A Thesis report

On

QUANTITATIVE RISK ASSESSMENT OF LPG STORAGE TANK FOR POOL FIRE

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RISK ASSESSMENT OF LPG STORAGE TANK FOR POOL FIRE

A thesis submitted in partial fulfilment of the requirements for the Degree of Master of Technology

(Health, Safety & Environment)

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May, 2010

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CERTIFICATE

Certified that Mr. VinothKumar E. M. Tech. (HSE), UPES, R070208014 has successfully completed a Project on "QUANTITATIVE RISK ASSESSMENT OF LPG STORAGE TANK FOR POOL FIRE" under my Guidance.

Delhi.
Date: 24th April 2010.

Prof. Dr. Ram S. Hamsagar

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I am very much pleased to express my heartfelt and sincere thanks to **Mrs. KANCHAN BAHUKHANDI (COURSE CO-ORDINATOR)**, for his consistent encouragement and extended support.

At the outset, I render my thanks at the golden feet of the **almighty and my parents** who led me all the way to complete the project successfully

I express my sincere thanks to all of my friends for their moral support, help and encouragement for completing my project.

ABSTRACT

Quantitative Risk Assessment is an important and useful technique for industrial safety management, whereby they can obtain a systematically, critical appraisal of the effectiveness of a plant safety programme that is undertaken with a view to suggest improvements and up gradation.

In the process industry there is often a high probability may be for minor or major accident to happen. So it is essential that hazards are to be identified and control measures should be taken. A method that is usually employed for this purpose is Risk Assessment. Hazards are paramount and the focus to identify and control potential hazard in process installation emanates from techniques like Risk Assessment.

"Quantitative Risk Assessment of an LPG facility" the title chosen for this project work, is getting prime importance in the oil industry, since recent years there has been a tremendous spurt in the marketing of LPG.

POOL FIRE begins with the release of flammable material from process equipment or storage. If the material is liquid, stored at a temperature below its normal boiling point, the liquid will collect in a pool. The surroundings will give the geometry of the pool. If the liquid stored under pressure above its normal boiling point, then the fraction of the liquid will flash into vapour, with the un-flashed liquid remaining to form pool in the vicinity of the release.

This project "Quantitative Risk Assessment of LPG storage facility for POOLFIRE" enables us to take effective measures to prevent such failures in the first place and to control and contain such disasters to minimize all possible damage consequences to life and property.

TABLE OF CONTENTS

CHAPTER 1:

EXECUTIVE SUMMARY

1.1 Quantitative Risk Assessment (QRA) has been carried out in accordance with the National and International Standards, Guidelines and Codes of practices as applicable and some of the main ones are given below:

1. "World Bank Technical Paper-55, Techniques for Assessing Industrial Hazards"
2. "Chemical Process Quantitative Risk Analysis", American Institute of Chemical Engineers, Centre for Chemical Process Safety.
3. "Manual of Emergency Preparedness for Chemical Hazards", MOEF.
4. "Chemical Process Safety Fundamentals with Applications". By Daniel A. Crowl & Joseph F. Louvar
3. "Process Safety Analysis"-An introduction, by Bob Skeleton.
4. Major Industrial Hazards. By John Withers.
5. Process Safety Fundamentals. By Frank P. Lees.
6. Guide lines for Process Equipment Reliability data with data Tables. By American Institute of chemical engineers.
7. Standards/codes of practices of NFPA, OISD and BIS on storage and handling of relevant Petroleum Products and other bulk hazardous chemicals involved that have potential for major hazard scenario development.
8. Meteorological data for the specific site if available, the same would be used for developing the ASCLAP (Atmospheric Stability Class Prevalence) otherwise IMD data for the nearest observatory shall be used.

1.2 Maximum Credible Accident Scenarios developed and their results:

Pool formation after a catastrophic failure of an LPG-Bullet of 5000 Kg. LPG is taken.

The dyke or Sump has a depth of 2 m, Width (Cross wind) is 30 m and Length (Down wind) is 50 m. Effective pool radius is given by the following Formula:

Pool Radius=SQRT((Length * width) / 3.14285)

Sump Depth (m)	Cross wind Sump width (CW) (m)	Down wind Sump Length (DW) (m)	Effective Pool Radius (PR) (m)	LPG Pool Depth (PD) (m)
2.00	30.00	50.00	21.85	1.93

LPG-being a Compressed Liquefied Gas (CLG) it undergoes Flashing on release. The input data and the results of flashing are computed as given below:

LPG-Liquid Leak Flashing:

Given data											
Quantity of LPG (Q) Leaked (Kg)	Mol. Wt (MW)	Density (D) of LPG at Storage Temp. (Kg/m3)	Storage Pressure (Kg/cm2)	Specific Heat (Cp) of LPG (Cal/g Deg. C)	Storage Temp. (To) of LPG (Deg. C)	Final Temp (Tv) after Flashing (Deg. C)	Latent heat (Hv) of vaporization of LPG (Cal/g)	Saturated Vapour Pressure (SVP) of LPG at Storage Temp. (Kg/cm2)	Substrate Temperature (ST) Deg. C)	Substrate Constant for 1-Min-rapid Evaporation (MN1)	Substrate Constant for Slow & Steady Evaporation (SS)
5000	44.46	597	10	0.549	25	-33	102.1	1	25	0.00075	0.015
Results											

Flash Fraction (ff) (Out of 1)	Mass Flashed (mv) (Kg)	Quantity entrained (me) in Flashed LPG (Kg)	Fraction Entrained (fe) (Kg)	Total Fraction Flashed+ Entrained (Tff) (Out of 1)	Total Quantity Flashed+ Entrained (mve) (Kg)	Quantity of Liquid (ml) left after flashing forming Liquid Pool (Kg)	Volume of Liquid (vlp) forming Liquid Pool (m3)	One Min. Rapid Pool Evaporation (rpev) due to heat transfer from earth (Kg)	Quantity left (mlrpev) after One Min. rapid Pool Evaporation (Kg)	Rate of Slow and Steady evaporation (ssv) due to wind and heat conduction from earth (Kg/s)	Time required (tm) for Evaporation of LPG in pool after One Min. Rapid Evaporation (Hrs)
0.3659781	1829.89	274.48	0.05	2104.37	2104.37	2895.63	4.85	371.43	2524.20	2.13	1.50

1.3 Following is a summary of IHR effect distances of the results of Risk Assessment of POOL FIRE.

Distance, m	IHR, kW/m^2	Remarks
1- 9.27	> 37.5	IHR >=37.5: 100% Fatality and Limit of 1-Min to ignite wood without contact with Fire
10 – 14	> 25 & < 37.5	IHR <37.5 and >25: Min to ignite wood (without flame contact). 100% fatal in 1 min. Significant injury in 10 Sec.
14.58 – 58	> 12 & <= 25	IHR <=25 and >12.5: Min to ignite wood (with flame contact). 1% fatal in 1 min. First degree burn in 10 Sec.
> 58	> 4 & <= 12.5	IHR>4 & <=12.5 means Pain after 20 Sec. Blistering unlikely.
100	1.60	IHR 1.6 is equivalent to Solar Radiation is safe

1.4 Following is the summary of distances and its dose ranges: Dose is computed by the formula Dose = $C^n.T$ where C=Concentration (For Fire it is IHR), n is a constant and has a value of 1. Dose is the amount of heat radiation received as a person escapes from 1-m distance of fire rill he reaches safe radiation of 1.6 KW/m2 (Solar radiation) of surface area of his body exposed to radiation. So the dose decreases as he escapes from fire. Details of Dose computation may be seen at Chapter-5. I have found that the total dose received by person in the LPG-Pool fire comes to 3652.71 at 100 m distance where the IHR =1.6 KW/m2.

1.5 PROBIT value for POOL FIRE:

PROBIT for pool fire	Fatality PROBIT	% Fatality	Fatality area(m^{2})	No. of employees exposed	Absolute fatality for a population density of 50/Ha	Frequency of catastrophic failure of LPG bullet/plant year
	4.94	27.61	1134.11	5.67	1.57	0.000123319

1.6 Chances of ignition of spill pool:

POOL FIRE ignition chances and FAR value	Immediate onsite ignition	Delayed onsite ignition	Combined chances of ignition	Chances of no ignition	Net frequency of LPG bullet failure	FAR value Employees Fatal in 10^8 years of exposure
	0.1821	0.1226	0.3047	0.6953	0.000037571	0.012969091

One year is a very small period for computing far in order to have a reasonably understandable value we must have a very large period of exposure. 10^8 hours of exposure is taken as a standard period. This corresponds to of exposure for FAR. This means 1000 people likely to be exposed to work hazard during an active work life of 40 years 300 days covering a single shift of 8-hours. 100,000,000 hours / (24 hrs. per day). (365 days per year) = 11415.5 years of exposure *or say 11000* years:

$$FAR = \frac{10^8}{H.N} \sum_{i=1}^{i} (Fi.\ Ni.)$$

Where: *Fi* = Frequency/Yr of i^{th} accident, *Ni* = Fatality number in the i^{th} accident and H = Number of Hours of Exposure/year worked N = Total number of employees exposed.

Meaning of FAR : number of times a person meets a fatal accident when exposed to a system of hazards over a period of 10^8 hours of exposure.

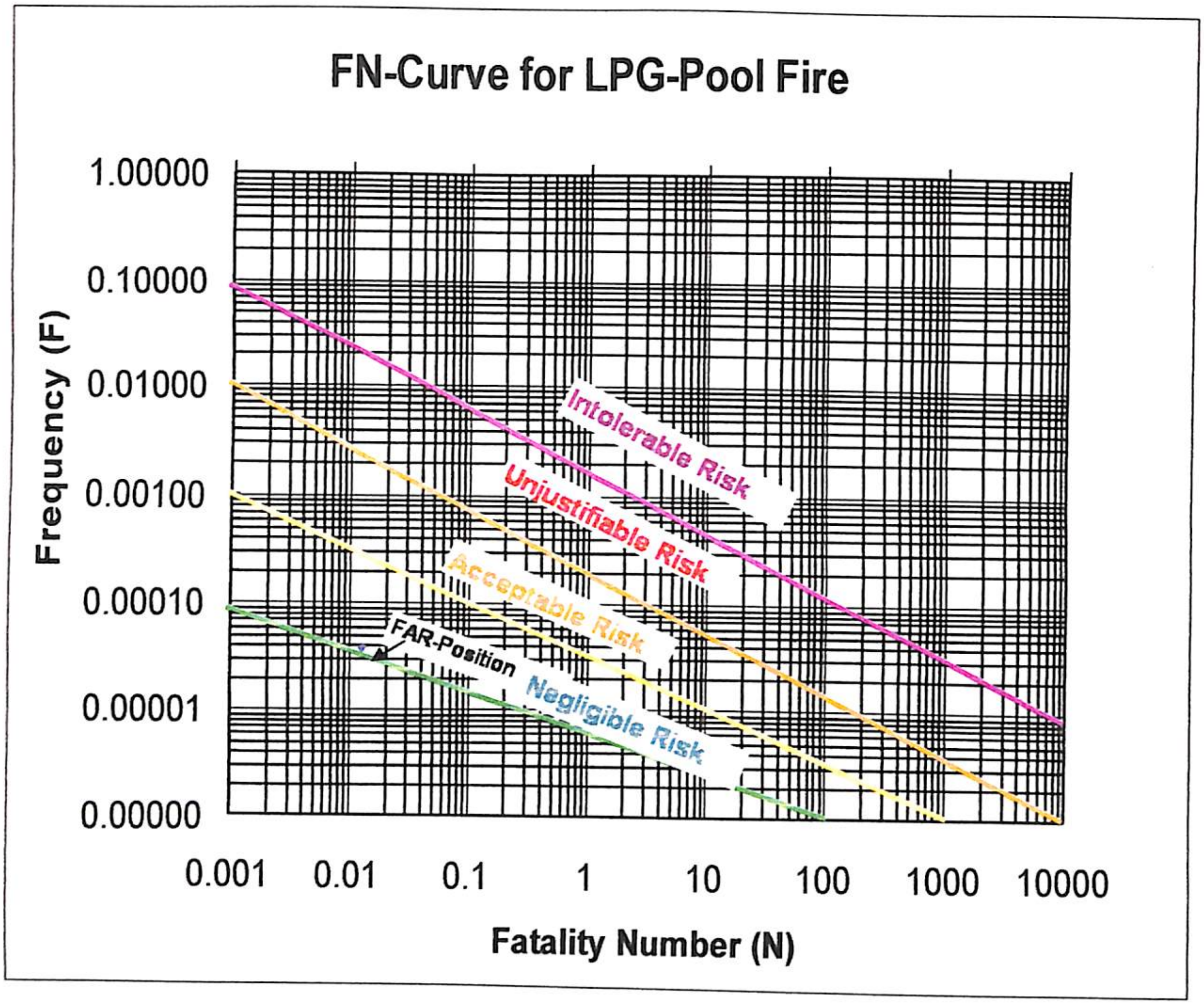
NOTE: FAR is a measure of risk of fatality to employees

1.7 Yard Sticks for Evaluating Risks:

The main yard sticks for evaluating the Risk of a given facility are the following:

i. Fatality Accident Rate (FAR): This is a fatality Risk of exposure of the hazards of a given facility to the employees exposed over a period of 10^8 hours of exposure.

ii. FN-Curve: This is Frequency (F) of the occurrence of disasters Vs. the Fatality Number (N).



iii. Individual Risk: This is the risk of fatality to the neighbouring population exposed to the hazards of the facility studied. This is too complex and not computed.

iv. ALARP Comparison: This is the final evaluation of the Risks in comparison with International guidelines for acceptable Risk.

1.8 Causes and prevention of disasters:

There are 8 main causes of containment loss and these are 1. Over pressurization, 2.Brittle fracture, 3. Flange, gasket, seam failure, 4.Weld casting failure, 5.Vibration, 6.Corrosion erosion, 7.External loading impact, 8.Internal explosion. Behind all these the predominant root cause is human error. According to Heinrich 98% of all accidents are caused by human error of which 80% by direct man-machine interface (Operational) error and 10% due to design and maintenance errors. So basic effort in preventing disasters is to change the men manning the system. The basic requirement is to shed the typically Indian "*Chalta Hai*" culture and "*Bindas*" attitude and ensure compliance to all the relevant rules, regulations, standards and codes of practices about which there is a general lack of awareness.

1.9 Observations and recommendations:

These are given in Chapter 2.0 and they cover the following main areas

i. Conformance to Statutory requirements,

ii. Inspection, Testing and Maintenance systems,

iii. Operating system,

iv. Emergency prevention and preparedness system,

v. Training.

