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Preventing Catastrophic Incidents in Chemical Process Industries with Help of Process Hazard Analysis-Experiment on Hydrogen Manufacturing Unit of Petroleum Refinery

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Abstract: *The chemical process industry is subject to various federal and local regulations and requirements that are challenging to meet and resource intensive. Time and human factors often lead to a "Check Box" mentality where requirements are fully complied with "On Paper" with little or no emphases on quality of compliance. Occupational Safety and Health Administration's (OSHA) Process Safety Management (PSM) requirements are often exposed to this "check box" mentality, especially the Process Hazard Analysis (PHA) element which is the engine that drives and affects the whole PSM program. Poor implementation of PHA affects mechanical integrity, operating procedures, training, and emergency response; and is considered a root cause of most major incidents. Unfortunately, poor quality PHAs are widespread, hard to identify and can be more dangerous than conducting no PHA at all since it may provide a false sense of safety. Unfortunately, existing literature as well as recognized and generally accepted good engineering practices (RAGAGEP) do not provide sufficient guidelines for assessing PHA quality. The guidelines proposed in this thesis help in properly auditing PHA studies by identifying traps and bad practices that most companies fall into when performing PHAs. Hydrogen is widely produced and used in the process industries with growing use in the public domain. While the former area of focus would obviously necessitate process safety considerations, the latter involves activities such as transportation in which occupational safety issues for individuals are paramount. The current research addresses this issue by identifying several areas of application in the hydrogen economy for three key process safety concepts: (i) inherently safer design, (ii) safety management systems, and (iii) the use of case studies. This study thus illustrates, by means of referenced examples, the transferable nature of key process safety concepts to various features of the emerging hydrogen economy. The primary thesis of this work is the notion that inherently safety design principles, Process Hazard Analysis Techniques, safety management systems, and lessons learned from case histories have broader implications for safety than would be apparent by restricting their use solely to the process industries.*

Keywords: Preventing Catastrophic Incidents

I. Introduction

Most accidents occur because we do not know how to prevent them but because we do not use the information that is available. The recommendations made after an accident are forgotten when the people involved have left the plant; the procedures they introduced are allowed to lapse, the equipment they installed is no longer used, and the accident happens again. It is vital to assess the process and the risks involved properly to prevent incidents occurring in any Process facility.A Process Hazard Analysis (PHA) is one of the most important elements of the Process Safety Management (PSM) Program. A PHA is an organized and systematic effort to identify and analyze the significance of potential hazards associated with the processing or handling of highly hazardous chemicals. The PHA analyzes the potential causes and consequences of fires, explosions and releases of toxic chemicals; and the equipment, instrumentation, human actions and other factors which might affect the process. The PSM Rule allows the use of several PHA methods. Most accidents do not occur because we do not know how to prevent them but because we do not use the information that is available. The recommendations made

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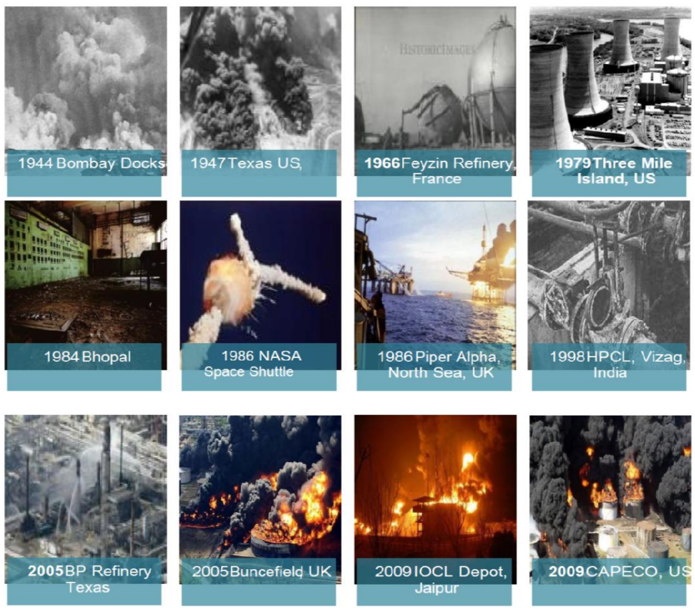
after an accident are forgotten when the people involved have left the plant; the procedures they introduced are allowed to lapse, the equipment they installed is no longer used, and the accident happens again. It is vital to assess the process and the risks involved properly to prevent incidents occurring in any Process facility.The Process Hazard Analysis (PHA) is a systematic approach for identifying, evaluating, and controlling the hazards of processes involving highly hazardous chemicals. It focuses on equipment, instrumentation, utilities, human actions, and external factors that might impact the process.

The organization must be performing an initial Process Hazard Analysis (hazard evaluation) on all processes covered by this standard. The process hazard analysis methodology selected must be appropriate to the complexity of the process and must identify, evaluate, and control the hazards involved in the process.



