessel or a pipeline, a fraction of LPG vaporizes immediately and the other portion forms a pool if the released liquid quantity is more [3]. LPG from the pool vaporizes rapidly entrapping some liquid as droplets as well as considerable amount of air, forming a gas cloud [10]. The gas cloud is relatively heavier than air and forms a thin layer on the ground. The cloud flows into trenches and depressions and in this way travels a considerable distance.

LPG is a highly flammable gas which results in fire and explosion in case if it leaks during the unloading or loading process and from the storage container. The various fire and explosion scenarios associated with LPG are jet fire, pool fire, flash fire, Confined vapour cloud explosion(CVCE), unconfined vapour cloud explosion (UVCE) and Boiling liquid expanding vapour cloud explosion (BLEVE). In LPG storage system fire and explosion accidents are happened due to leakage from tank or pipelines. [4]. QRA is used for different purposes it is one of the most important risk management program. [5] Following are the main steps in QRA studies

(i) Hazard Analysis
(ii) Probability evaluation
(iii) Consequence Analysis
(iv) Risk Analysis

(a) Hazard Analysis

The knowledge of what can go wrong is the first stage of the risk assessment process. Hazard identification involves the investigation of all the situations that may cause a potential accident, followed by an analysis of the combinations or sequences of events which could produce this. Typical hazard identification techniques are:

(i) Check lists
(ii) Statistical analysis
(iii) FMEA
(iv) HAZOP

Among these, the Hazard and Operability analysis (HAZOP) is the technique most frequently used for considering, systematically, deviations from the design intent by the application of a series of guide words to process parameters, in order to identify possible problems [3]. In LPG installations no process operations are performed; therefore the expected accidental events can be attributed to random causes (i.e. failure due to material defects, wrong assembly /maintenance), external causes (collisions, fire) and disoperation during transferring operations (incorrect coupling of loading/unloading arm)[9].

(b) Probability evaluation

The probability evaluation requires the determination of the circumstances and conditions which the occurrence of hazardous events is depending on and how those are interrelated. It allows estimating the expected frequency of occurrence of an accidental event. This is frequently performed by Fault Tree analysis, i.e. a logic combination of causes which may induce a specific undesired event (top event) coupled with event tree analysis, to identify the scenarios associated with the top event [4]