All these observations and recommendations need to be implemented to ensure the high levels of safety.

1.10 Conclusions:

The advanced QRA Study conforming to International and National standards, Guidelines and Codes of practices as applicable shows the full characteristics of MCAS Scenarios and Comprehensive recommendations made should be implemented. These requirements need to be built in to EMP and Mock drills and training organized for prevention and managing emergencies to ensure highest standards of safety.

CHAPTER-2:

Benefits to me from the Research Work:

i. I got a deep insight in to the theory of Quantitative Risk Assessment procedure,

ii. I got a good experience of Programming in Excel,

iii. I got an insight in to the phenomenon of Flashing of a Compressed Liquefied Gas like LPG.

iv. I understood the International Guidelines for Various steps in QRA development.

v. I understood the meaning and importance of the final yard sticks of measuring Risk through QRA and these are FAR-the Risk of fatality to Employees, ISO-Risk-The Risk of fatality to Neighbouring Population and FN-Relation the Relation between Frequency (F) and fatality Number (N).

CHAPTER 3

RECOMMENDATIONS:

3.1 Main Observations and Recommendations:

Safety distances: OISD-144 gives various inter distances between various facilities in Petroleum installations. OISD-144 requires a min. distance separating LPG-bulk storage and other facilities. These may be checked and confirmed by a Safety Audit.

Specific Recommendations for the Hazards of ignition sources across the boundary.

i. **Emergency response:** In the event of any major LPG-Leak and the wind direction as seen from wind sock Approach the site of disaster from upwind and start Fogging which is to be resorted to in the area between the LPG-leak point downwind area and continued till the leak is stopped and all the LPG-vapours disperse fully. The fire crew should stand at a safe distance from the vapour zone. This is to be built in to the EMP. This system of fogging downwind of any LPG Gas leak and stopping of all vehicles and ignition sources should be resorted to in any direction that is downwind of the leak and this requirement should be built in to the EMP and Mock drill procedures for preventing fire and explosions.

ii. **LPG-Detectors:** LPG-Detectors are to be set up in the area. It is necessary to provide detectors at least on the four corners of LPG-facility area.

3.2 General Observations and Recommendations:

<table>
<tr><th>Sr. No.</th><th>Observations</th><th>Recommendations</th></tr>
<tr><td>1. 0</td><td colspan="2">Knowledge and awareness of employees concerned with LPG-Storage and handling: Following Departments are involved in Storage and Handling of LPG in bulk:
i. Operation Department: This department is responsible for all unloading, Storage and Handling of bulk LPG.
ii. Safety Department: This department is concerned in safety checking and advising of bulk LPG storage and handling.
iii. Security Department: This department is concerned with fire fighting and leakages of LPG.
iv. Any External maintenance Company: This Company is to have installed the facility and it is their property and is responsible for its inspection, maintenance.</td></tr>
<tr><td>1.1</td><td>Overall knowledge and awareness: There general awareness is in general knowledge and awareness of bulk LPG storage and handling in all the departments concerned. The knowledge and awareness is normally confined to small leakages and small fires only. There is generally complete lack of knowledge and awareness of major hazards of leakages, fires, explosions, spill pool formations, flash evaporations, BLEVE etc. and their prevention and control methods.</td><td>All concerned have to be intensely trained and made aware of the main aspects of prevention and control of major disasters of LPG. Detailed training and mock drills are needed to be organized. Some of the basic issues relating to behaviour of LPG in major disasters that came up during discussions were explained and are described separately in the report.</td></tr>
</table>

1.2	**Inspection, Testing and Maintenance of LPG-Facilities:** This is said to be the responsibility of the maintenance department. There should be a checklist and system of Inspection, Testing and Preventive maintenance as required under relevant OISD-Standards	i. It is recommended that the one trained person for inspection, testing and maintenance should be stationed near the facility visit the LPG-Facilities every day and should be readily contactable on phone/mobile instantly during any emergent need to inspect, test or carry out maintenance. ii.Standard checklists and printed forms for inspection, testing and Preventive maintenance should be developed based on the relevant OISD-Standards and BIS Standards.
1.3	**Maintenance Records:** Systematic recording of inspections, testing and maintenance work to be done in a computerized data base form using advanced software application to enable processing the data for MIS-Reports for improving the systems.	i. All records of inspection, testing and maintenance should be codified and computer data based for processing and obtaining MIS reports of processed information for management decision for improving continually the Preventive maintenance for replacement and overhauling of critical facilities like pumps, valves, relief valves etc. ii. All Break downs to be recorded mode wise and mode wise breakdown data base created with an advanced maintenance data base software for generating FMECA reports for improving maintenance system
1.4.	**Emergency Management Plan (EMP) and Mock drills:** There should be an Emergency Management Plan in accordance with the one	Carry out EMP for one of the specific scenarios given in the Risk Assessment study once in six months and maintain record of Mock drills.

	recommended by in OISD –144 Chapter-II. Mock drills have to be conducted on one of MCAS and since no Risk Assessment study was done so far, there has been no effective Mock drill exercise	
1.5	**Legislations, Standards and codes of practices:** One copy of all relevant rules, standards and codes of practices should be available at the LPG-facility	Recommended that all the OISD-Standards and BIS Standards as applicable to LPG-Storage and handling be obtained
2.0	**Design of the LPG-Storage and Handling facility:** The design of the storage and handling facility for LPG to be examined with reference to all the relevant legislations, rules, standards and codes of practices namely: Factories Act and Rules, MSIHC-Rules, Explosives Act and Rules, OISD-Standards, Pressure vessel rules.	

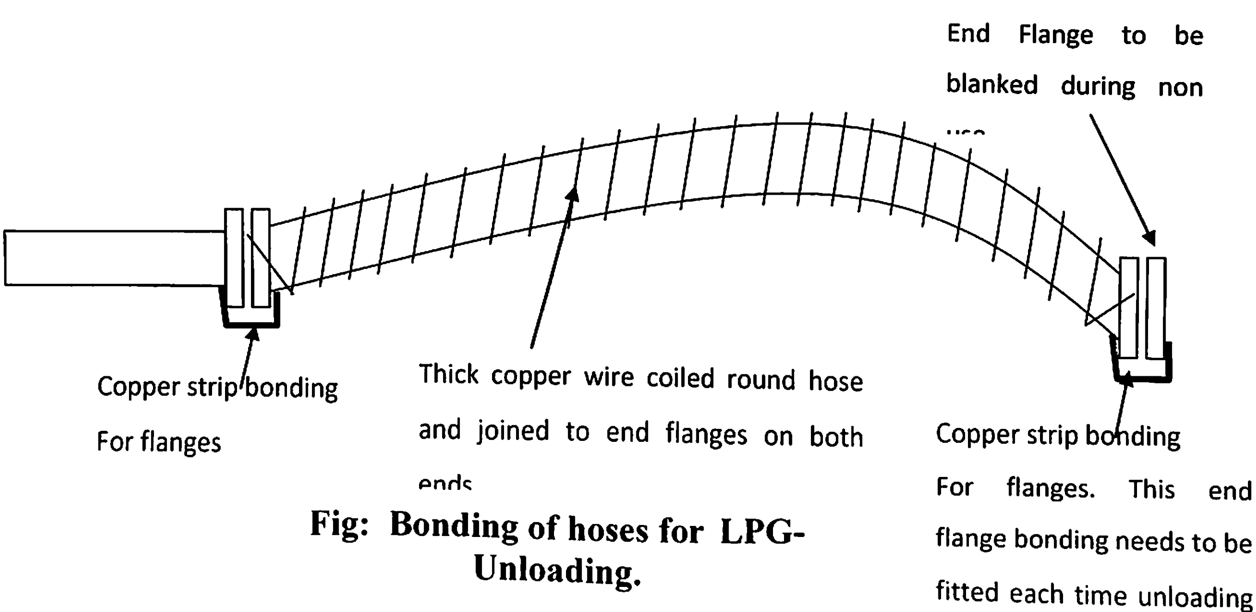


Fig: Bonding of hoses for LPG-Unloading.

2.1	**Gas Detectors:.**	Recommend installation of Hydrocarbon Gas detectors at least at the four corners of the LPG-facility.
3.0	**Fire fighting system:**	
3.1	**Fire and Explosion prevention during LPG-Gas leaks only:** The main requirement of fire/explosion prevention after any LPG or any other flammable gas leak is to prevent fire, flash fire and explosion.	i. Fire/ flash fires and explosions are preventable by starting the LPG-Deluge systems. ii. At least 5-Nos. of Fine spray/fog nozzles to be deployed at the LPG-Facility area. iii. These fine spray/fog nozzles to be immediately commissioned and the fire crew to position themselves cross wind of the LPG-Gas leak dispersion and start extensive Fogging and continue to do so till the leak of LPG-Gas is controlled and all the residual Gas disperses completely. **Caution: The Deluge system and fine water spray to be done only for LPG-Gas areas and water drops should never be allowed to fall on any LPG-liquid pools which require Fogging.**
3.2	**Fire and Explosion prevention during LPG-Liquid leaks:** Control of fire and explosion during liquid LPG-Leak requires Fogging guns or Steam discharge facilities. None of these facilities exist in the organization. The high volume fogging guns work on 30-40 Kg/cm2 pressure and these convert 100% of water in to fine Fog that never settles down but keeps floating in the air. The fogging guns can be used on the vapours of LPG above liquid-Pool of LPG	i. The phenomenon of LPG-Liquid leak is very complex and has not been understood by anyone in the organization. This needs to be rigorously trained and effective knowledge imparted on this. ii. When there is liquid LPG-Leak, the following three stage vaporization takes place: a. First stage there is what is known as "Flashing" takes place. Flashing is explosive boiling of a liquid stored above its

	to prevent fire and explosion. Alternatively steam can be used which also forms immediately fog in the air.	atmospheric Boiling point. LPG-is such a liquid. During flashing about 30-40% of LPG boils off forming a Puff cloud instantly taking heat from the liquid LPG itself and leaving behind cryogenic liquid LPG at its B. Pt. Of about 2 deg. C (B. Pt. Of Butane). b. This cryogenic Liquid LPG when falls on the ground below, it again starts boiling by taking heat from the ground below (Substrate). This generally takes about 1-min and is called 1-min. rapid evaporation. c. Finally the ground also cools to the B. Pt. Of LPG and the liquid residual liquid LPG after the Flashing and 1-min. rapid evaporation, remains as a liquid Pool which very slowly evaporates due to heat conduction from the ground (Substrate) and wind. iii. Liquid LPG should never come in contact with water or foam as the water or foam being at much higher temperature than the B. Pt. Of LPG, there will be vigorous boiling of LPG on contact with water or Foam. iv. One should use only Fog or Steam to dilute the LPG vapours on the Liquid LPG-Pools to prevent fires and explosions. vi. All this must be well understood, incorporated in the EMP and Mock drilled.

4.0 HAZCHEM Code for LPG		
4.1	There should be awareness of the HAZCHEM Code and its meaning for LPG.	It is necessary to know about the HAZCHEM Code for LPG and its meaning. This is described below
The HAZCHEM code for Propane, Butane and LPG is the same **2 W E where 2-stands for FOG to be used for Fire Fighting. For Foam the HAZCHEM code is 3. W stands for full BA- during fire fighting and E stands for evacuation.** In contrast for petrol the HAZCCHEM code is 3 Y E (Y-shaded) showing 3-for use of Foam. All flammable whose B. Pt. is above ambient temperature require use of foam (HAZCHEM First code-3) and all cryogenic flammable liquids having B. Pt. below ambient temperature require use of Fog (HAZCHEM First code-2). More about HAZCHEM Code may be seen at Appendix-9.		
5.0 Unloading Operations		
5.1	There should be a check list of unloading operations	Appendix-14 gives the requirements of unloading of LPG from lorry tankers and others. The existing checklist is modified by incorporating all the requirements of OISD Standard for unloading of LPG from Lorry Tankers. In addition, the checklist should add that all lights, radio to be switched off and mobile phones if any and the key for starting the engine to be taken from the driver and kept with the controlling supervisor till the unloading operation is over.
6.0 Work Permit System		
6.1	There should be a work permit system in use	Work permit system recommended under OISD-105.

7. RECOMMENDATIONS

1. Emergency lightings at LPG storage are to be provided.
2. Provision of bonding strips for the flanges in LPG services to ensure good bonding proposal should be under examination periodically. This may be continued.
3. Continuous daily safety inspection of LPG cylinder filling area is to be carried out with check list. Records have to be maintained and corrective measures are to be taken then and there..
4. The automatic gas detection system may be provided for cylinder storage shed.
5. Actuation of water spray system at LPG Bullets by Quartzite may be considered.
6. The Discharge of LPG sphere safety valve may be connected to the flare system.
7. Automatic start of fire pumps in case of decrease of pressure in the fire pump line may be considered.
8. Operating point of fire water lines may be provided with operating instructions noticed at these points must be easily identifiable.
9. Some measures have to be taken to do explosive meter check before releasing LPG truck regularly.
10. The emergency procedure in case of a leak shall be displayed at the loading area.
11. A safe job procedure for draining operation of the LPG sphere and bullets shall be displayed.
12. Two different types of level indicators shall be provided on spheres so that the chances of over filling and system failure can be considerably reduced.
13. Housekeeping has to be done properly in the cylinder filling area.
14. The sprinkler of the bulk loading bags may be interlocked with the emergency shutdown system.
15. Spark arrester in the exhaust of the LPG truck is must. In some vehicle, if they are disconnected with the exhaust pipe, a strict rule has to be made to prohibit entry of such vehicles.
16. The number of sprinklers and fire water ring main system is not up to the OISD standards .This required review.
17. Earth electrode must to be easily identifiable.
18. If noise level near the water bath is high display boards may be kept for using ear muffs/ear plugs.
19. More safety posters and safety slogans may be displayed in the LPG facilities.