II. Literature Review

As a result of this constant conflict between safety and short-term financial goals, most literature available contains guidelines backed up by existing regulations. The issue is that most regulations are reactive, governmental, and/or legislative responses to major incidents or catastrophes. Thus, these regulations are not always comprehensive. Moderate or minor incidents do not always trigger a new regulation to control the risk, even if it had the potential to have much higher consequences. Another reason why regulations may not always be comprehensive is that creating a regulation requires enormous resources to ensure proper monitoring and enforcement, especially when a regulation applies to a whole country with small and big businesses. So, it may not always be practical to create a regulation. Therefore, the majority of PHA auditing knowhow exists in the form of company internal processes/procedures, or is embedded into the minds of experienced employees who do not always have the time to document or publish their knowledge. In addition, due to the qualitative nature of most of the available risk assessment techniques, PHAs prove to be often elusive and difficult to audit. Expansive than the natural expansive soil in its original state, before addition of the chemical stabilizers (Hunter 1988). Hence, in soils containing soluble sulfates, physical stabilization techniques may be more appropriate than chemical stabilization methods. A good example of risk assessment auditing guidelines resource which is based on existing regulations is the Guidelines for Auditing PSM Systems developed by the Center for Chemical Process Safety (CCPS). In this study contains guidelines on auditing Hazard Identification and Risk Analysis studies, mostly includes guidelines based on federal regulations such as OSHA and EPA regulations for PSM and RMP, respectively. Their developed guidelines do also incorporate state regulations such as New Jersey, California, and Delaware as well. However, they are not comprehensive enough and they do not focus on quality of implementation of PHA. They do give guidelines for auditing the overall performance of the PHA element implementation. For example, this resource does not adequately address the experience validation requirements of PHA team members and other sources of variance such as the inaccurate assessment of risk.

III. Hazard Evaluation

There are also requirements within legislation such as in the MSIHC Rules, PNGRB Rules, etc. requiring those companies handling hazardous materials to have in place an adequate Safety Management System (SMS) and to fulfil specified obligations. These requirements range from the preparation of Major Accident Prevention Policies to submission of detailed safety reports to a competent authority. IS 15656 (2006) Code of Practice gives detailed guidance on Hazard Identification and Risk Analysis for use in the Indian Industry. The OSHA regulation 29CFR 1910.119, for Process Safety Management in the USA mentions PHA as an integral element of such systems, advocating systematic techniques for the identification of hazards.

- Study 1: Concept Stage Hazard Review
- Study 2: FEED/Project Definition
- Study 3: Detailed Design Hazard Study
- Study 4: Construction Design Verification
- Study 5: Pre-Commissioning Safety Review
- Study 6: Project Closeout / Post Start-up Safety Review.

IV. Selection of Techniques

A successful hazard evaluation program requires tangible management support; sufficient, technically competent people (some of whom must be trained to use the hazard evaluation techniques); adequate, up-to-date information and drawings; and selection of the techniques (matched to the complexity and hazard of the process). Fortunately, a variety of flexible hazard evaluation techniques exist. Below is a simple listing of generally accepted techniques:

4.1 Qualitative Techniques

- Preliminary Hazard Analysis (PreHA)
- Checklist
- What-If Analysis
- What-If/Checklist Analysis
- 2 Guide Word Analysis
- Hazard and Operability (HAZOP) Analysis
- Failure Modes and Effects Analysis (FMEA)

4.2 Quantitative Techniques

- Layer of Protection Analysis (LOPA)
- Dow Fire and Explosion Index (F&EI)
- Dow Chemical Exposure Index (CEI)
- Fault Tree Analysis (FTA)
- Event Tree Analysis (ETA)
- Human Reliability Analysis (HRA)

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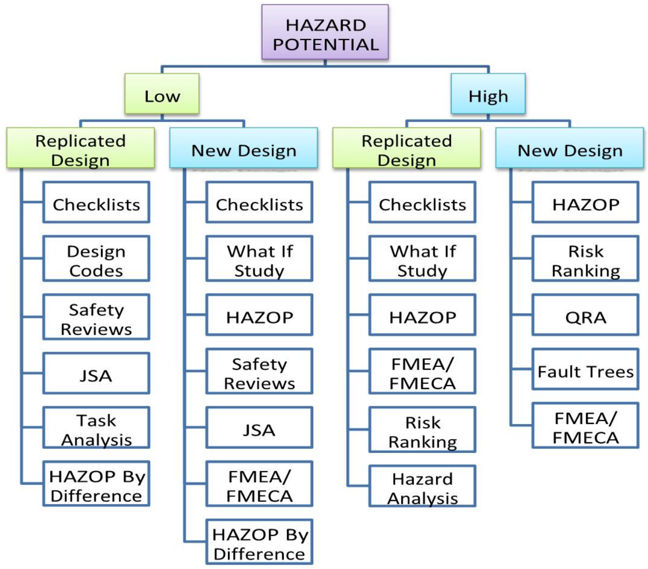
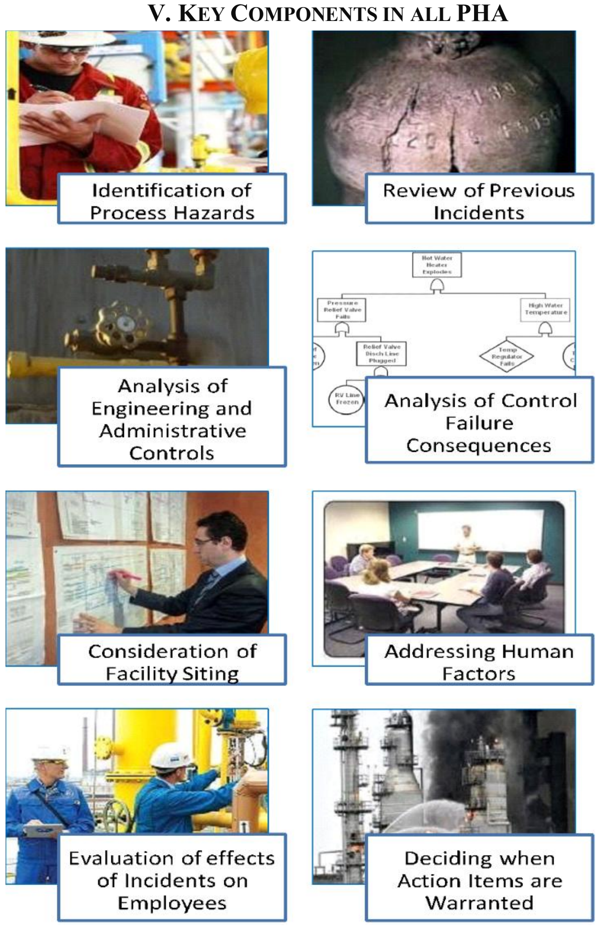