(c) Consequence Analysis

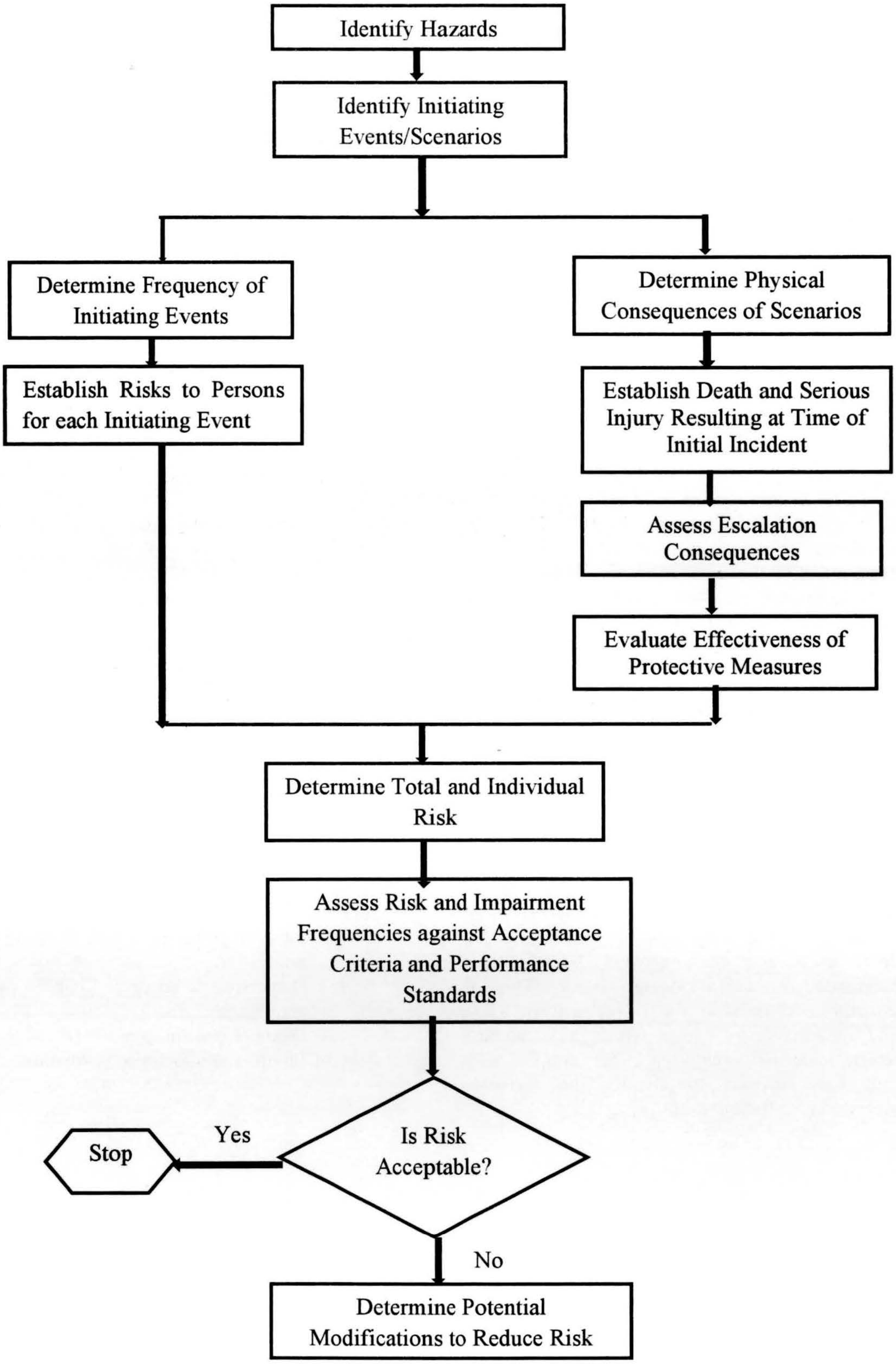
Consequence analysis is carried out based on the source model. How the materials are discharged such as from pipeline or tank and the type of failure etc. Then based on source model the fire and explosion outcomes are carried out based on the ignition probability[6]. Usually the event trees are used to identify the different event outcomes from any leakage scenario [7]. The jet fire (immediate ignition), vapour cloud fire (flash fire), pool fire (delayed ignition), vapour cloud explosion (delayed ignition-explosion), toxic cloud (no-ignition), safe dispersion are the outcome cases of any leak of hazardous material leakage. [9]. All these steps are covered by the modelling software during the analysis the complete assessment is structured as follow.

(i) **Source term characterization** is strictly related to the typology of accidental event and allows identifying the characteristics of the release (flow-rate, quantity, physical conditions, etc.)[8]. The substances present in bulk in LPG installations are C3–C4 mixtures ranging from propane to butane which behave as a gas liquefied by pressure.
(ii) **Identification and study of physical phenomena involved** is based on the source term characteristics and external conditions like meteorological conditions, presence and type of ignition etc., allows to identify the intermediate i.e. Dispersion and final phenomena like Fire and Explosion.
(iii) **Damage assessment** of the analysis allows to determine the damage produced by thermal radiation as well as by the overpressure effects on the population and property.

The factors that govern the severity of consequence of the loss of containment are as follows:

(i) Intrinsic properties e.g. flammability, flash point
(ii) Dispersive energy e.g. pressure, temperature
(iii) Quantity present
(iv) Environment factors e.g. weather

(d) Risk Assessment flow chart



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(e) Release Rate Estimation

Contained material may be released to atmosphere as liquid, vapor or a mixture of both. For liquids, a leak below the liquid level in the source of containment will result in a stream of escaping liquid. If the liquid is stored above its atmospheric boiling point, a leak below the Release rate depends on the process parameters and fluid flow characteristics.

DNV PHAST v 6.70 has been used to model the potential release scenarios and release rates. For getting realistic picture of scenarios, unless stated otherwise, a release from different ruptures sizes was modelled for different time periods considering the facility like ROV, GMS etc.