20. Parking lines may be provided for truck, with traffic colour code.
21. The testing facility of unloaded cylinders must be improved.
22. Using steel chair in the truck loading area by the drivers must be stopped.
23. Identification procedures for outside persons must be done.
24. The concise safe operating procedure booklet may be distributed to the employees.
25. Do's and Don'ts may be displayed at suitable locations.
26. Safety instructions for draining operations are to be displayed.
27. Illumination is to be improved in filling area.
28. Drains vents and sample points should be provided with double isolation valves.
29. Communication system between loading area and the pump area is to be improved.
30. Area is insufficient for the truck movement in the tank truck Gantry area. Modification if possible can be made.
31. Safety instruction booklet is not available in the trucks. IOTL can distribute the safety booklets to the truck drivers and insist on carrying it all the time.
32. Fire wall may be provided in between empty cylinder storage area, filled cylinder storage and filling area.
33. Quartzite bulbs in the sprinkler system must be replaced as and when they are used in an emergency.
34. Safety showers are to be provided at the sphere area.
35. Periodic testing of fire alarm system for electric circuits to be carried out. Presently the system is not reliable.
36. More personnel should be exposed to first Aid training and frequency of training should also be increased.
37. The present system of fire call fails often. This should be studied in depth and improved.
38. Employees health monitoring program should be carried out periodically.
39. Fire /Accident/Near miss accident reports should be properly filled in and sent to concerned agencies without delay.

CHAPTER 4

DETAILED REPORT

INTRODUCTION

4.1 OBJECTIVE OF THE PROJECT

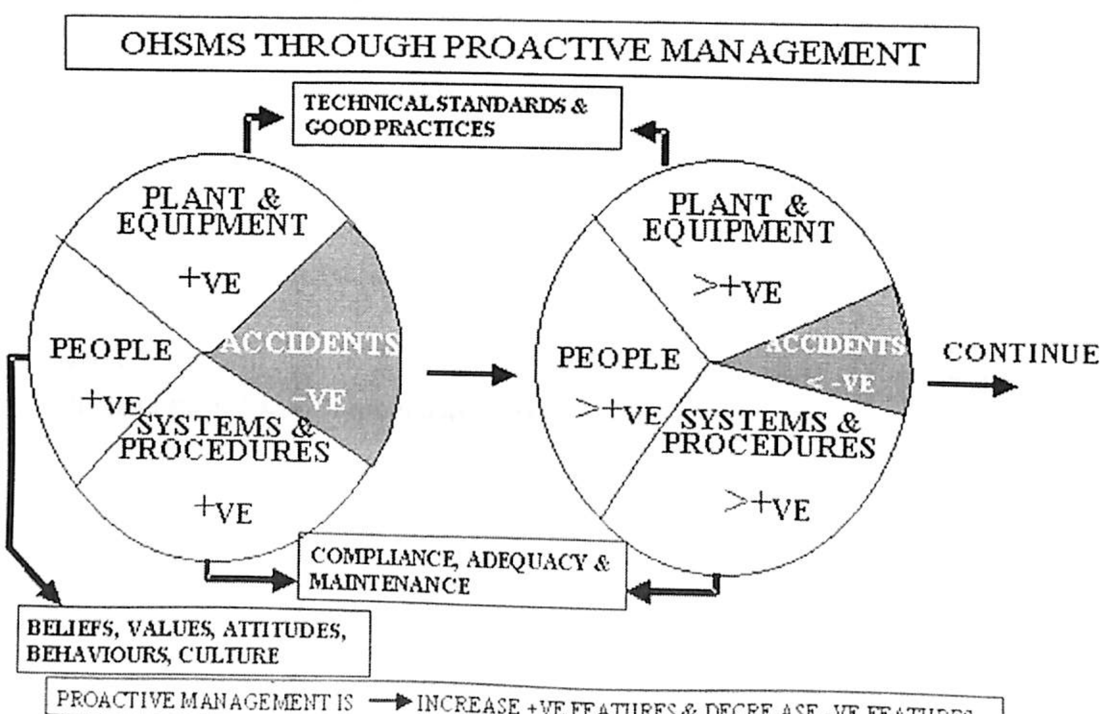
The objective of this project on QRA of LPG storage tanks for POOL FIRE is to pre-create through computer modelling, the potential maximum credible loss scenario (MCLS) in the storage facility for its consequences and likely frequency of such disasters before they really get caused and to enable effective measures to prevent such failures in the first place and to control and contain such disasters to minimize all possible damage consequences to life and property.

4.2 SCOPE OF THE PROJECT

4.2.1 What is Quantitative Risk Assessment (QRA)?

Risk Assessment is a Proactive Accident Prevention technique and is depicted by the following diagram of Occupational Health and Safety Management System (OHSMS) from the European Process Safety Centre's Model:

FIGURE-1



SOURCE "SAFETY PERFORMANCE MEASUREMENT", EUROPEAN PROCESS SAFETY CENTRE

The main scope of the project is

1. To undertake literature survey to find worldwide similar disasters.
2. To build basic software in Excel platform to simulate certain parameters.

3. To undertake modelling for damage consequences of storage tank failure to life and property.

4. To point out conditions under which accident can take place.

5. To make recommendations for mitigation of such accidents and control measures.

4.3 METHODOLOGY OF THE PROJECT

Methodology:

Following is the methodology of the proposed project work.

1. Data Collection

2. Computer Modelling

Following computer modelling shall be undertaken

a. Source modelling for quantifying primary release scenarios from main piping failure and tank failures.

b. Development of Secondary Scenarios:

Including **POOL FIRE**

c. Development of Tertiary Scenarios:

Damage to life and property and quantifying using PROBIT models.

d. Computation of final risk parameters namely

- **FAR** [Fatality Accident Rate].
- **FN Relation** showing relation between Frequency and Fatality number.
- Risk of fatality to employees.
- **ISO Risk.** Showing risk of fatality to neighbouring population.

4.4 KEY TERMS USED IN QUANTITATIVE RISK ASSESSMENT STUDY

QRA: Quantitative Risk Assessment is pre-creating disasters in the computer and learning all about them for prevention and control.

Hazard identification is a qualitative exercise to identify potential hazardous chemicals and activities

Risk evaluation: Risk is both Frequency of occurrence and damage consequences to life and property. Risk evaluation requires evaluation of these risk parameters.

MCAS is Maximum Credible Accident Scenario also called Maximum Credible Loss Scenario (MCLS).

Frequency-magnitude relations are equations showing frequency of chemical releases and their magnitude. They have the general formula:

LOG(Q) = A.LOG(F) + B

Where

Q is quantity released ,

F is frequency of release,

A and B are constants specific to each release.

Logic Diagrams: These are diagrams showing development of failures or events. A Fault Tree shows failure of machines due to Faults and an Event Tree shows development of sequence of Events triggered by one event

FMECA: Are Failure Modes, Effects and Criticality of equipments. Equipments can fail in different modes and FMECA determines the Critical failures for Preventive Maintenance Schedule (PMS)

PROBITS: is short for Probability Units. These are equations for Fatality, Injury and Property damage from various chemical and physical agents

FAR: is Fatality Accident Rate shows the chance of fatality of employees of an industry.

FN-Relation: shows relation between Frequency (F) and fatality Number (N) of accidents.

Individual Risk or ISO-Risk: is the risk of fatality to neighbouring population of industries.

4.5 LITERATURE REVIEW

1. Manual of EHS management by Dr. Ram S. Hamsagar.

2. Hydrocarbon process safety by J.C Jones.(chap 2&3).

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4. OISD-STD-158(Recommended practices on Storage and Handling of Liquified Petroleum Gas.

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4.6 LESSONS FROM ACCIDENTS

There are many lessons to be learnt from the accidents that have occurred in the field of oil and gas processing. A few such cases are quoted below:

1) Feyzin, France – 4th Jan 1966

- Fire around LPG storage vessels due leakage through drain.
- Catastrophic rupture of storage sphere
- Ignition source – car at a distance of about 160 meters from source of release
- 18 persons killed and 81 injured

Equipment Failure:

1. impact failures were the most common cause for accidents during transport.
2. mechanical failures were the most frequent cause for accidents during process, transfer and storage activities.
3. during transfer activities a large number of accidents occurred due to separation between the vessel and hose due to a coupling failure, and then a failure in the automatic shut-off valves.

Human/Organisational Failure:

1. direct operator error
2. insufficient training, lack of competence, lack of information, lack of coordination, excessive confidence
3. inadequate operating procedures

2) Rio-De-Janeiro, Brazil – 30th march 1972

- Fire around LPG storage sphere due to LPG leakage from drain
- BLEVE of LPG storage sphere
- 37 persons killed and about 53 injured

3) Lake Charles, Louisiana – 1967

- Failure of valve on butane pipeline
- Vapour covered five acres of area
- Explosion followed
- 7 persons killed and about 13 injured

4) Baton Rouge, Louisiana – 1989

1. 8 inch C2-C3 pipeline rupture
2. Explosion followed
3. Extensive damage and fire involved storage tanks and separator unit

5) Texas Refinery- March 2005

1. Overpressure and relief of the Raffinate Splitter
2. Release from Blow-down drum stack caused a vapor cloud.
3. 15 persons killed and over 170 injured.

SOME COMMON LESSONS LEARNED FROM ACCIDENTS

LPG Lessons: Storage

1. Plant/Equipment - Lessons Learned from Past Accidents:
2. Hand-valves to have mechanical locking devices
3. Valves to be un-movable when not in use (e.g. interruption of power)
4. Additional shut-off ball valves in order to be able to limit accidental releases
5. New valves installed to have an improved safety design (better technology)
6. Threaded coupling not to be tightened by hammering
7. Routine opening of closed containment is unacceptable unless a strict written operational procedure is used.
8. As a containment measure for accidental releases the installation of a water barrier is foreseen around LPG tanks

Organisation/Management - Lessons Learned from Past Accidents:

1. Safeguarding system to prevent theft: 24 hours covering installation
2. Development of appropriate monitoring and review procedures for the business
3. Emergency communication strategy needed including direct link between off-site emergency communication centre and company
4. Scenario similar to accident had been simulated therefore it should have been preventable, or the emergency planning should have been better
5. Investigation required of the operations for cylinder filling, including training and emergency procedures
6. Inadequate maintenance recording and documentation
7. Inspection frequency review and increased mitigation measures
8. Corrosion management to be made more demanding

LPG Lessons: **Safety Features**

Lessons learned from (existing) safety features:

No exclusive lessons to be learned on safety features that have not been included in the previous sections. A short summary of the most important elements would include:

1. Redundant valves, especially for auto-shutoff and emergency isolation.
2. Remote isolation of equipment such as pumps.
3. Water sprays, also known as water deluge, on storage tanks. Effective against pool fires, but uncertainties remains regarding the degree of protection provided from a jet fire.
4. Process control devices, e.g. level, pressure control.
5. All process monitoring and control devices to be routinely inspected and maintained.

LPG Lessons: **General**

Plant Layout

1. Good housekeeping essential (removal of flammable material etc.)
2. Tanks should have the smallest number of connections
3. Concentrate leakage sources (valves, flanges etc) in easily accessible zones, separated from the vessel walls by concrete walls
4. Improve ventilation in order to dilute possible LPG leaks and avoid gas build-up
5. Restricted zones (including barriers where appropriate):
6. Restrict access of unnecessary personnel in general
7. Restrict access to vehicles in order to reduce accidental impact
8. Restrict ignition sources (labs, electrical lines etc.)

Equipment – Storage

1. Adequate/appropriate level control on tanks
2. Tanks should be insulated to guard against heating etc (and to avoid BLEVEs)
3. Strong enough to be able to withstand forces such as fire-fighting sprays
4. Tanks should be mounded
5. Tanks could be underground for extra protection (difficult for inspection)
6. Ground around the tank should be sloped to catch liquid spillages

Equipment – Transfer

1. Fittings and connectors the most critical parts, problems often due to faulty design or inadequate maintenance
2. Metal pipes for transfer of liquids, not flexible hoses
3. Auto-shutoff or stop controls of transfer equipment, e.g. pumps etc placed in suitable locations

4. Remote-controlled valves at the fixed end of loading pipes
5. Pressure/weight monitoring and control

Organisation/Management and Emergency Planning

1. Correctly designed and functioning "Emergency Shut-Down" systems (isolation of spills, fuel sources etc.)
2. Avoidance of excessive alarms: sheer volume of alarms means operators become de-sensitised
3. Adequate process analysis: HAZOPs etc.
4. Adequate fire-fighting, water-spray systems etc.
5. Effective gas detection and automatic emergency isolation
6. Better information availability:
    1. Operating instructions in the plant
    2. Safety regulations
    3. Internal emergency plan
    4. Location of fire-fighting appliances, shelters etc.
    5. Warning and detection systems
    6. More effective communication between personnel, especially between shifts
    7. Better training of operators and emergency personnel:
    8. Must include knowledge of risk, regulations, internal emergency plan, use of fire-fighting appliances etc.
    9. Simulations/exercises should be carried out, especially under abnormal operating conditions and with rescue personnel/services
    10. Appropriate supervision: facilities should be run and operated by qualified engineers or skilled technicians with experience.
    11. Accidents to be reported, investigated and learned from: knowledge and the ability to use it are critical in the prevention and management of accidents.

4.7 QUANTITATIVE RISK ASSESSMENT

4.7.1 IMPORTANT DEFINITIONS

RISK

Risk is Probability or Chance or Likelihood of the Occurrence of an Accident and its Consequences to Life and Property

ACCIDENT

Accident is an Undesirable and an Unplanned event.

HAZARD

Hazard is Potential of an Accident.

SAFETY

Safety is control of Hazards, Risks and Dangers.

4.7.2 OVERVIEW OF QUANTITATIVE RISK ASSESSMENT (QRA):

Involves fully Quantifying through Mathematical Modelling both Frequency of occurrence and Damage consequences of an Accident and in a QRA study, we are concerned only with worst kind of Accidents and not minor or any other major accident. Risk Assessment is to simply identify and develop preventive measures for day-to-day safety improvements. These worst kind of disasters are called Maximum Credible Accident Scenarios (MCAS) or Maximum Credible Loss Scenario (MCLS). Scenario is a verbal picture of an Accident. Credible Scenario is an Accident arising out of failure of only one equipment in contrast to Incredible Scenario that considers several equipments failing simultaneously. An uncontrolled Credible Scenario might turn in to an Incredible Scenario. In a QRA study we are concerned with only Credible Scenarios from major equipment failures.

Intensity of Heat Radiation (IHR):

Every fire radiates some electromagnetic waves of which Heat radiations also called infra red radiations are generated by al fires. When Heat radiations or Infrared radiations strike the body surface or any object, the radiation is absorbed and heat up the body. This heating effect of Heat radiation on the surface of an object called IHR is measured in terms of Energy absorbed in units of Kilo Watts per meter square (KW/m2).

Note: This IHR causes injuries depending on the intensity of IHR level which decreases in cube root formula as distance from the fire increases. We shall be computer modelling Fires of different types like pool fires, jet fires, flash fires and fireballs in Risk Assessment.