V. KEY COMPONENTS IN ALL PHA



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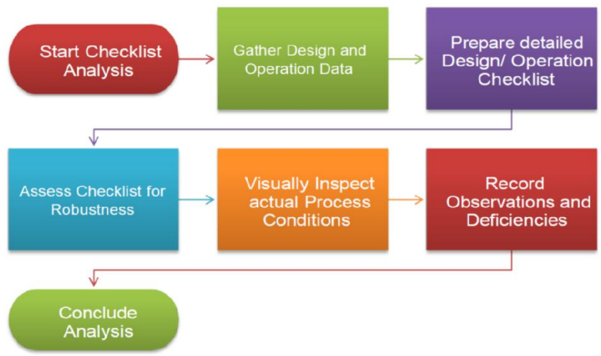
5.1 PHA Methods

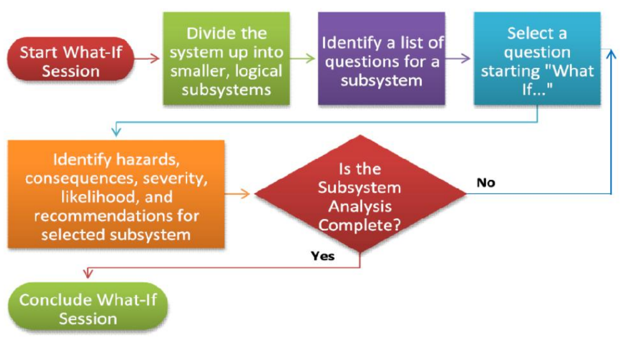
A. Checklist Analysis

A checklist analysis is used to verify the status of a system. The checklist analysis method is versatile, easy to use and can be applied at any stage in the life of a process.



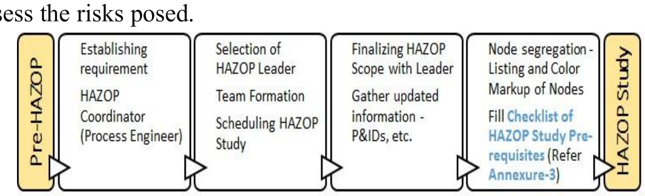
B. What-If Analysis

The purpose of a what-if analysis is to identify hazards, hazardous situations, or specific accident events that could produce an undesirable consequence. This analysis comprises experienced personnel brainstorming a series of questions, which begin with "What if…?". Each question represents a potential failure in the facility or mis-operation of the facility



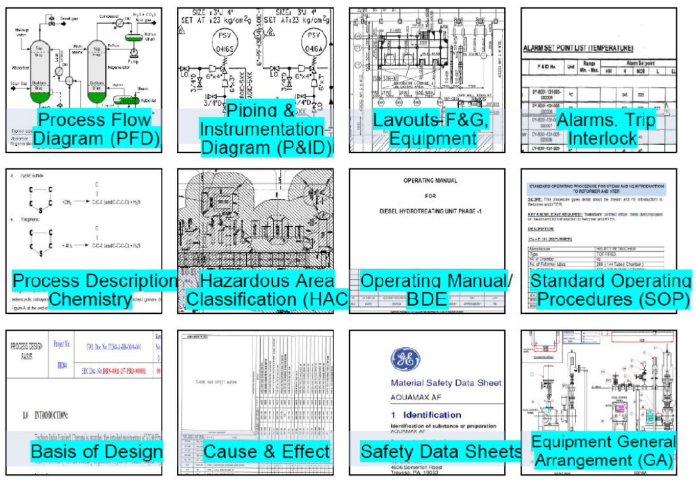
C. HAZOP Studies

HAZOP Study is a technique used to identify the potential hazards and operational problems critical to the plant design/ operational integrity, and assess the risks posed.



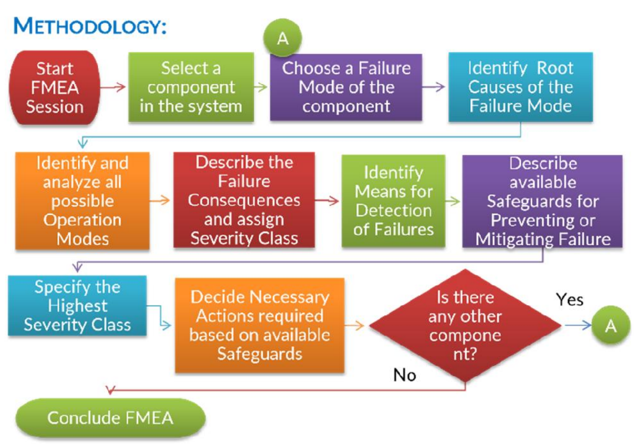
The basic concept behind HAZOP studies is that processes work well when operating under design conditions. When deviations from the process design conditions occur, operability problems and accidents can occur. A HAZOP Analysis addresses hazards and proble ms affecting operability. The HAZOP study method uses guidewords to ask questions about any potential deviation to the mode of operation, evaluating the related Causes and Consequences.