(f) Dispersion and Stability Class

The factors which govern dispersion are mainly Wind Velocity, Stability Class, Temperature as well as surface roughness. One of the characteristics of atmosphere is stability, which plays an important role in dispersion of pollutants. Stability is essentially the extent to which it allows vertical motion by suppressing or assisting turbulence. It is generally a function of vertical temperature profile of the atmosphere. The stability factor directly influences the ability of the atmosphere to disperse pollutants emitted into it from sources in the plant. In most dispersion problems relevant atmospheric layer is that nearest to the ground. Turbulence induced by buoyancy forces in the atmosphere is closely related to the vertical temperature profile.

Temperature of the atmospheric air normally decreases with increase in height it varies from time to time and place to place. This rate of change of temperature with height under adiabatic or neutral condition is approximately 1^{o}C per 100 meters. The atmosphere is said to be stable, neutral or unstable according to the lapse rate is less than, equal or greater than dry adiabatic lapse rate i.e. 1^{o}C per 100 meters.

Pasquill has defined six stability classes ranging from A to F.

A=extremely unstable, B=moderately unstable, C= slightly unstable, D=neutral, E=stable, F= highly stable

(g) Risk Tolerance

After the risk is calculated, the results must be compared to either governmental or company criteria to determine if the risk is tolerable. If the level of risk does not meet the "acceptable" risk criteria, then additional mitigation may be required. One concept that is being used extensively is as low as reasonable practical (ALARP). Figure 1 shows the ALARP concept. This concept suggests that, at some point, the cost to mitigate a hazard is so high that it is no longer practical to implement the option. Cost-benefit analysis can be used to determine if ALARP has been achieved.

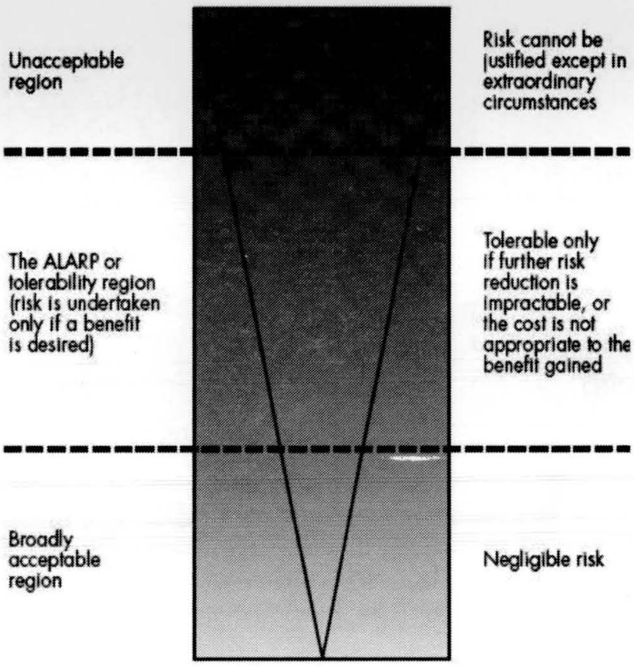

Fig. 1: - Tolerance level of Risk.

IV RESULTS AND DISCUSSIONS

In this study we considered different failure of LPG bottling plant and on the basis of simulation studied following finding is listed below

(a) Inlet / Outlet line failure of Mounded Bullets

The Mounded Bullets have been provided with an inlet / outlet line size of 4". In case, leakage / rupture of the inlet / outlet line, liquid LPG will flow out from the Mounded Bullets as jet .The outflow of LPG is large and needs to be stopped at the shortest possible time. The consequence of 1 minute spill of LPG due to rupture or various leakages

(i) The spilled liquid may catch fire resulting in jet fire.

(ii) ii) The spill liquid may not catch fire. In that event it shall evaporate forming vapour cloud which may disperse safely beyond its Lower Explosive Limit (LEL) in the direction of the wind, if there is no ignition source between its upper and lower flammability limits.

(iii) The dispersing vapor cloud may come in contact with an ignition source between its explosive limits. In that event flash fire will occur and unconfined vapor cloud explosion may result with shock wave. Anything coming within the fire zone will be severely affected.

For consequence analysis following cases has been considered:

Full bore failure, 20% CSA failure, 20mm diameter hole and 10mm diameter hole and Consequence distances due to flash fire, jet fire and overpressure are calculated and presented in Table 4.1.