TYPES OF RISKS

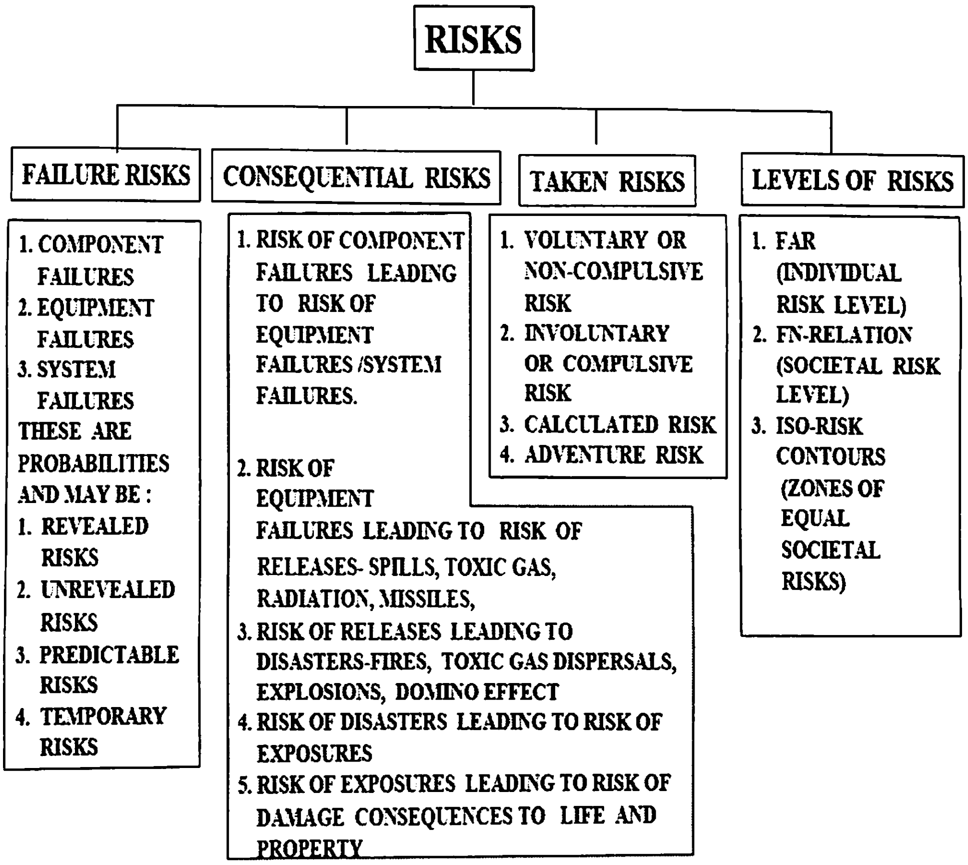


Figure 2: Types of Risks

A more comprehensive framework for QRA, adapted from "Guide lines for Chemical Process Quantitative Risk Analysis", American Institute of Chemical Engineers is shown in Fig.3.2.1

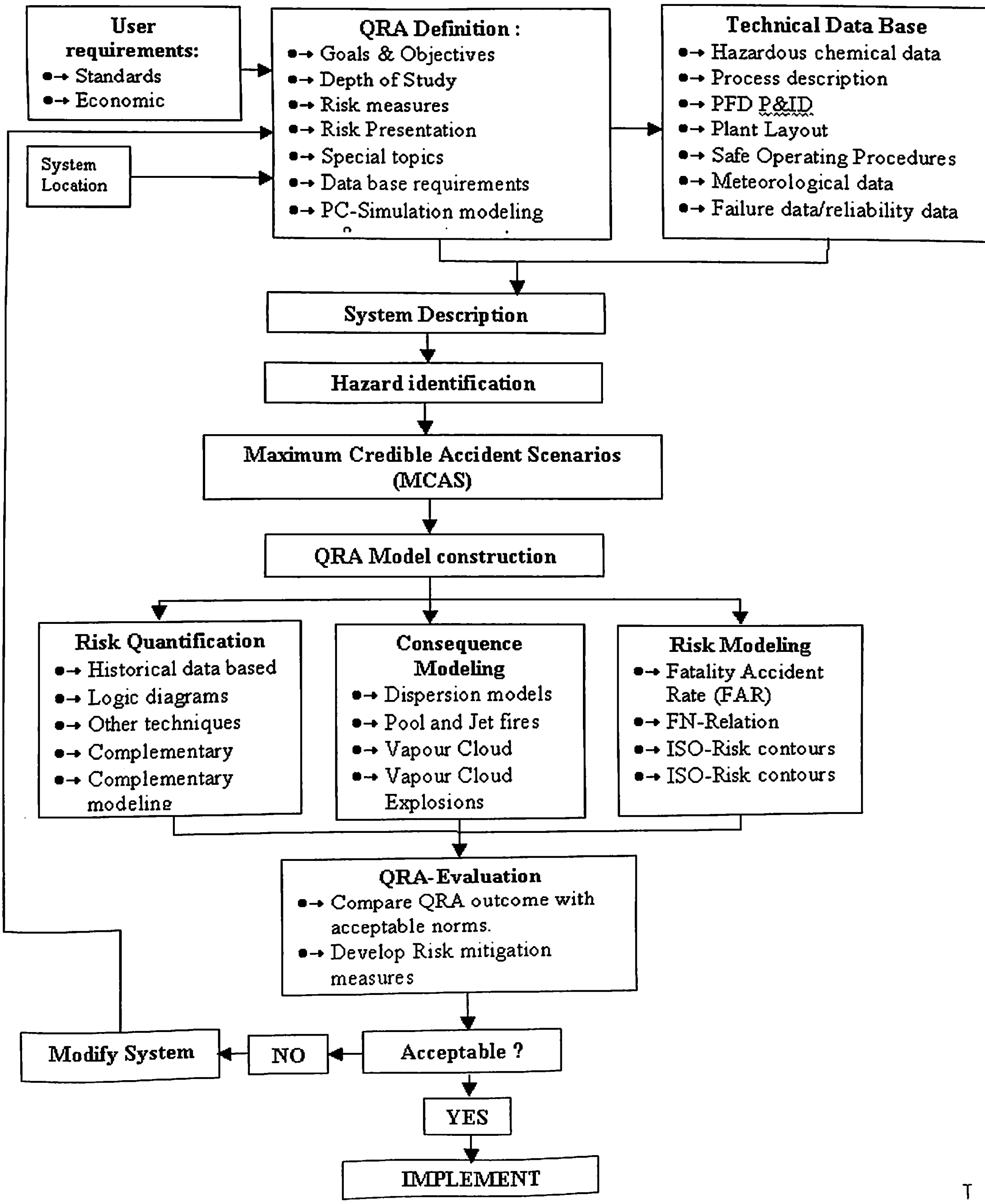


Figure 3: Framework of QRA

4.8 METHODOLOGY OF RISK ASSESSMENT

Hazard Identification: ***Phase - i***

The qualitative phase: DOW indices, HAZOP, Scenario development etc.

Disaster Simulations: ***Phase - ii***

Vulnerability zones, probits (damage consequence)

Quantifying risk: ***Phase - iii***

Application of failure rate/ reliability theory, logic diagrams: fault tree, event tree, FMECA. Historical data based magnitude-frequency relationships.

Risk Analysis : ***Phase – IV***

Fatality Accident Rate (FAR) : a measure of risk of Fatality to Employees, FN-curves showing Frequency (F) vs. Fatality Number (N), ISO-risk curves : zones of equal societal risks, determine acceptability of risk through ALARP (At Least As Low as Practical) a risk acceptability model developed by HSE of UK.

4.9 SCENARIO DEVELOPMENT

What is a Scenario?

In the context of a chemical accident, A scenario, is the nature of potential chemical accidents in terms of Primary Scenarios arising out of Containment Loss, followed by Energy releases in the form of Chemicals, radiations etc., followed by Secondary effects like toxic gas dispersals, spill evaporation vapour dispersals and fires and explosions (UVCE,CVCE, UG, Fireball, Flash fire, BLEVE) and Tertiary effects like their consequences in terms of damage to life and property .There can be virtually infinite scenarios oaf potential accidents as far as magnitude of release is concerned. So we can never generate all possible potential Accident Scenarios. For Quantitative Risk Assessment (QRA), we make use of worst possible Accident Scenarios arising out of failure of only one equipment or piping system. Accident Scenarios caused by worst kind of failure of major hazardous storages, reactors, piping are called Maximum Credible Accident Scenarios (MCLS) or Maximum Credible Loss Scenarios (MCLS) and we make use of only MCAS or MCLS for QRA Study. The reason is if we are prepared to prevent and contain and control worst type of scenarios we can also prevent and control and contain smaller ones as well.

Credible and Incredible Scenarios:

A credible scenario is an accident caused by failure of a single equipment or piping. In contrast, an Incredible Scenario is a number of accidents caused by either simultaneous failures of more than one equipment, piping, instruments etc., or secondary accidents caused by Domino effect from one accident. Incredible scenarios are not normally used in QRA study, but where potential exists, measures for preventing are given.

The basic primary scenarios will include the following containment loss scenarios:

1. Containment Loss Scenarios: resulting from failure of an equipment or piping. This gives rise to release of gases, vapours, liquids, dusts etc.

2. Secondary Scenarios: These include the following:

a. Flash vaporization: scenarios for flammable liquids stored above their atmospheric Boiling Pt. (BLEVE Case) leading to

• **Flash Puff scenario taking heat from the flashing liquid and cooling the un-vaporized liquid to cool to its atm. B. Pt. (Cryogenic Liquid)**

• **Cryogenic pool formation:** Spill pool evaporation scenarios including:

One min. rapid evaporation: of left over cryogenic liquid pool cooling a layer of the Substrate to liquid temperature by heat conduction and slow down of rapid vaporization followed by steady state pool evaporation due to substrate heat conduction.

• **Fires and Explosions:** Pool fires, Jet Fires, Unconfined Vapour Cloud Explosion (UVCE). Boiling Liquid Expanding vapour Explosion (BLEVE)

3. Confined Flammable Gas Explosion: This can be caused without a primary containment loss and results directly by formation of a flammable mixture of a flammable gas with air and ignition. This is called Confined Vapour Cloud Explosion (CVCE).

4. Mechanical Bursting: Caused by a pressure vessel has rise in pressure due to failure of compressor trip and SRV.

5. Flammable gas leak scenarios:

a. Bursting of a flammable gas container under pressure causing a gas puff.

b. Leak from a major pipeline of gas leading to a plume scenario of flammable gas.

6. Containment loss scenario of other hazardous Toxic gases: Leading to dispersions.

a. Bursting of a toxic gas container under pressure causing a gas puff of toxic gas.

b. Leak from a major pipeline of gas leading to a plume scenario of toxic gas.

The Tertiary scenarios will include the following:

For flammable liquid/gas containment loss scenarios:

1. Immediate ignition of puff causing Fire Ball scenario
2. Delayed ignition of the puff causing UVCE
   (Unconfined Vapour Cloud Explosion)
3. No ignition leading to puff dispersion.
4. Ignition of spill pool causing POOL FIRE.
5. No ignition causing dispersion of pool evaporation.
6. Delayed ignition of pool vapours causing
   UVCE, Flash back and pool fire

The Tertiary Scenarios: include damage consequences to life in terms of Fatality and Injuries, and to property.

4.10 WORLD BANK GUIDELINES ON SCENARIO DEVELOPMENT

World Bank for Project funding, requires the following Scenarios to be developed as given in their **"Technical Paper-55 Techniques for Assessing Industrial Hazards"**

Table 3.5: World Bank requirements for Scenario development for project Funding:

S/NO	Equipment	Scenarios as per World Bank Technical Paper-55	% Failure (refers to % of dia.)
1	All tanks at ambient conditions (All piping and Bund wall are considered as part of the system.	1. Vessel failure 2. Main piping leak	100 100 & 20
2	Pressurized / refrigerated storage or transport vessels Buried or non-buried.	1. BLEVE (Non-buried case only) 2. Rupture 3. Weld failure Note: Bund walls if any to Be taken in to account.	Total rupture ignited -do- 100 & 20
3	Centrifugal and reciprocating Pumps	1. Casing failure 2. Gland leak	100 & 20 20
4	Centrifugal, axial, reciprocating	1. Casing failure 2. Gland leak	100 & 20 20

	compressors		
5	Reactors, separators, contactors, heat exchangers, fired heaters, columns, pig launchers/receivers, reboilers	1. Vessel rupture 2. Vessel leak 3. Manhole cover leak 4. Nozzle failure 5. Instrument line failure 6. Internal explosion	100 100 largest pipe 20 100 100 & 20 100
6	Valves all types	1. Housing leak 2. Cover leak 3. Stem failure	100 & 20 20 20
7	Filters, Strainers	1. Body leak 2. Pipe leak	100 & 20 20
8	Hoses, bellows, articulated arms	1. Rupture leak 2. Connection leak 3. Connection mechanism failure	100 & 20 20 100
9	Pipes, flanges, welds, elbows	1. Flange leak 2. Pipe leak 3. Weld failure	20 100 & 20 100 & 20
10	All flares or vent stacks, the manifold vent scrubber and knockout drum are also considered as part of this component	1. Manifold drum leak 2. Discharge beyond specification	100 & 20 Should be estimated

Note: These World Bank requirements relates not only MCLS (100% failures) but also lower (Practically more likely) 20%failures as well. In QRA study we generally make use of only MCLS or MCAS.

4.11 LIQUIFIED PETROLEUM GAS (LPG)

DEFINITION OF LPG

LPG is defined as those hydrocarbons which are gaseous at atmospheric pressure but may be conducted to the liquid state at normal temperature by the application of moderate pressure. Though they are normally used as gasses, they are stored and transported as liquid under pressure.

PROPERTIES

LPG marketed in INDIA confirms to Indian Standard specification IS4576

LIQUID DENSITY

LPG in the liquid state is nearly half as heavy water. Specific gravities range from 0.55 to 0.58.Knowledge of this property helps us in calculating the safe quantities that can be filled in a given container whose volume is known. Any container should have 5% ullage available at the assessed temperature.

VAPOUR SPECIFIC GRAVITY

LPG vapour nearly twice as heavy as air.LPG vapour tends to settle down and hence there should be adequate ground level ventilation wherever LPG is handled. Coefficient of expansion of liquid is approximately 12 times that of water. In conjunction with liquid density should be taken into consideration while arriving at the safe filling capacities of container.

VAPOUR PRESSURE

The vapour pressure of LPG in equilibrium with its liquid in a closed container exerts a pressure known as vapour pressure and the magnitude of this pressure depends on the ambient temperature and not on the quality of contents. It is to be noted that vapour pressure increases rapidly with the increase in temperature.