Essential documentation Required for HAZOP



D. Failure Modes and Effects Analysis (FMEA)

FMEA is a technique used to identify hazards/ ways in which a component/ system can fail to perform their design intention. A FMEA is used to examine each potential failure mode of a process to determine the effects of the failure on the system. A failure mode may be identified as a loss of function, a premature function, an out-of-tolerance condition, or a physical characteristic, such as a leak, observed during inspection. The effect of a failure mode is determined by the system's response to the failure



E. Fault Tree Analysis (FTA)

An FTA is a graphical, top-down analysis that starts with a hazardous event and works backwards to identify the causes of the preceding event. A Fault Tree is a visual logical model which is used to describe how a specific unwanted event (Top Event) in a system may be caused by the effects of a single failure or a combination of failures.

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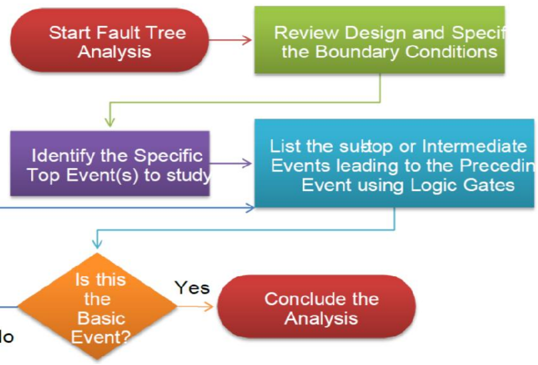
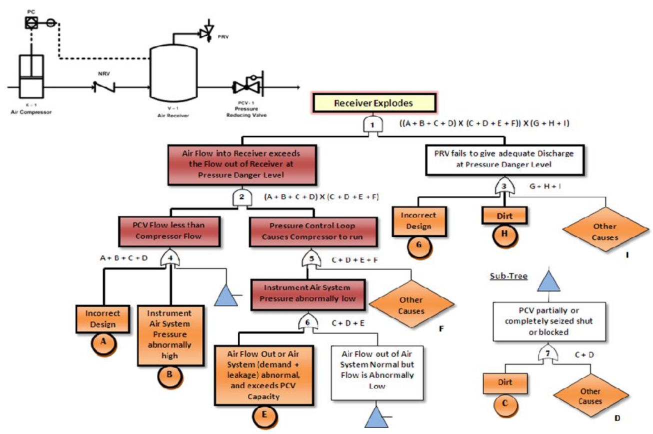
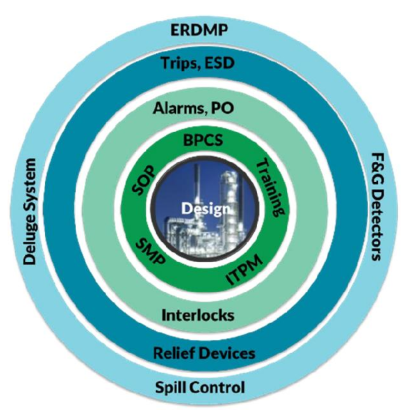




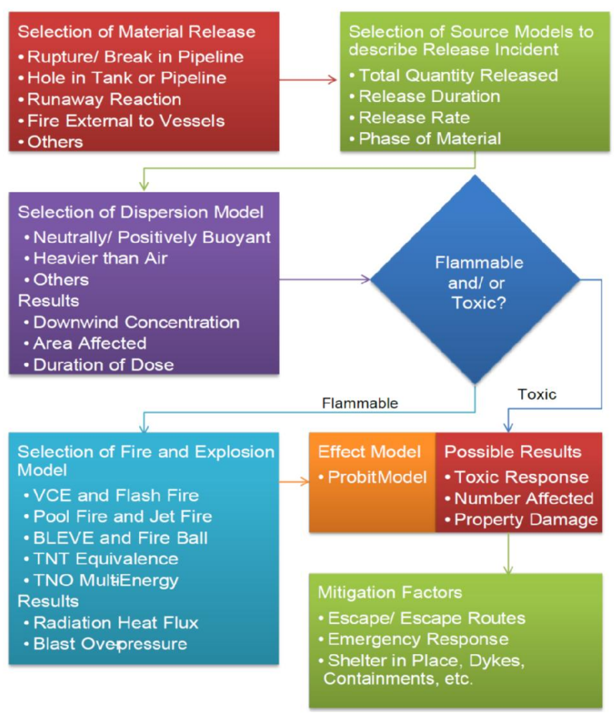
F. Layer of protection analysis (LOPA)

It is a simplified Risk Assessment Method. It provides a method for evaluating the risk of hazard scenarios and comparing it with the risk tolerance criteria to decide if existing safeguards are adequate, and whether additional safeguards are needed. The Protection Layers can be either Preventive or Mitigating. Preventive Layers act by avoiding an occurrence of the scenario, and include:

- Inherently safer design features;
- Active Physical Protection Devices, such as Relief Valves;
- Basic Process Control System; and
- Safety Instrumented Functions (SIF)



G. Consequence Analysis



H. Risk Criteria

Authority and Application	Maximum Tolerable Risk (per year)	Negligible Risk (per year)
VROM, The Netherlands (New plant)	1.0E-6	1.0E-8
VROM, The Netherlands (Existing)	1.0E-5	1.0E-8
HSE, UK (Existing hazardous plants)	1.0E-4	1.0E-6
HSE, UK (New Nuclear Plants)	1.0E-5	1.0E-6
HSE, UK (Substance transport)	1.0E-4	1.0E-6
HSE, UK (New housing near plants)	3 x 1.0E-6	3 x 1.0E-7
Hong Kong (New Plants)	1.0E-5	Not used

VI. Software Methodology

The proposed software tool consists of two separate parts with shared classes and databases. The first part is used for the actual simulation of the analyzed system. In this software module, the connection of our tool with the software methodology is established and when the simulation case is open and active, individual streams and operation units are checked for the possibility of performing a HAZOP study.