Table 4.1
Inlet / Outlet line failure of Mounded Bullets

Scenario	ReleaseRate(Kg/s) & Duration(s)	Mass Released(Kg)	Event		HazardDistance (m) from Release Point			
					2F	2B	3D	5D
Full bore failure	RR:33.72RD : 60	2023	Flash fire (LEL)		157	133	135	141
			Jet fire(KW/m^2)	4.5	125	125	120	115
				12.5	101	100	95	89
				37.5	84	84	78	72
			Overpressure (Bar)	0.03	396	406	438	394
				0.1	278	305	336	294
				0.3	234	267	298	257
20% CSA failure	RR:5.9RD : 60	355	Flash fire (LEL)		46	41	41	40
			Jet fire(KW/m^2)	4.5	57	57	54	52
				12.5	46	46	43	40
				37.5	39	39	36	33
			Overpressure (Bar)	0.03	194	165	165	141
				0.1	152	128	128	106
				0.3	136	114	114	93
20 mm dia. hole	RR : 4.72RD : 60	283	Flash fire (LEL)		40	36	36	34
			Jet fire(KW/m^2)	4.5	51	51	49	47
				12.5	42	42	39	37
				37.5	35	35	32	30
			Overpressure (Bar)	0.03	165	147	147	123
				0.1	128	114	114	93
				0.3	114	102	102	81
10 mm dia. hole	RR : 1.18RD : 60	71	Flash fire (LEL)		14	13	12	10
			Jet fire(KW/m^2)	4.5	27	27	26	25
				12.5	22	22	21	19
				37.5	19	19	17	16
			Overpressure (Bar)	0.03	67	54	53	41
				0.1	51	40	40	29
				0.3	46	35	35	24

RR: Release Rate; RD: Release Duration

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(b) Vapor LPG release from SRV of Mounded Bullets

Each Mounded Bullets are provided with two nos. of Safety Relief Valves of line size 6″ each and their set pressures are 13.6 Kg/cm^2 and 14.2 Kg/cm^2 to release the excess pressure which may be build due to overfilling. When the pressure inside the vessel drops, the SRVs close automatically. In case of release of LPG in two-phase (vapor & liquid) through safety valve, it will be discharged at a height of 12m above ground in vertical direction and dispersed in the direction of wind. For this study we consider following cases and results presented in table 4.2.

Case I: - Single SRV pop-up of 13.6 Kg/cm^2 pressure

Table 4.2
Vapor LPG release from SRV of Mounded Bullets.

Scenario	ReleaseRate(Kg/s)& Duration(s)	Mass Released(Kg)	Event		HazardDistance (m) from Release Point			
					2F	2B	3D	5D
SRVpop-up	RR : 62.62RD : 180	11272	Flash fire(LEL)		4	3	4	5
			Jet fire(KW/m^2)	4.5	52	51	61	72
				12.5	NR	NR	NR	NR
				37.5	NR	NR	NR	NR

(c) Suction line failure of LPG pump for Bottling operation / Tank Lorry filling;

The LPG pump takes its suction from the Mounded Bullet and pumps it to the filling shed for filling of empty LPG cylinders or tank lorry. The details of the pump are as follows:

No. of pumps	:	2
Type of pump	:	Centrifugal
Capacity	:	45m^3/hr
Suction pressure	:	6-7 Kg/cm^2
Operating temperature	:	25 ^{0}C
Suction line size	:	4″

In case of LPG pump suction line failure, a portion of the leaked liquid will flash off immediately and the remaining liquid will fall and spread on the ground unrestricted. In suction line, gasket failure is one of the foreseeable credible scenarios. Gasket failure of flange joint may be full gasket or partial. Experience shows that gasket failures are mostly partial and segment between two bolt holes mainly fails. The consequences of three minute release of LPG due to rupture or various leakages may be the following:

(a) The spilled liquid forms jet and catches fire resulting in jet fire.
(b) The spilled liquid does not catch fire but evaporates forming a vapor cloud and disperse safely to beyond its LEL.
(c) The evaporating vapor cloud may come in contact with an ignition source between its explosive limit resulting in flash fire and unconfined vapor cloud explosion depending upon the congestion.