BOILING POINT

Boiling point of the liquid is the temperature at which the vapour pressure of the liquid equals atmospheric pressure .Boiling point of LPG is below '0' degree centigrade. The pressure inside a container filled with LPG is always higher causing the gas to gush out when the valve is opened.

EXPLOSIVE LIMITS

LPG will ignite only when mixed with air, a concentration is reached at which the mixture just becomes explosive ie ignitable. This is called Lower Explosive Limit.

As the concentration of the gas is further increased, a point is reached at which the mixture ceases to ignite and the concentration of the gas just before this point is called Upper Explosive Limit. A flame can be propagated only in a mixture of gas and air if the gaseous concentration lies between these two limits

ODOUR

LPG is odourless, however to make it easily detectable when leaking an odour giving chemical called mercaptans(sulphur compound) is added in such quantities to maintain 20ppm which ensures a distinct detectable smell.

COLOUR

LPG is colourless.

OTHER CHARACTERISTICS

LPG expands 250 times its volume

LPG has a very low viscosity

4.12 SOURCES AND PRODUCTION OF LPG

A. Wet Natural Gas, from oil wells.

B. From crude oil

A. Wet Natural Gas

This is processed to obtain,

1. Dry Natural Gas
2. LP Gases
3. Natural Gasoline

LP Gases separated from the above by

1. Compression and cooling
2. Absorption.

THE COMPRESSION PROCESS

Wet gases are fed into the compressor and the gases which are saturated at the production pressure and temperature are compressed so that the volume is greatly reduced thus reducing the amount of hydrocarbons which can remain in pressure vapour phase As a result of this compression, the gases get heated and

This counteracts the effect of reduction in volume. The gases are therefore cooled after compression so that heavier constituents condense and can be separated.

ABSORPTION PROCESS

Wet gases under pressure passes up an absorption tower counter to a downward flow of absorption oil. (Generally a petroleum fraction between heavy gasoline and light gas oil).This absorbs the LPG and natural gasoline while the dry natural gas comes out at the top. The saturated absorption oil passes through a distillation column where the mixture of LPG and natural gasoline is boiled as mild gasoline. This is further distilled to separate propane and butane and natural gasoline and lean oil recycled.

DISTILLATION PROCESS

B. REFINERY OPERATIONS

1. by the process of distillation

2. Catalytic cracking.

4.13 HAZARDS OF LPG

LPG marketed in India has a maximum vapour pressure specification limit of 16.87kg per sq.cm at 65 deg centigrade. At ambient temperature of 38deg c the pressure inside the container would be about 9kg per sq cm.LPG is flammable and explosive in nature. It gives rise to fire hazards as well as non fire hazards. There are also hazards due to the manner in which LPG is stored, transported and used.

NON FIRE HAZARDS

TOXICITY

LPG is essentially non toxic, but contains "Simple Asphyxiate". There present a respiratory hazard only if their concentration is high enough,25% or more, to cause excessive dilution of the oxygen content in the atmosphere

CRYOGENIC HAZARDS

Whether a spill of LPG occurs from low temperature or pressurised storage, some of the liquid that spills will be at its boiling point. If personnel come into contact with the cold liquid they can receive severe freeze burns which can cause even death.

OVER PRESSURISATION

When the vessel or pipe is "liquid fill" by closing valves at both ends, the pressure increase inside can be sufficient to cause the vessel or pipe to rupture. Therefore it is advisable to provide pressure relief valves for all vessels for all the vessels and pipe sections that can be isolated when liquid full.

FIRE HAZARDS

LPG is highly flammable and explosive in nature. If released to atmosphere and allowed to vaporise, LPG can pose very serious hazards depending on the type of leak or spill and the availability of ignition sources .The various types of fire hazards are

a. VAPOUR CLOUD FIRE AND EXPLOSIONS

Whenever LPG is released from its containment system, the liquid will start to vaporise and some portion of liquid will quickly flash to vapour the remaining liquid will be heated by the surroundings. The vapour generated by the flashing and boiling will start to mix and will be carried downwind with air, thus creating a vapour cloud and start to ignite if it encounters ignition sources in flammable portion

The flammable vapour liquid may explode by the pressure waves produced if the LPG is leaked into an enclosure (control room, compressor building etc)the possibility of an explosion will be increased.

b. POOL FIRES

A leak or spills of sufficient size will result in an accumulation of liquid on the ground. If ignited, the resulting fire is known as a pool fire. Objects and personnel outside the actual flame volume can also be damaged or injured by the radiant heat emitted by the flame torch fires.

When LPG is leaking from pressurised container, the leak may take the form of spray of liquid droplets and vapour. If ignites, the resulting fire is known as a torch fire.

C. BLEVE HAZARDS

A boiling liquid expanding vapour explosion is the name given to the catastrophic failure of pressurised storage tank containing LPG. BLEVE also causes over pressure effects similar to an explosion and can propel parts of the tank shell for long distance Objects or persons that come in to contact with a flame and radiant heating on can be seriously damaged or injured.

Studies on the effect of radiant heating on human skin show that an indefinite exposure to heat flux of 1.39kw per sq cm, can be tolerated without pain. Higher fluxes can produce pain, severe burns or even death.

4.14 LPG STORAGE VESSELS

Tanks for the storage of LPG are pressure vessels either of horizontal or spherical construction approximately 2cubic metres of tank volume is required for holding 1 ton of LPG as commercially marketed. Details of the facilities available for storage of LPG

HORIZONTAL STORAGE VESSELS

Horizontal storage vessels (also commonly known as bullets) which can in many instances be shop fabricated and moved to in one or more pieces are normally used for unit capacities up to 200 cubic metres

SPHERES

1. Spherical vessels or spheres (also commonly known as Horton spheres) are the most economical for storage of capacities more than 400 cubic metres. The occupied area required is less than that of a horizontal vessel of equipment capacity.
2. The stress on the sphere is more evenly distributed.
3. The spheres are best studied to encounter wind velocities.

Spheres area made of low carbon steel which requires specialised welding techniques 100% radiography of welded seems required to be carried out depending on the thickness/type of the steel used

An LPG sphere is designed as per ASME sec8, Div 2,1989 or as per IS2825 or BS5500. The following aspects are taken into consideration while designing an LPG sphere.

LPG STORAGE VESSEL DESIGN DATA

1. Design pressure
2. Design temperature
3. Specific Gravity
4. Capacity
5. Wind velocity
6. Erection weight
7. Operating weight

The spheres are generally installed at an elevation of about 4 metres above ground level on structured steel supports which are encased in concrete to them from collapse in the event of fire.

STORAGE VESSEL FITTTINGS

1. SAFETY RELIEF VALVE

The function of the Safety valve is to automatically open and release the pressure when the pressure increases above a certain pressure limit and close when the pressure drops so that the pressure at anytime within the pressure vessel does not exceed the design pressure. The safety relief valves are set to open at 110% of the design pressure and prevent the fire exposure from rising about 120% of the design pressure.

2. LIQUID LEVEL GAUGING DEVICE

This generally is a tape mechanism attached to a float on the surface of the liquid. The position of the tape varies based on the position of the float and the level of the product can be read from the graduation of the tape.

3. HIGH LEVEL ALARM

The device is provided to ensure against filling in excess of the safe filling height. This is float type and is connected electrically to an annunciator system. when the liquid level in storage tank reaches pre specified limit the alarm, give an indication so that the product receipt can be suspended and over filling of tanks avoided

Safe filling height for a vessel depends on the maximum temperature of the contents even likely to be attained under normal operating condition. It is assessed to be 55 degrees centigrade in our country. A minimum ullage of 5% after allowing for expansion of the contents is to be provided at maximum assessed temperature.

4. PRESSURE GAUGE

These are generally bourdon pressure gauges which are to be fitted to vapour space of the vessel.

5. THERMOWELL

It consists of a temperature indicator fitted in a sleeve

6. LIQUID OUTLET LINE

7. VAPOUR EQUALISER

8. PRODUCT RETURN LINE

9. DRAIN LINE-with double block and quick closing valve.

10. REMOTE OPERATED VALVE (ROV)

ROV are pneumatic air to open valves and are provided on product return line of the LPG vessel. These valves are operated by solenoid valve which gets an electrical impulse from the remote locations. Hence are called ROV.

The ROV closes on the following conditions.

a) Air failure

b) Fire

The air supply to the ROV is routed through thermal fuses which melt at 70 degrees resulting in air supply being cut off to the ROV.

c) Manually-by switching of the power supply to SOV. They gets de energised and the air output to the ROV gets vented.

11. AUXILLARY GAUGE

This gauge is provided in addition to the main level gauge. It works on the principle of differential pressure.

12. HIGH PRESSURE ALARM

This is provided as an alert against excessive risk of pressure about the designed parameter due to operational reasons or ambient conditions.

13. MANHOLE

The number, size and location of fittings will depend upon the service and the piping layout adopted.

INSPECTION OF STORAGE VESSELS

The storage vessels in LPG service are inspected thoroughly using ultrasonic scan test as per code ASTM-A-578/435 once every 4 years. LPG bullets and spheres having the fire proofing on the outside surface is examined for cracks, bulging and deterioration of fire proofing.

SAFETY CONSIDERATION IN DESIGN OF LPG STORAGE FACILITIES

1. Minimum flanges must be connected to the sphere.
2. Minimum two numbers safety valve each having 100% relieving capacity would be installed on sphere. This should be connected to flare system wherever applicable.
3. Minimum two different types of level indicators and one independent high level switch.
4. Fire proofing protection should be good enough to safeguard structure for 30 to 60 minutes.
5. Fire detection system audio visual alarm which will operate ROV on inlet and outlet lines and trip the pumps.
6. All electrical equipment must be flame proof including light fittings, telephones, fans etc.
7. All electrical equipment must be grounded properly and proper earthling should be done for storage vessels

4.15 SHUT DOWN PROCEDURE FOR STORAGE VESSELS

a) Pump away as much hydrocarbon liquid as possible through normal suction line.

b) Block off the fill line upstream of the water flooding connection and can seal the valve closed.

c) Put sufficient water in vessels to float the remaining hydrocarbon liquid above the suction inlet and pump out the remaining water through normal suction, keeping a close watch on interface.

d) Drain water through the water draw-off until vapour appears.

e) De pressuring the vessels to the flare system or if necessary to atmosphere and blank all inlet and outlet lines.

f) Remove safety valve after checking pressure and vent vessels to atmosphere through valve under safety.

g) Start filling vessel with water keeping , a log of level, temperature, and pressure overflow the water through top safety valve nozzle and eventually through top manhole.

h) When flushing water is gas free, start to drain off the water after opening the atmosphere vent at the top of the sphere to admit air to replace the volume water being drained off.

i) Drain remaining water through water draw-off and steam the vessel

j) After steaming is completed , allow drum to cool and open man ways.

k) Take gas test and check for oxygen content inside the drum. If, necessary , steam educators should be installed for providing fresh air draft. Assess head to test for toxic materials. e.g: Hydrogen Sulphide.

l)Precautions should be taken to keep the interior of the sphere wet as deposits of iron sulfide may present

4.16 MAIN CAUSES OF CONTAINMENT LOSS

There are 8 main causes

1. Over pressurization
2. Brittle fracture
3. Flange, gasket, steam failure,
4. Weld casting failure,
5. Vibration,
6. Corrosion erosion,
7. External loading impact,
8. Internal explosion.

Behind all these the predominant root cause is human error. According to Heinrich 98% of all accidents are caused by human error of which 80% by direct man-machine interface (Operational) error and 10% due to design and maintenance errors. So basic effort to prevent disasters is by changing the men manning the system. The typical Indian "*Chalta Hai*" culture and "*Bindas*" attitude is the basic requirement to ensure compliance to all the relevant rules, regulations, standards and codes of practices about which there is a general lack of awareness.

4.17 LIQUID FIRE or POOL FIRE

POOL FIRE

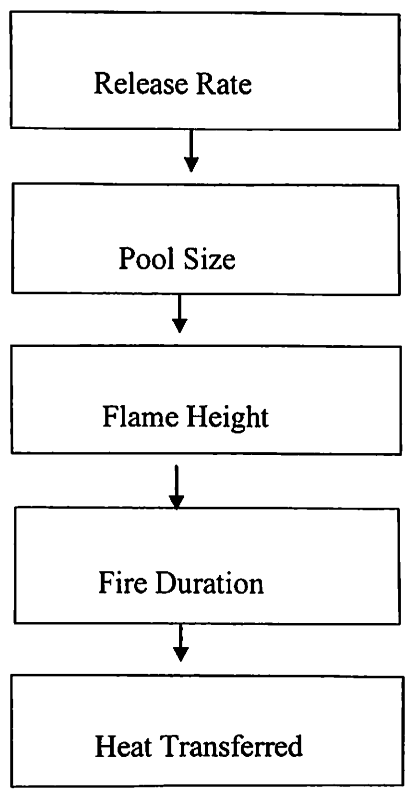
Pool fire begins with the release of flammable material from process equipment or storage. If the material is liquid, stored at a temperature below its normal boiling point, the liquid will collect in a pool. The surroundings will give the geometry of the pool. If the liquid stored under pressure above its normal boiling point, then the fraction of the liquid will flash into vapour, with the un-flashed liquid remaining to form pool in the vicinity of the release.

CHARACTERISTICS OF LPG-POOL FIRE:

LPG POOL FIRE is a very rare phenomenon in hot climatic conditions like in India and yet it is possible. When large spillage of LPG takes place a fraction flashes reducing the residual LPG to its Atmospheric Boiling point which also rapidly evaporates for about a minute on falling on the ground and then the remaining LPG forms a pool in a cooled ground where LPG slowly and steadily evaporates due to heat conduction from the ground and wind. This vapour if ignited forms a pool fire.