Advanced Software for Consequence Analysis

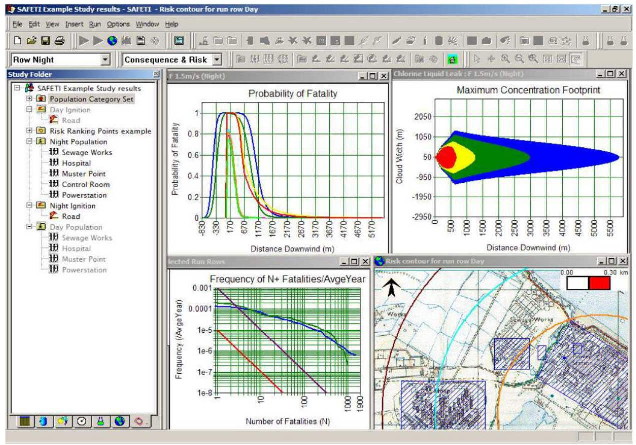
- Estimate the consequences of a release of a toxic or flammable material
- Model releases from; catastrophic ruptures, leaks, line ruptures, relief valves and rupture disks
- Models include; Multi-component mixtures, aerosol and pool formation, Jet & pool fires, BLEVE & vapor cloud explosion, toxic effects

6.1 Availability of Software

- DNV PHAST/PHAST
- SHELL FRED/ SHEPHERD
- PHA PRO (HAZID/HAZOP/ENVID)
- Exsilentia (IPF/SIL)
- Detect 3D
- PIPENET
- FLARE SIM
- FLARE NET
- MAROS
- HYSYS/UNISIM

6.2 What will it enable you to do?

- Use Multi Energy, Baker Strehlow Tang and BLEVE Blast models
- Define Regions of congestion/confinement
- Calculate location specific Overpressure
- Exceedance Frequency
- Define Building Types library
- Each Building type has specific vulnerability to overpressure, radiation and toxic effects
- Place buildings and insert Population of different categories within those buildings
- Define Areas and report risk by population category and/or area
- Assess Escalation frequency
- Calculate individual and societal risk using;
- Phast Consequence modelling
- Population density
- Ignition sources
- Accident frequency rates
- Wind rose data
- Output includes;
- FN Curves, Tabular Risk Ranking,
- Risk Contours



VII. EXPERIMENT

Process Hazard Analysis study for Hydrogen Manufacturing Unit by using QRA Technique Based on the QRA study for the Hydrogen Manufacturing Unit (HMU)

7.1 Objectives

- Quantify the level of individual fatality risks associated with the HMU unit.
- Demonstrate that the level of risks is in compliance with the UK HSE guidelines

7.2 Major Risk contributors LPG as feed

Large leak from the pipeline connecting to the vessel 22%
Medium leak from the pipeline connecting to the vessel 13%

7.3 Major Risk contributors Naphtha as feed

Large leak from the pipeline connecting to the vessel 13%
Medium leak from the pipeline connecting to the vessel 10%

7.4 Major Risk contributors Natural Gas as feed

Large leak from the Reactor 10 %
Medium leak from the Reactor 7%

7.5 Major Risk contributor's RF Gas as feed

Large leak from the reactor 10%

VIII. SCOPE OF STUDY

Verify the individual and societal risk levels in accordance with UK HSE criteria
Tabulation of the consequences in terms of:
Distances to radiation levels, Lower Flammability Limit (LFL) and explosion overpressure for different weather classes according to specific criteria classes

8.1 Basic of Hydrogen

Hydrogen is the first element in the periodic table, with chemical symbol H. It consists of one proton (a core unit of positive charge) and one electron (negative charge). It has atomic number 1 and atomic weight of 1.00794.u, being the lightest element on the periodic table

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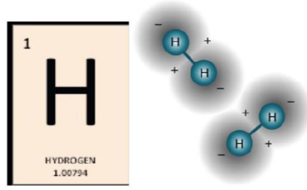
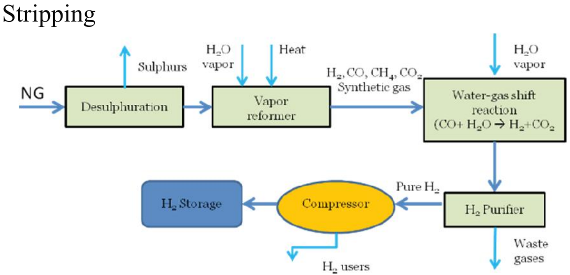


A. Hydrogen Applications

- Chemical Industry
- Automobile
- Laboratories
- Alternative Fuels etc.

B. Hydrogen Manufacturing process in Petroleum Refinery

- Feed Preparation
- Hydrogenation And Desulphurization
- Adiabatic Pre-Reforming
- Tubular Steam Reforming
- Heat Exchange Reforming (Hter)
- Shift Conversion
- Hydrogen Product Purification By Psa
- Steam Production By Waste Heat Recovery
- Process Condensate Stripping



C. Letter Code of Equipment Identification

- F: Fired Heaters
- BC: Air Heaters
- B: Steam Super Heaters
- BR: Waste Heat Boiler
- CA: Stack
- C: Towers
- R: Reactors
- E: Heat Exchanger Equipment (Including process gas boiler)
- EA: Air Coolers
- V: Process Vessels, Tanks and Accumulators

8.2 QRA Methodology

In a QRA, hazard identification uses similar techniques, but has a more precise purpose – defining the boundaries of a study in terms of materials to be modelled, release conditions to be modelled, impact criteria to be used, and identifying and selecting a list of failure cases that will fully capture the hazard potential of the facilities to be studied. Failure cases are usually derived by breaking the process system down into a larger number of sub- systems, where failure of any component