For consequence analysis following cases has been considered: Full bore failure,20% CSA failure and 10mm dia. Hole and Consequence distances due to flash fire, jet fire and overpressure are given in Table: -4.3

Table 4.3

Suction line failure of LPG pump for Bottling operation / Tank Lorry filling

Scenario	Release Rate(Kg/s)& Duration (s)	Mass Released(Kg)	Event		HazardDistance (m) from Release Point			
					2F	2B	3D	5D
Full bore failure	RR : 5.02 RD : 180	904	Flash fire (LEL)		41	37	37	35
			Jet fire(KW/m^2)	4.5	53	53	50	48
				12.5	43	43	40	37
				37.5	36	36	33	30
			Over pressure(Bar)	0.03	177	149	150	125
				0.1	139	115	115	94
				0.3	124	103	103	82
20% CSA failure	RR : 4.32RD : 180	777	Flash fire (LEL)		37	33	33	31
			Jet fire(KW/m^2)	4.5	49	49	47	45
				12.5	40	40	38	35
				37.5	34	34	31	28
			Overpressure(Bar)	0.03	192	134	134	120
				0.1	126	103	103	91
				0.3	113	91	91	81
10 mm dia. Hole	RR : 1.18RD : 180	212	Flash fire (LEL)		15	13	12	10
			Jet fire (KW/m^2)	4.5	27	27	26	25
				12.5	22	22	21	19
				37.5	19	19	17	16
			Over pressure(Bar)	0.03	67	54	53	41
				0.1	51	40	40	29
				0.3	46	35	35	24

RR: Release Rate; RD: Release Duration

(d) LPG pipeline failure inside the shed

Liquid LPG is coming from the LPG pump to carousel machine through 3" (80mm) dia. pipeline at 15 Kg/cm^2 pressure and at ambient temperature. In case of this incoming line is leaked .For consequence analysis following cases has been considered: Full bore failure and 10 mm diameter hole and Consequence distances due to flash fire, jet fire and overpressure are given in Table-4.5Table 4.4:- LPG pipeline failure inside the shed

Scenario	Release Rate(Kg/s)&Duration(s)	Mass Released(Kg)	Event		Hazard Distance (m) from Release Point			
					2F	2B	3D	5D
Full bore failure	RR : 4.47RD : 180	805	Flash fire (LEL)		38	34	34	32
			Jet fire(KW/m^2)	4.5	50	50	48	45
				12.5	40	40	38	36
				37.5	34	34	32	29
			Overpressure (Bar)	0.03	163	135	135	121
				0.1	127	103	103	92
				0.3	113	91	92	81
10 mm dia. hole	RR : 1.87RD : 180	336	Flash fire (LEL)		16	15	15	14
			Jet fire(KW/m^2)	4.5	31	31	30	28
				12.5	24	24	22	21
				37.5	17	17	15	13
			Overpressure (Bar)	0.03	44	42	42	41
				0.1	30	29	29	29
				0.3	25	25	25	24

RR: Release Rate; RD: Release Duration

Iso-risk contour has been plotted by PHAST Risk Micro software v 6.70 (Latest) of M/s DNV Technica which is shown in figure I. Iso-risk contour has been calculated by considering facilities i.e. Mounded bullets, LPG loading/unloading through tank lorry, carousel filling and other facilities. Iso-risk contour of 1x10⁻⁶ is going outside the plant boundary in North-West direction and in South-West direction with 38m & 10m respectively but it is not harmful as there is no habitation near the plant premises within 0.5 Km.