EVALUATION PROCESS OF POOL FIRE

FIGURE-5

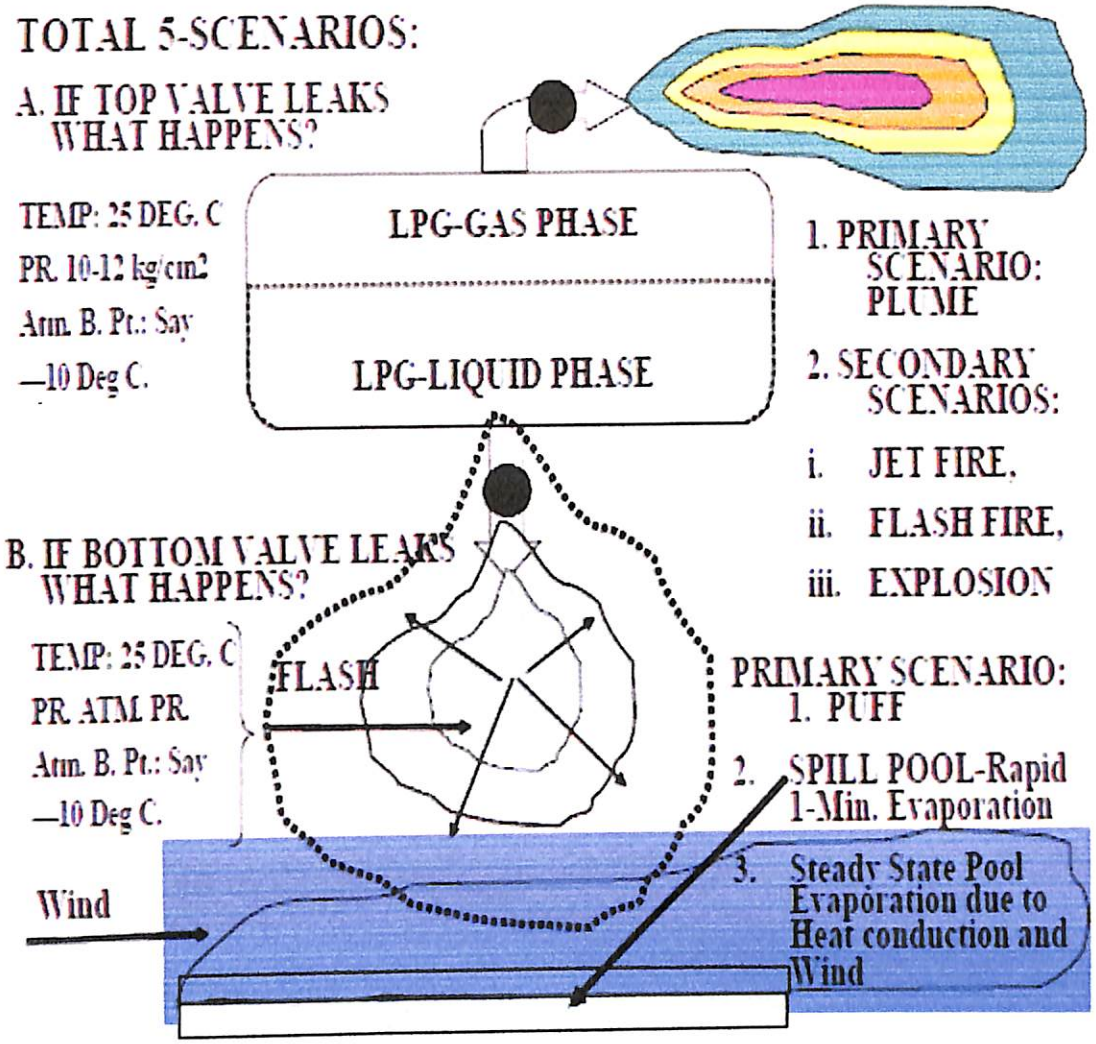


Note:

The POOL FIRE evaluation can also be done like as the above process. This Evaluation is as per the (Centre for chemical process safety).Reference: Chapter 5(Fire Hazard Analysis).

FIGURE-4

SCENARIOS OF LPG



4.18 POOL FIRE COMPUTATION

Given Data:

Sump Depth	Cross wind Sump width (CW) (m)	Downwind Sump Length (DW) (m)
2.00	30.00	50.00

Equation 1.Effective Pool radius (PR)

When a flammable liquid spills from the storage tank, spill pool will be formed. So the effective pool radius can be calculated from the following formula.

Cw= 30 m

Dw= 50 m

$$PR = \sqrt{Cw * \frac{Dw}{\pi}}$$

$$= \sqrt{\frac{30 * 50}{3.14}}$$

Hence PR=21.85 m

Cw = Cross wind sump width (m)

Dw= Down Wind sump length (m)

Equation 2.LPG Pool depth (PD)

Pool depth is the depth of pool formed. It can be calculated from quantity of LPG leaked and effective pool radius.

Q= 5000 kg

PR= 21.85 m

$$PD = \frac{Q}{\pi * PR^2}$$

$= 5000/(3.14*21.85^2)$

=1.93m

Q = Quantity of liquid left after forming liquid pool (kg)

PR= Effective pool radius (m)

LPG Liquid leak Flashing

Equation 3. Flash Fraction(ff)

It is fraction of liquid flashed into vapour when it is released from high temperature to low temperature.

Cp=0.549Cal/g.deg.c

To=25 deg.c

H_v=-33 Cal/g

$$ff = -\left(1 - e^{\left[Cp \cdot \frac{To-Tv}{Hv}\right]}\right)$$

$$ff = -(1 - 2.718282^{\,[0.549*(25+33)/102.1]})$$

$$= 0.36597811$$

Cp = Specific Heat of LPG cal/g.deg. C

To = Storage temperature of LPG deg. C

Tv = Final temperature after flashing deg. C

Hv = Latent heat of vaporization of LPG cal/g

Equation 4.Mass of LPG flashed (Mv)

ff =0.36597811

Q=5000kg

$Mv = ff * Q$ = 0.36597811 * 5000

= 1829.89

Ff – Flash fraction

Q = Quantity of LPG leaked kg

Equation 5.Quantity entrained in flashed LPG (kg): M_e

Me = If (ff<0.1, 0 (if AND (ff≥0.1, ff≤0.2), (0.1*Mv), (If (ff>0.2, 0.15*Mv))) kg

1. If ff<0.1,then M_e=0
2. If ff≥0.1, ff≤0.2,then M_e= 0.1 * M_v
3. If ff>0.2, then M_e= 0.15 * M_v.

   For our result flash fraction is greater than 0.2

   Hence the value of M_e= 0.15*1829.89

   M_e= 274.48kg

Equation 6.Fraction entrained (Fe)

$M_e = 274.48$ kg

Q= 5000 kg

$Fe = \frac{Me}{Q}$ = 274.48/5000

$F_e = 0.054896$

Q = Quantity of LPG leaked in kg

Equation 7. Total fraction flashed and entrained(Tff)

M_e=1829.89

M_v=274.48

$$Tff = Me + Mv$$

$$= 1829.89 + 274.48$$

$$= 2104.37 \text{ kg}$$

Equation 8. Mass left after flashing forming liquid pool (M*l*)

Q=5000kg

T_{ff}=2104.37

$Ml = Q - Mve = Q - Tff$

= 5000 – 2104.37

= 2895.63 kg

Q = Quantity of LPG leaked kg

Mve = Total mass of flashed + entrained in kg

Equation 9. Volume of liquid forming liquid pool (Vlp)

Ml=2895.63kg

D=597kg/m^3

$Vlp = \frac{Ml}{D}$ in m3

= 2895.63/597

= 4.85 m^3

Ml = mass left after flashing forming liquid pool in kg

D = Density of LPG at Stated temperature kg/m3

Equation 10.

Rapid Pool Evaporation in one minute due to heat transfer from earth :

$$rpev = [(MN1 * (ST - TV)^2/HV) * ((CW * 100 * DW * 100) + (((2 * DW * 100) + (2 * C$$
$$]/1000$$

= [(0.00075*((25+33)^2/102.1))*(30*100*50*100)+((2*30*100)+(2*50*100))*1.93]/1000

= 371.43 kg

Mvop = Mass vaporized in 1 min (or) 1 min rapid pool evaporation due to heat transfer from earth (kg)

MN1=Substrate constant for 1-min rapid pool evaporation

ST= Substrate temperature deg°C

TV= Final temperature after flashing deg°C

Equation 11. Mass left after 1 min rapid pool evaporation $Ml\ Rvep$

$$Ml\ Rvep = Ml - Rvep$$

= 2895.63 – 371.4 = 2524.23 kg

Ml= mass left after flashing forming liquid pool (kg)

Rvep= 1min rapid pool evaporation due to heat transfer from earth in kg

Equation 12.

$$SSV = (SS * (ST - TV)/HV) * ((CW * 100 * DW * 100) + ((2 * CW + 100) * (2 * DW * 100)$$

= {(0.015* (25+33)/102.1) * ((30*100*50*100)+(2*30*100+2*50*100)* 1.93/ 6000}

= 2.13 kg/sec

Equation 13.

$$Tm = SSV * \frac{MlRvep}{60 * 60}$$

= 2.13 * (2524.23/3600)

= 1.5 hr

Pool fire computation

Equation 14.

Pool diameter = 2* Pool radius

= 2 * 21.85

= 43.7 m

Equation 15.

$b.rate = ((V_\infty/(100 * 60))) * (1 - \exp(-svlk * 100 * 2 * PR)) * D$ in kg/sec

$= ((0.73/6000)) * (1 - \exp^{(-0.027 * 100 * 2 * 21.85)} * 597$

= 0.072635 kg/sec

V_∞ = 0.73 (A constant)

PR= Effective Pool Radius (m)

D= Density of LPG at stored temperature (Kg/m^3)

b. rate= Mass burning rate ($Kg/m^2/S$)

Equation 16.

$Length = 42.0 * Pool\ diameter(((b.rate)/(AD * \sqrt{(9.81 * 2 * PR)})))^{0.6}$

$= 42 * 41.73((0.072635/(1.129 * \sqrt{(9.81*41.73)}))^{0.6}$

= 57.42 m

Length= Length or height of fire (m)

b.rate= Mass burning rate in $Kg/m^2/S$

AD= Air Density (Kg/m^3)

PR= Effective Pool Radius (m)

Equation 17.

$mxdia = \frac{Length}{2}$ (m)

= 57.42/2

= 28.71

Mxdia=Maximum diameter of fire (m)

Length=Length or height of fire (m)

Equation 18.

$$dstmxdia = 0.61 * Length\ (m)$$

$= 0.61 * 57.42$

$= 35.02$

dstmxdia=Distance of maximum diameter of fire from base of fire

Length= Length or height of fire (m)

Equation 19.

$$flmctht = dstmxdia + Sump\ depth\ (m)$$

$= 35.02 + 2$

$= 37.02$ m

flmctht=Flame Centre Height (m)

dstmxdia= Distance of maximum diameter of fire from base of fire (m)

Equation 20.

$$\alpha = 3.2 * ((maxdia * wnd * (air\ density)/(air\ viscocity))^{0.07}$$

$$) * ((wnd * wnd/(maxdia * 9.81)))^{0.7}) * (((liq\ density)/1.2928)^{-0.6})$$

$= 3.2 * ((28.71 * 2 * (1.129/0.00018)^{0.07}) * (2*(2/28.71*9.81)^{0.7}) * (597/1.2928)^{-0.6}$

$= 0.000511174$

α = Tan/cos of flame tilt angle

Equation 21.

$$fldsthtsml = dstmxdia - htsml\ (m)$$

$= 35.02 - 1$

$= 34.02$

fldsthtsml=Flame distance from height simulation (m)

dstmxdia= Distance of maximum diameter of fire from base of fire (m)

htsml= Height of simulation (m)

Equation 22.

$$Area = \left(11.0 * \frac{maxdia}{14.0}\right) * (4.0 * length + maxdia)$$

$= (11 * (28.71/14)) * ((4*57.42) + 28.71)$

$= 5228.23\ m^2$

maxdia= Maximum diameter of fire (m)

length= Length or height of fire(m)

Equation 23.

$$q = 141.84 * \left(1 - \exp\left(\left(-0.055 * \frac{maxdia}{0.3048}\right)\right)\right) * 0.048 * \sqrt{molwt}$$

$= 141.84*(1\text{-}\exp^{(-0.055*(28.71/0.3048))}) * 0.048 * \sqrt{44.46}$

$= 45.14$ kW/m^2

q= Heat flux (Kw/m^2)

maxdia= Maximum diameter of fire(m)

mol.wt= Molecular weight of LPG

Equation 24.

ki=((((fldsthtsml^2.0)+(maxdia/2+dstforihr^2.0)))^0.5)

= 34.25 (inter value)

fldsthtsml= Flame distance from height simulation (m)

Maxdia=Maximum diameter of fire (m)

Dstforihr= Distance for IHR computation(m)

Equation 25.

alph1=(sqrt((1.0+4.0*(alph*alph)))-1.0)/(2.0*alph)

= 0.000511174

alph1 = a value derived from alpha

alph = Tan/Cos of flame tilt angle

Equation 26.

tang is Tilt angle=asin(alph1)

= 0.000511174

tang = flame tilt angle due to wind(Deg)

alph1 = a value derived from alpha

Equation27.

Maxihr is Max IHR=q*area*7.0/(88.0*((mxdia/2.0)+dstforihr)* ((mxdia/2.0)+dstforihr)) (kW/m^2)

= 45.14 * 5228.23 * 7 / (88 * ((28.71/2 + 1) * (28.71/2) + 1)

= 88.77 kW/m^2

Maxdia=Maximum diameter of fire (m)

Dstforihr= Distance for IHR computation (m)

Compute Probit

Equation 28.

dose=(q*area*cos(ang)*7.0/(88.0*(dist*dist)))*reducing from dist of Solar radiation/1.5

= (45.14* 5228.23*cos(0.000511174)*7)/(88*(100*100))*100/1.5

= 96.76

Equation 29.

ftprbt=2.56*log(pow(1000.0*foo.dose,(4.0/3.0)))-14.9

= 2.56*log $((1000.0*3652.71^{(4/3)}),10)$-14.9

= 4.94

ftprbt= Fatality Probit

Equation 31.

Fatality Area =Fatality distance$^{(2)}$ * 3.14159in m

= 19^2 * 3.14159

= 1134.113 m^2

Equation 32.

Number of employees exposed= Fatality Area*0.0001*50

= 1134.113 * 0.0001 * 50

= 5.67

Equation 33.

Absolute fatality for a Population density of 50/Ha= Fatality area*0.0001*50*Fatality Probit/100

= 1134.113 * 0.0001 * 50 * 27.61/ 100

= 1.56

Equation 34.

General Equation for Magnitude (Q) Vs Frequency (F):

Log (Q) = A Log(F)+B

A and B are Constants.

Equation 35.

Transposing for Frequency: Frequency (F) = (10.0^log(Quantity in MT)/A-B/A)*0.0001

$F = 10^{((\log(5)-0.79)/-1)} * 0.0001$

= 0.000123319/ plant yr

Equation 36.

Fatality Accident Rate (FAR): Showing Risk of fatality to Employees.