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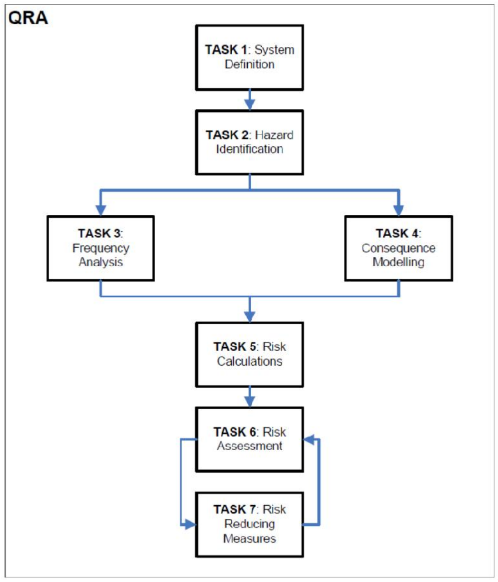
in the sub-system would cause similar consequences. In pipeline case, this can be performed by breaking the line into sections depending on availability of isolation valves along the line.



- QRA Approach
- Hazard Identification
- Consequence Modelling/PHAST Software

8.3 Frequency Analysis

A. Failure Case Scenarios

Following scenarios have been identified for the HMU from the PFD stream no., pressure, temperature is taken from the mass and energy balance sheet, elevation of all the equipment is measured from the Plot plan of HMU. The mass inventory is taken as the sum of static inventory and dynamic inventory. Dynamic inventory is calculated by multiplying flow rate (taken from mass & energy balance sheet) with isolation time which is considered as 15min

S.No.	Case Description	Associated Equipment	Stream number	Pressure (barg)	Temperature (deg C)	Phase	Inventory (m3)
1	LPG from BL to V-101	Interconnecting P/L, V-101	2005	9	40	Liquid	310.110
2	Naphtha from BL to V-102	Interconnecting P/L, V-102	2004	3	40	Liquid	243.011
3	Ng from BL to E-101A/S	Interconnecting P/L, E-101A/S	2010	36.5	40	Gas	15017.235
4	RFG from BL to E-101A/S	Interconnecting P/L	2000	36.5	40	Gas	14381.298
5	LPG from V-101 to E-101A/S	Interconnecting P/L, P-101A/S	2060	36.5	40	Liquid	19.64
6	Naphtha from V-102 to E-101A/S	Interconnecting P/L, P-102A/S	2060	36.5	40	Liquid	5436.574
S.No.	Case Description	Associated Equipment	Stream number	Pressure (barg)	Temperature (deg C)	Phase	Inventory (m3)
7	Interconnecting p/l from E-101A/S to R-101	Interconnecting P/L, R-101, E-102A/S	2060	35.5	380	Gas	5643.420
8	Interconnecting p/l from R-101 to R-103	Interconnecting P/L, R-102, R-103,E-104	2100	30.1	490	Gas	49260.695
9	Interconnecting p/l from R-103 to R-104	Interconnecting P/L, R-104	2150	29.4	421	Gas	13238.489
10	Interconnecting p/l from R-104 to R-105	Interconnecting P/L, R-105,E-105, E-106	2207	23.1	210	Gas	80980.544
11	Interconnecting p/l from R-105 to V-104	Interconnecting P/L, E-107, E-108,EA-101, E-109, V-104	2340	21.7	149	Gas	80729.931
12	Interconnecting p/l from V-104 to PSA unit	Interconnecting P/L	3000	21	40	Gas	64600.013
13	Interconnecting p/l from PSA Unit to product H2 to BL	Interconnecting P/L	4260	20	45	Gas	40702.089

B. Continuous Releases

If ignited immediately, a continuous release will form a jet fire. If ignition is delayed, a flammable cloud would be formed and drifted with the wind. In such situation, if the cloud is ignited (after some delays), a flash fire or Vapour Cloud Explosion (VCE) may result, depending upon the degree of congestion within area and energy strength of the ignition source.

C. Instantaneous Releases

An instantaneous release would result from catastrophic rupture of a storage vessel (such as the storage cylinders, the trailers etc.) or reactors. If ignition is immediate, a fireball may be formed depending on the nature of the material. If ignition occurs after some delay similar to continuous release, a flash fire or VCE may be the consequence.

List of Failure Cases

S.No.	Case Description	Associated Equipment	Hole sizes (mm)			
			Small	Medium	Large	Full bore rupture
1	LPG from BL to V-101	Interconnecting P/L, V-101	5	25	101.6	-
2	Naphtha from BL to V-102	Interconnecting P/L, V-102	5	25	100	203.2
3	Ng from BL to E-101A/S	Interconnecting P/L, E-101A/S	5	25	101.6	-
4	RFG from BL to E-101A/S	Interconnecting P/L	5	25	101.6	-
5	LPG from V-101 to E-101A/S	Interconnecting P/L, P-101A/S	5	25	101.6	-
6	Naphtha from V-102 to E-101A/S	Interconnecting P/L, P-102A/S	5	25	101.6	-
7	Interconnecting p/l from E-101A/S to R-101	Interconnecting P/L, R-101, E-102A/S	5	25	100	150
8	Interconnecting p/l from R-101 to R-103	Interconnecting P/L, R-102, R-103,E-104	5	25	100	150
9	Interconnecting p/l from R-103 to R-104	Interconnecting P/L, R-104	5	25	100	150
10	Interconnecting p/l from R-104 to R-105	Interconnecting P/L, R-105, E-105, E-106	5	25	100	150
11	Interconnecting p/l from R-105 to V-104	Interconnecting P/L, E-107, E-108,EA-101, E-109, V-104	5	25	100	150
12	Interconnecting p/l from V-104 to PSA unit	Interconnecting P/L	5	25	100	150
13	Interconnecting p/l from PSA Unit to product H2 to BL	Interconnecting P/L	5	25	100	304.8

Release Duration

Release duration of 3600 seconds is chosen for this study. This includes the time to detect, isolate and the subsequent blow down (if possible) of the node from which leak occurs. After the leak is detected and the section is isolated it is understood that no more inventory is entering the section.