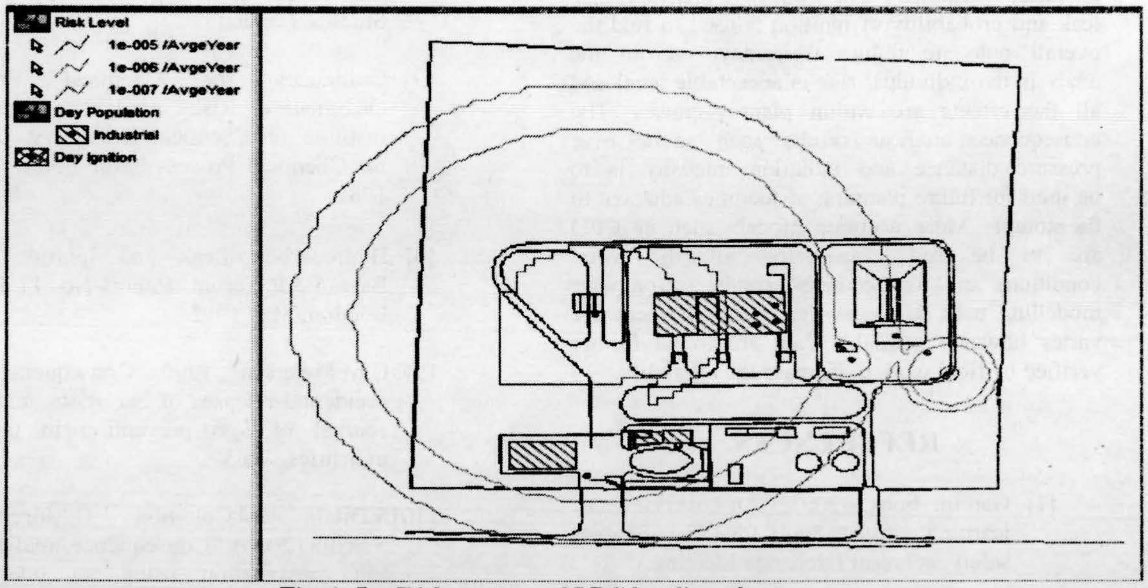

Fig. 1: Iso-Risk contour of LPG bottling plant

It is also observed from FN curve figure 2 that Societal Risk is in tolerable range for plant personal.

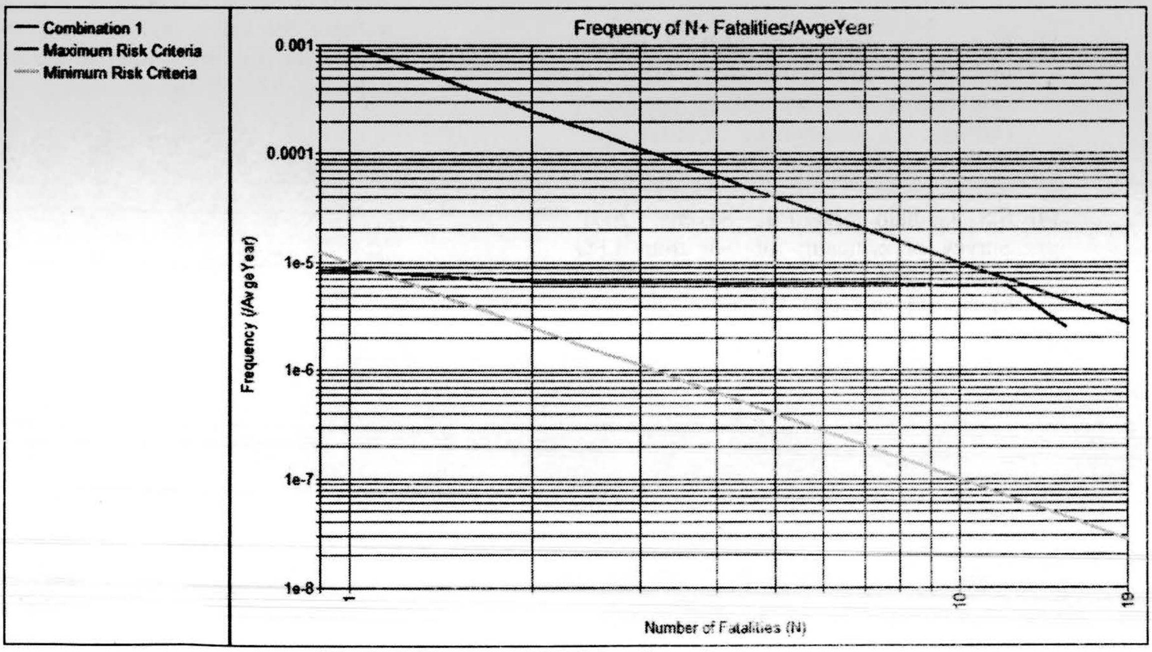

Fig. 2: F/N curve of LPG bottling plant

V CONCLUSION

In this work Quantitative Risk Assessment of LPG storage bullet and its handling system is analysed. From the consequence analysis it was found that jet fire, pool fire, VCE, BLEVE are the potential scenarios. The frequency analysis for a leak and probability of ignition is used to find the overall outcome failure frequency. From the analysis the individual risk is acceptable level and all the effects are within plant premises. The consequence analysis results such as the over pressure distance and radiation intensity is to be used for future planning of facilities adjacent to the storage. More accurate models such as CFD are to be used considering all the wind conditions and for accurate results. Computer modelling used to assess the safety distances are varies however available data are to be further verified by field work to increase the reliability.

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