FAR=

10000000/(No.Hours worked/year*No.Exposed)*SUM(Frequency*No. Fatal in each MCLS)

= (10000000/(80000 * 5.67)) * 1.57 * 0.000037571

= 0.0129

Unit

Employees Fatal in 10^8 years of exposure

4.19 CONTROL MEARSURES AGAINST FIRE AND EXPLOSION

Engineering controls

1. SOP (standard operating procedures)
2. Periodic testing and maintenance
3. Corrosion monitoring
4. Oxygen- air source control
5. Energy- ignition source controls
6. Equipment and design controls
7. Detection and suppression systems
8. Operating plans and practices
9. Fire Prevention and Protection Measures
10. Internal and external audits

➢ **Standard operating procedures**

A well defined SOPs are kept in practice and regularly updating of SOPs are carried out by consulting with the field operators, area managers, shift in charge, technical services and contractor employees and problems faced in performing their regular jobs taken as consideration.

➢ **Periodic testing and maintenance:**

All the critical equipment i.e. pressure relief valves, pumps, temperature and pressure controllers are periodically maintained by the maintenance department.

➢ **Oxygen- air source control:**

1. Inert gas purging
2. Seals and gaskets (double gaskets)
3. Ventilation
4. Inert gas blanket

➢ **Energy- ignition source controls:**

1. No mobile phones are used
2. Spark arrestors are fixed at all ignition sources
3. Authorised vehicles movement with spark arrestor.
4. Grounding and bonding
5. Elimination of open flames

6. Explosion proof electrical equipment
7. Area classification.

➢ **Equipment and design controls:**

1. Equipment design specifications
2. Equipment layout
3. Access control
4. Emergency shutdown and controls

➢ **Detection and suppression systems:**

1. Gas and fire detection equipment
2. LEL sensors
3. Warning and alarm system

➢ **Operating plans and practices:**

1. Site specific operating procedure
2. Codes of practice and IRPs
3. Worker training and education
4. Pre- start up safety review
5. Safe work permit system
6. Management of change

➢ **Internal and external audits:**

Internal audits should be conducted by internal auditing teams and external audits are conducted by third party

Fire Prevention & Protection Measures:

1. Passive System – Preventive systems

2. Active System - Protection systems

Fire prevention system (FPS) are classified as -

- Fixed FPS
- Semi Fixed FPS

- Portable FPS

➢ **Fixed FPS**

- Hydrants
- Monitors (Water, Water cum Foam Monitors)
- Risers
- Medium Velocity Spray System / Deluge Valves
- Fire & Gas Detection/Alarm System
- Fire Water Pumps & Fire Water Network
- Jetty Tower Monitor System

➢ **Semi Fixed FPS** Semi Fixed Foam Pourer System

➢ **Portable FPS**

- Extinguishers (DCP & Co2 Type)
- Hoses / Branches
- Fire Buckets
- Portable Monitors
- Foam Trolley
- Trailor Fire Water Pumps
- Fleet of Fire Tenders viz. Foam Tenders, Foam Nurser, DCP Tender & Water Tankers

➢ **First Aid Fire Fighting Equipment**

- Extinguishers (DCP & Co2 Type)
- Hoses / Branches
- Fire Buckets
- Foam Trolley

Emergency controls:

1. Onsite emergency Management Plan (OSEMP)
2. Emergency fire control equipment
3. Emergency escape equipment
4. Emergency escape routes

Fire and explosion hazard Management (FEHM)

FEHM Philosophy:

What a company believes. Its approach to hazard management and what risk it is willing to accept.

FEHM Process:

This is the company's overall, systematic approach to identifying, reducing and managing hazards. It defines how and when a company plans to execute its philosophies.

- **The overall strategic approach the company establishes for managing fire and explosion hazards.**
  - Hazard/ risk assessment
  - Inherently safe design
  - Assigned responsibilities
  - Process safety management
  - Education and training
  - Safety management systems
  - Site specific prevention planning
  - Communication

- **Stages of a fire and explosion hazard management process:**

Stage1. Assess fire and explosion hazards for planned operations

Stage2. Identify need for site specific fire and explosion prevention plan

Stage3. Evaluate and choose fire and explosion control measures

Stage4. Develop and implement fire and explosion prevention plan

Stage5. Monitor effectiveness and revise process as needed

Fire and explosion prevention plans:

These concise plans document the protocols required for specific operation. They show how the FEHM philosophy and process will be applied to a specific job and work site.

- **Prevention plans:**

  The specific measures that determine how the FEHM process is implemented.

- **Prevention barriers and controls:**

  System and equipment design

  Layout and spacing

  Equipment inspection and maintenance

  Operating procedures

- **Protective and emergency controls:**

  Gas and fire detection

  Emergency controls and shutdowns emergency response

  Equipment and procedures

  Fire protection systems

4.20 CONCLUSION

The advanced QRA Study conforming to International and National standards, Guidelines and Codes of practices as applicable shows the full characteristics of MCAS Scenario and Comprehensive recommendations made should be implemented. These requirements need to be built in to EMP and Mock drills and training organized for prevention and managing emergencies to ensure highest standards of safety.

CHAPTER-5:

Excel Software development:

The Excel based software for QRA0-Study of LPG-Bullet is given below:

LPG-Flashing and Liquid Pool Radius:

Pool Radius computation:

Sump Depth	Cross wind Sump width (CW) (m)	Down wind Sump Length (DW) (m)	Effective Pool Radius (PR) (m)	LPG Pool Depth (PD) (m)
2.00	30.00	50.00	21.85	1.93

LPG-Liquid Leak Flashing:

Given data											
Quantity of LPG (Q) Leaked (Kg)	Mol. Wt (MW)	Density (D) of LPG at Storage Temp. (Kg/m3)	Storage Pressure (Kg/cm2)	Specific Heat (Cp) of LPG (Cal/g Deg. C)	Storage Temp. (To) of LPG (Deg. C)	Final Temp (Tv) after Flashing (Deg. C)	Latent heat (Hv) of vaporization of LPG (Cal/g)	Saturated Vapour Pressure (SVP) of LPG at Storage Temp. (Kg/cm2)	Substrate Temperature (ST) Deg. C)	Substrate Constant for 1-Min-rapid Evaporation (MN1)	Substrate Constant for Slow & Steady Evaporation (SS)
5000	44.46	597	10	0.549	25	-33	102.1	1	25	0.00075	0.015

Results											
Flash Fraction (ff) (Out of 1)	Mass Flashed (mv) (Kg)	Quantity entrained (me) in Flashed LPG (Kg)	Fraction Entrained (fe) (Kg)	Total Fraction Flashed+ Entrained (Tff) (Out of 1)	Total Quantity Flashed+ Entrained (mve) (Kg)	Quantity of Liquid (ml) left after flashing forming Liquid Pool (Kg)	Volume of Liquid (vlp) forming Liquid Pool (m3)	One Min. Rapid Pool Evaporation (rpev) due to heat transfer from earth (Kg)	Quantity left (mlrpev) after One Min. rapid Pool Evaporation (Kg)	Rate of Slow and Steady evaporation (ssv) due to wind and heat conduction from earth (Kg/s)	Time required (tm) for Evaporation of LPG in pool after One Min. Rapid Evaporation (Hrs)
0.3659781	1829.89	274.48	0.05	2104.37	2104.37	2895.63	4.85	371.43	2524.20	2.13	1.50

Formula for Flashing:		Unit
ff (Flash Fraction) =	Cp*(To-Tv)/Hv	Out of 1
mv (Mass of LPG Flashed) =	ff*Q	Kg
fe (Fraction Entrained) =	me/Q	Out of 1
Tff (Total Fraction Flash+Entrain) =	Q/(mv+fe)	Out of 1
mve (Total mass Flash+Entrain) =	Q*(mv+fe)	Kg
ml (Mass left after flash) =	Q-mve	Kg
vlp (Volume of liquid forming Pool =	ml/D	m3
mv1 (Mass vaporized in 1-Min) =	(((MN1*(((ST-Tv)^2)))/Hv)*((CW*100*DW*100)+((2*CD*100+2*DW*100)*PD)))/1000	
mlrpev (Mass left after 1-Min Rapid Vaporization =	Q-	Kg

M

v1

ssv (Rate of Slow and Steady vaporization =			(SS*(ST-Tv)/Hv)*(DW*100*CW*100+((2*DW*100+2*CW*100)*PD))/(60*1000)

Compute Pool fire

Other Variables used in Computations:

Name of liquid = LPG			brate = mass burning rate in kg/m2/s
Vinfinity =	0.73	A Const.	length = length or height of fire
K1 =	0.019	A Const.	maxdia = maximum diameter of fire
svlk=	0.027	A Const.	dstmxdia = Distance of max. diameter of fire from base of fire.
wnd is Wind velocity (m/s) =	2	m/s	flmcntht = Flame center height.
pooldia is 2*PR Pool diameter (m) =	43.69	m	alph = Tan/Cos of flame tilt angle
htsml is Height of simulation (m) =	1	m	alph1 = a value derived from alph
D is Liquid density (kg/m3) =	597	kg/m3	q = Heat flux
AD is airdnsity is Air density (kg/m3) =	1.12928	kg/m3	mmax =/Max IHR at flame center height
AV is Air viscosity (kg/m.s) =	0.0001812	kg/m.s	ihr = Max. ihr at ht simulation
VD is Density of fuel vapour at B.Pt. (kg/m3) =	2.2577	kg/m3	tang = flame tilt angle due to wind.
poolht is Pool height (m) =	1	m	

molwt is Molecular Wt.=	44.46	wrt Hydrogen
dstforihr is dist. for IHR computation (m) =	1	m
brate =((vnf/(100.0*60.0))*(1.0-exp(-vlk*100.0*2*PR)))* D	0.072635	Kg/s

*length=42.0*pooldia*((brate/(airdnsity*sqrt((9.81*2*PR))))^0.6)*	57.42	m
mxdia=length/2	28.71	m
dstmxdia=0.61*length	35.02	m
flmcntht=dstmxdia+poolht	37.02	m
alph=3.2*((mxdia*wnd*airdnsity/airvscosity)^0.07)*((wnd*wnd/(mxdia*9.81))^0.7)*((liqdnsity/1.2928)^-0.6)	0.000511174	A const
fldsthtsml is Flame Dist from Ht. Simul=flmcntht-htsml	34.02	m
area=(11.0*mxdia/14.0)*(4.0*length+mxdia)	5828.23	m2
q is Heat Flux=141.84*(1.0-EXP((-0.055*mxdia/0.3048)))*0.048 *sqrt(molwt)	45.14	KW/m2
ki=((((fldsthtsml^2.0)+(mxdia/2+dstforihr^2.0)))^0.5)	34.25	Inter.Value
alph1=(sqrt((1.0+4.0*(alph*alph)))-1.0)/(2.0*alph)	0.000511174	A Const.
tang is Tilt angle=asin(alph1)	0.000511174	Deg
maxihr is Max IHR=q*area*7.0/(88.0*((mxdia/2.0)+dstforihr)*((mxdia/2.0)+dstforihr))	88.77	KW/m2

Formula for Flashing:

		Unit
ff (Flash Fraction) =	Cp*(To-Tv)/Hv	Out of 1
mv (Mass of LPG Flashed) =	ff*Q	Kg
fe (Fraction Entrained) =	me/Q	Out of 1
Tff (Total Fraction Flash+Entrain) =	Q/(mv+fe)	Out of 1
mve (Total mass Flash+Entrain) =	Q*(mv+fe)	Kg
ml (Mass left after flash) =	Q-mve	Kg
vlp (Volume of liquid forming Pool =	ml/D	m3

mv1 *(Mass vaporized in 1-Min)* = (((MN1*(((ST-Tv)^ 2)))/Hv)*((CW*100*DW*100)+((2*CD*100+2*DW*100)*PD)))/1000

mlrpev (Mass left after 1-Min Rapid Vaporization = Q-Mv1 Kg

ssv (Rate of Slow and Steady vaporization = (SS*(ST-Tv)/Hv)*(DW*100*CW*100+((2*DW*100+2*CW*100)*PD))/(60*1000)

Compute Pool fire

Given data

Other Variables used in Computations:

Name of liquid = LPG			brate = mass burning rate in kg/m2/s
Vinfinity =	0.73	A Const.	length = length or height of fire
K1 =	0.019	A Const.	maxdia = maximum diameter of fire
svlk=	0.027	A Const.	dstmxdia = Distance of max. diameter of fire from base of fire.
wnd is Wind velocity (m/s) =	2	m/s	flmcntht = Flame center height.
pooldia is 2*PR Pool diameter (m) =	43.69	m	alph = Tan/Cos of flame tilt angle
htsml is Height of simulation (m) =	1	m	alph1 = a value derived from alph
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VD is Density of fuel vapour at B.Pt. (kg/m3) =	2.2577	kg/m3	tang = flame tilt angle due to wind.
poolht is Pool height (m) =	1	m	
molwt is Molecular Wt.=	44.46	wrt Hydrogen	
dstforihr is dist. for IHR computation (m) =	1	m	

brate =((vnf/(100.0*60.0))*(1.0-exp(-vlk*100.0*2*PR)))* D	0.072635	Kg/s
length=42.0*pooldia*((brate/(airdnsity*sqrt((9.81*2*PR))))^0.6)	57.42	m
mxdia=length/2	28.71	m
dstmxdia=0.61*length	35.02	m
flmcntht=dstmxdia+poolht	37.02	m
alph=3.2*((mxdia*wnd*airdnsity/airvscosity)^0.07)*((wnd*wnd/(mxdia*9.81))^0.7) *((liqdnsity/1.2928)^-0.6)	0.000511174	A const
fldsthtsml is Flame Dist from Ht. Simul=flmcntht-htsml	34.02	m
area=(11.0*mxdia/14.0)*(4.0*length+mxdia)	5828.23	m2
q is Heat Flux=141.84*(1.0-EXP((-0.055*mxdia/0.3048)))*0.048 *sqrt(molwt)	45.14	KW/m2
ki=((((fldsthtsml^2.0)+(mxdia/2+dstforihr ^2.0)))^0.5)	34.25	Inter.Value
alph1=(sqrt((1.0+4.0*(alph*alph)))-1.0)/(2.0*alph)	0.000511174	A Const.
tang is Tilt angle=asin(alph1)	0.000511174	Deg
maxihr is Max IHR=q*area*7.0/(88.0*((mxdia/2.0)+dstforihr)* ((mxdia/2.0)+dstforihr))	88.77	KW/m2