Frequency Discussion

Estimation of the likelihood of occurrence of each of the failure cases modelled has been done based on historical failure frequencies of process equipment. The historical failure data are based on an extensive research on several failure frequency databases worldwide. The most reputable, comprehensive and appropriate data are selected for each of the equipment failure frequencies quoted. The failure frequency for associated piping has been taken from Leak software, failure frequency for process vessels, columns, heat-exchangers, pumps and filters.

8.4 Consequence Analysis

A. Consequence Assessment

For each defined failure case for the Hydrogen Manufacturing Unit, the consequence modelling is carried out to determine the potential effects of releases, the results of which are discussed in terms of hazard distances. The corresponding consequences in terms of flammable and explosive effects are modelled and analyzed by using PHAST RISK software version 6.54. The flammable consequences that may potentially arise from failure of an equipments or lines are:

- Pool Fire
- Jet fires;
- Flash fires;
- Fireball; and/or
- Explosions.

Pool Fire

The consequence analysis is performed using DNV proprietary software PHAST. PHAST is a consequence and impact assessment module integrated within DNV risk calculation software PHAST Risk. The following descriptions are based on the different hazard types modeled, which are jet fires, flash fires, vapor cloud explosions, pool fires. a Pool fire is represented by the thermal radiation envelope. Three levels of radiation are presented in this report, i.e.:

- 4 kW/m2; this level is sufficient to cause personnel if unable to reach cover within 20s; however, blistering of the skin (second degree burn) is likely; 0: lethality.
- 12.5 kW/m2; this level will cause extreme pain within 20 seconds and movement to a safer place is instinctive. This level indicates around 6% fatality for 20 seconds exposure.
- 37.5 kW/m2; this level of radiation is assumed to give 100% fatality.

Jet Fire

A jet fire may result from ignition of a high-pressure leakage of gas from process plants or storage tanks. Jet fires are characterized by a high momentum jet flame that is highly turbulent. The flame is lifted above the exit opening from which the gas is discharged generally at high pressure. This distance appears because the combustion process can only take place when the flow velocity is reduced sufficiently to allow stable combustion.

The extent of the consequence of a Jet fire is represented by the thermal radiation envelope. Three levels of radiation are presented in this report, i.e.:

- 4 kW/m2; this level is sufficient to cause personnel if unable to reach cover within 20s; however, blistering of the skin (second degree burn) is likely; 0: lethality,
- 12.5 kW/m2; this level will cause extreme pain within 20 seconds and movement to a safer place is instinctive. This level indicates around 6% fatality for 20 seconds exposure.
- 37.5 kW/m2; this level of radiation is assumed to give 100% fatality.

Flash Fire

A flash fire is the non-explosive combustion of a flammable vapour cloud resulting from a release of volatile material into the open air, which, after mixing with air, ignites. The flame initially propagates slowly, often 10m/s or less, and in the Shell Maplin, Sands experiments often was unable to overcome the wind speed to flash back to the source. However, where congestion or confinement exist, flame speeds can accelerate to hundreds of m/s and overpressure effects will result.particularly for materials that have high boiling points. Flash calculations were conducted to consider the vaporization of light components in the streams, especially for high pressure or high temperature process conditions. Flashed vapor and light component releases will behave as jets, with jet fire and vapor cloud impacts modelled in the same way as for gas releases

Vapour Cloud Explosion (VCE)

Due to the large volume of flammable materials and highly flammable material with higher proportion of the more volatile components, there is significant potential for Vapour Cloud Explosion Events (VCE) in case any ignition source is not available immediately. Maximum flammable fuel volume for prediction of explosionoverpressure effects estimated to be considerable based on flow rate, isolation time (15 mins), time for vaporization and probability of VCE scenario.

Toxic Consequences

In the event of a release of toxic material (eg.H2S or NH3) not being ignited, the concentration of material in the cloud is progressively reduced by dilution with air until the concentration is well below any toxic effects. Such Unignited releases do not directly affect the plant, but cloud affect people enveloped by the cloud. Distances to 3% fatality level, the IDLH concentration and the exposure limit have been calculated using the dispersion models.