Distance (m)	Max. UHR	
1	88.77	
2	78.25	
3	69.49	
4	62.12	IHR >=37.5: 100% Fatality and Limit of 1-Min to ignite wood without conbtact with Fire
5	55.87	
6	50.51	
7	45.89	
8	41.88	
9	38.37	
9.27	37.50	
10	35.28	
11	32.56	
12	30.13	IHR <37.5 and >25: Min to ignite wood (without flame contact). 100% fatal in 1 min. Significant injury in 10 Sec.
13	27.97	
14	26.03	
14.58	25.00	

15	24.29	
16	22.71	
17	21.29	
18	19.99	
19	18.81	
20	17.73	IHR <=25 and >12.5: Min to ignite wood (with flame contact). 1% fatal in 1 min. First degree burn in 10 Sec.
21	16.74	
22	15.83	
23	15.00	
24	14.23	
25	13.51	
26.56	12.50	
58	4.00	IHR>4 & <=12.5 means Pain after 20 Secs. Blistering unlikely.
100	1.60	IHR 1.6 is equivalent to Solar Radiation is safe

Note: You have to manually adjust distances to get IHR values at 37.5, 12.5, 4 and finally 1.6

Distance	Dose	Distance	Dose
100	96.76	50	48.38
99	95.79	49	47.41
98	94.83	48	46.45
97	93.86	47	45.48

96	*92.89*	*46*	*44.51*
95	91.92	45	43.54
94	90.96	44	42.57
93	89.99	43	41.61
92	89.02	42	40.64
91	88.05	41	39.67
90	87.08	40	38.70
89	86.12	39	37.74
88	85.15	38	36.77
87	84.18	37	35.80
86	83.21	36	34.83
85	82.25	35	33.87
84	81.28	34	32.90
83	80.31	33	31.93
82	79.34	32	30.96
81	78.38	31	30.00
80	77.41	30	29.03
79	76.44	29	28.06
78	75.47	28	27.09
77	74.51	27	26.13
76	73.54	26	25.16
75	72.57	25	24.19
74	71.60	24	23.22
73	70.64	23	22.25

72	69.67	22	21.29
71	68.70	21	20.32
70	67.73	20	19.35
69	66.76	19	18.38
68	65.80	18	17.42
67	64.83	17	16.45
66	63.86	16	15.48
65	62.89	15	14.51
64	61.93	14	13.55
63	60.96	13	12.58
62	59.99	12	11.61
61	59.02	11	10.64
60	58.06	10	9.68
59	57.09	9	8.71
58	56.12	8	7.74
57	55.15	7	6.77
56	54.19	6	5.81
55	53.22	5	4.84
54	52.25	4	3.87
53	51.28	3	2.90
52	50.32	2	1.94
51	49.35	1	0.97
		Total Dose	3652.71

ftprbt=2.56*log(pow(1000.0*foo.dose,(4.0/3.0)))-14.9

Injprbt=3.0186*log(pow(1000.0*foo.dose,(4.0/3.0)))-38.48

PROBIT Value (Y)		**%Fatality**	
Fatality PROBIT	**4.94**	**27.61**	
Fatality Area m2=Fatality distance^2*3.14159		**1134.11**	**m2**
No. of Employees Exposed		**5.67**	
Absolute fatality for a Population density of 50/Ha		**1.57**	

PROBIT TO % fatality

```
if( prb>8.09)  result=100.0;
if(prb<=5.0)  result=exp((prb-1.865)/.7843);
if( prb>5.0 && prb<=8.09) result=100-exp((8.135-prb)/0.7843);
```

Frequency of catastrophic failure of LPG-Bullet:

Frequency is determined by magnitude-Frequency relationship

General Equation for Magnitude (Q) Vs Frequency (F): Log(Q) = AxLog(F)+B

Transposing for Frequency: Frequency (F) =	**(10.0^log(Quantity in MT)/A-B/A)*0.0001**	**0.000123319**	**Per Plant Year**

Quantity in MT =	**5**
Const-A =	**-1**
Const-B =	**0.79**

Chances of Ignition of LPG Spill Pool: Determined by Wiekema studies described in "Major Industrial Hazards" by John Withers.

Immonsite=releasesize/1703.17^(1/2.246)	**0.1821**
if(immonsite>=1.0) Immonsite=0.99;	
if(immonsite<0.0) immonsite=immonsite*(-1.0);	
if(AND(immonsite>0.0),immonsite<1.0), immonsite=immonsite)	
delay onsite=releasesize/11353.2^(1/2.5178)	**0.1226**
if(delay onsite>1.0) delay onsite=1.0;	
if(delay onsite<0.0) delay onsite=delay onsite*(-1.0);	
if((immonsite+delayonsite)>1) delay onsite=1-immonsite;	
Chances of no-ignition=1-(immediate ignition+delayed ignition)	**0.6953**
Combined ignition chance to cause fire=	**0.3047**
Net Frequency of LPG-Bullet failure with ignition forming fire=LPG-Bullet failure frequency*chances of ignition	**0.000037571**

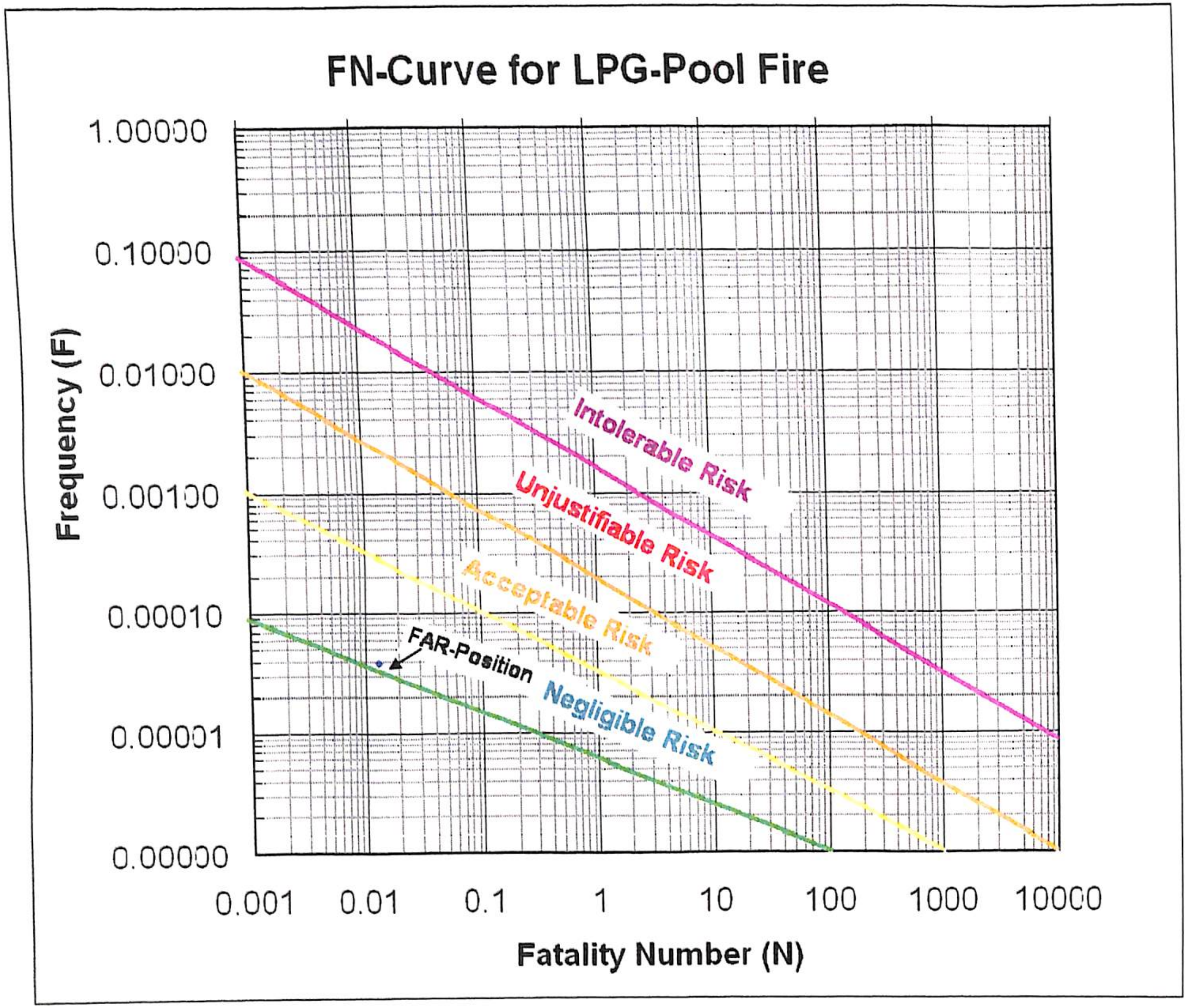
Fatality Accident Rate (FAR): Showing Risk of fatality to Employees.

FAR corresponds to Risk of fatality among 1000 people likely to be exposed to a specific work hazard during an active work life of 40 years, 300 days covering a single shift of 8-hours. This means 96,000,000 hours taken as 100,000,000 hours (i.e. 10^8) / (24 hrs. Per day).(365 days per year) = 11415 years of exposure or say 11000 years:

	FAR Value	**FAR Unit**

FAR= 10000000/(No. Hours worked/year*No. Exposed)*SUM(Frequency*No. Fatal in each MCLS)	0.012969091	Employees Fatal in 10^8 years of exposure

Frequency (F) Vs Fatality Number (N) position:



REFERENCES

1. Manual of EHS management by Dr. Ram S. Hamsagar.
2. Hydrocarbon process safety by J.C Jones.(chap 2&3).
3. Chemical process safety fundamental and application
   By-Daniel A Crowl and Joseph F Louvar.
4. OISD-STD-158(Recommended practices on Storage and Handling of Liquified Petroleum Gas.
5. Centre for chemical process safety (Fire Hazard Analysis).

Appendix 1

MATERIAL SAFETY DATA SHEET OF LPG (As given in OISD-114)

TABLE-1

1 CHEMICAL IDENTITY

Chemical Name : LIQUEFIED PETROLEUM GAS	Chemical Classification : Hydrocarbon Mixture	
Synonyms: LPG, Propane, Butane, Propylene, Purofax, Bottled Gas.	Trade Name : LPG	
Formula C_3H_8, C_4H_{10} (Mixture)	C.A.S.NO. 68476-85-7	UN. No. 1075
Regulated Identification	Shipping Name: Petroleum Gases, Liquefied. Codes/Label : Flammable, Class 2 Hazardous waste I.D. No: 5	

HAZCHEM Code : 2 W E

HAZARDOUS INGREDIENTS		C.A.S.NO.	HAZARDOUS INGREDIENTS		C.A.S.NO.
1.	Propane	74-98-6	3.	Propylene	115-07-1
2.	Butane	106-97-8	4.		

2. PHYSICAL AND CHEMICAL DATA

Boiling Point/Range °C	> -40	Physical State : Gas at 15 °C and 1 atm.	Appearance : Colourless
Melting / Freezing Point °C	Not Pertinent	Vapour pressure @ 35°C Not available mm Hg.	Odour: Mercaptan added as an odouriser
Vapour Density	1.5	Solubility in water @ 30°C	Others: Soluble in Organic Solvents.

(Air = 1)	Slight	Alcohol
Specific Gravity (Water = 1)	0.51-0.58 at 50°C	pH Not pertinent

3.FIRE AND EXPLOSION HAZARD DATA

Flammability (OC)	Yes	LEL	1.9%	Flash Point °C	-
TDG Flammability	2	UEL	9.5%	Flash Point °C	- 104.4 (CC)

Auto ignition Temperature °C	466.1 Propane. 405 Butane
Explosion Sensitivity to Impact	Not established
Explosion Sensitivity to Static Electricity	May explode.
Hazardous Combustion products	Emits CO. CO_2
Hazardous Polymerization	Does not occur

Combustible Liquid	No	Explosive Material	No	Corrosive Material	No
Flammable Material	Yes	Oxidiser	No	Others	
Pyrophoric Material	No	Organic Peroxide	No		

4. REACTIVITY DATA

Chemical Stability	Stable
Incompatibility with other material.	Strong Oxidisers.
Reactivity	No reaction with common materials but may react with oxidising materials.
Hazardous Reaction Products	Not available.

5. HEALTH HAZARD DATA

Routes of Entry	Inhalation. Skin.					
Effects of Exposure/ conc.	Concentration in air greater than 10% causes dizziness in few minutes. 1%					
Symptoms	Gives the same symptoms in 10 mts. High concentration causes asphyxiation. Liquid on skin causes frostbite.					
Emergency Treatment	If inhaled, remove the victim to fresh air area. Provide artificial resuscitation. Skin: Remove the wetted clothes & wash the affected area with plenty of water. Eyes: Flush with plenty of water for 15 mins. Seek medical aid immediately.					
$L.D_{50}$ (Oral-Rat)	Not listed	mg/kg		$L.D_{50}$		
Permissible Exposure Limit	Not listed	ppm	Not listed mg/m³	Odour Threshold	5000 to 20000 ppm	mg/m³
TLV (ACGIH)	1000 ppm	1800 mg/m³		STEL	Not listed ppm	Not listed mg/m³
NFPA Hazard Signals	Health	Flammability	Reactivity/Stability	Special		
	1	4	0			

6. PREVENTIVE MEASURES

Personal Protective Equipment.	Avoid contact with liquid or gas. Provide hand gloves, safety goggles, gas mask, protective over-clothing and shoes.
Handling and Storage Precautions	Keep in tightly closed cylinders in a cool, well ventilated area, away from heat, flame, sparks.

7. EMERGENCY AND FIRST AID MEASURES

FIRE	Fire Extinguishing Media	CO_2 . Dry Chemical Powder, Water Spray.
	Special Procedure	Keep the containers cool by spraying water if exposed to fire or heat.
	Unusual Hazards	If not cooled sufficiently, containers will explode in fire.

EXPOSURE	First Aid Measures	If inhaled, remove the victim to open air area & artificial resuscitation may be provided if required. If skin is affected with the liquid, remove the clothing & wash the affected area with plenty of water. Seek medical aid.
	Antidotes/Dosages	Not available.
SPILLS		
	Steps to be taken	Shut off leaks if without risk. Warn everybody that air mixture is explosive.
	Waste Disposal Method	Allow gas to burn under control.

Note: ***CO_2 now not permitted as it produces high static charge. NFPA recommends that Flammable Gas fires should not be normally extinguished as it leads to explosive vapour cloud formation. It is desirable to shut off isolation valves and let the residual gas burn.***

8. ADDITIONAL INFORMATION

Avoid contact with oxidisers. Olefinic impurities may lead to narcotic effect or it may act as a simple asphyxiant. A very dangerous hazard when exposed to heat or flame. If fire is big, keep surrounding areas cool by spraying water.