Flammable Consequence Results for LPG

S.No	Node	Description	Accident Scenario	Release Rate & Duration	Event	Impact criteria	Consequence Distance(m) D 11m/s	B 3m/s	F 3m/s
1	LPG from BL to V-101	Interconnecting P/L, V-101	Small	0.398kg/s & 3600s	Flash fire	LFL (13987.7 ppm)	5.06	6.86	8.88
					Jet fire	37.5Kw/m2	9.11	10.82	10.79
						4Kw/m2	15.92	17.65	17.57
			Medium	6415.90kg/s & 27.13s	Flash fire	LFL (13987.7 ppm)	1273.6	2023.02	2194.06
					Jet fire	37.5Kw/m2	561.91	712.21	707.47
						4Kw/m2	935.53	1164.39	1148.12
					Pool fire	37.5Kw/m2	218.41	204.74	198.50
						4Kw/m2	346.51	364.53	350.03
			Large	1.0265E5kg/s & 1.70s	Flash fire	LFL (13987.7 ppm)	4307.31	1013.28	1066.97
					Jet fire	37.5Kw/m2	1697.81	1793.73	1886.34
						4Kw/m2	2713.9	2839.83	2951.1
					Pool fire	37.5Kw/m2	290.53	243.58	259.80
						4Kw/m2	449.68	431.82	443.19
			Catastrophic Rupture	-	Flash fire	LFL (13987.7 ppm)	465.13	739.72	956.76
					Jet fire	37.5Kw/m2	223.97	283.44	281.87
						4Kw/m2	382.82	475.41	469.99
					Pool fire	37.5Kw/m2	103.12	100.96	93.60
						4Kw/m2	124.52	149.86	145.10
					Explosion	0.3bar	572	922	1139
2	LPG from V-101 to E-101A/S	Interconnecting P/L,P-101A/S, E-101A/S	Small	0.777kg/s & 3600s	Flash fire	LFL (13972.4 ppm)	6.34	9.02	10.87
					Jet fire	37.5Kw/m2	11.51	13.47	13.47
						4Kw/m2	20.30	21.84	21.84
			Medium	19.43kg/s & 595.69s	Flash fire	LFL (13972.4 ppm)	82.14	109.80	125.07
					Jet fire	37.5Kw/m2	49.01	57.66	57.66
						4Kw/m2	86.69	95.06	95.06
			Large	320.96kg/s & 36.07s	Flash fire	LFL (13972.4 ppm)	354.49	503.99	523.88

S.No	Node	Description	Accident Scenario	Release Rate & Duration	Event	Impact criteria	Consequence Distance(m) D 11m/s	B 3m/s	F 3m/s
					Jet fire	37.5Kw/m2	156.94	189.98	190.86
						4Kw/m2	270.74	309.90	312.96
					Pool fire	4Kw/m2	91.26	75.26	75.26
					Explosion	0.3bar	425	552	560
3	Interconnecting p/l from E-101A/S to R-101	Interconnecting P/L, R-101, E-102A/S	Small	0.1414kg/s & 3,600s	Flash fire	LFL (13972.4 ppm)	2.12	2.43	2.49
					Jet fire	37.5Kw/m2	NR	NR	NR
						4Kw/m2	NR	4.82	4.84
			Medium	3.53kg/s & 3,600s	Flash fire	LFL (13972.4 ppm)	9.19	11.68	12.55
					Jet fire	37.5Kw/m2	20.31	20.40	23.12
						4Kw/m2	30.60	30.79	30.89
			Large	56.57kg/s & 3,600s	Flash fire	LFL (13972.4 ppm)	67.16	70.26	71.86
					Jet fire	37.5Kw/m2	70.02	71.12	86.62
						4Kw/m2	118.82	120.89	120.89
			Catastrophic Rupture	-	Flash fire	LFL (13972.4 ppm)	102.90	109.29	109.38
					Jet fire	37.5Kw/m2	98.95	98.89	118.93
						4Kw/m2	167.82	173.60	174.90
4	Interconnecting p/l from R-101 to R-103	Interconnecting P/L, R-102, E-104	Small	0.1033kg/s & 3,600s	Flash fire	LFL (14982 ppm)	1.77	1.99	2.11
					Jet fire	37.5Kw/m2	NR	NR	NR
						4Kw/m2	NR	3.74	3.74
			Medium	2.58kg/s & 3,600s	Flash fire	LFL (14982 ppm)	7.43	9.51	10.23
					Jet fire	37.5Kw/m2	19.65	17.38	17.44
						4Kw/m2	25.91	26.16	26.23
			Large	41.34kg/s & 3,600s	Flash fire	LFL (14982 ppm)	54.83	53.89	57.48
					Jet fire	37.5Kw/m2	76.36	62.45	62.37
						4Kw/m2	103.76	104.87	104.44
			Catastrophic Rupture	-	Flash fire	LFL (14982 ppm)	83.40	79.58	83.77
					Jet fire	37.5Kw/m2	62.30	87.15	87.18

S.No	Node	Description	Accident Scenario	Release Rate & Duration	Event	Impact criteria	Consequence Distance(m) D 11m/s	B 3m/s	F 3m/s
						4Kw/m2	98.73	150.98	151.97
5	Interconnecting p/l from R-103 to R-104	Interconnecting P/L,R-103, R-104	Small	0.0603kg/s & 3,600s	Flash fire	LFL (52785.3 ppm)	1.25	1.38	1.41
					Jet fire	37.5Kw/m2	NR	NR	NR
						4Kw/m2	NR	NR	NR
			Medium	1.508kg/s & 3,600s	Flash fire	LFL (52785.3 ppm)	5.32	6.23	6.61
					Jet fire	37.5Kw/m2	NR	NR	NR
						4Kw/m2	19.70	19.04	19.11
			Large	24.13kg/s & 3,600s	Flash fire	LFL (52785.3 ppm)	34.14	35.46	36.73
					Jet fire	37.5Kw/m2	46.92	60.53	46.91
						4Kw/m2	75.08	78.33	74.94
			Catastrophic Rupture	-	Flash fire	LFL (52785.3 ppm)	54.09	55.15	57.22
					Jet fire	37.5Kw/m2	65.09	84.16	64.79
						4Kw/m2	107.55	110.08	107.11
6	Interconnecting p/l from R-104 to R-105	Interconnecting P/L, R-105, E-105, E-106	Small	0.0463kg/s & 3,600s	Flash fire	LFL (51062 ppm)	1.63	2.07	2.18
					Jet fire	37.5Kw/m2	NR	NR	NR
						4Kw/m2	NR	NR	NR
			Medium	1.158kg/s & 3,600s	Flash fire	LFL (51062 ppm)	6.59	8.88	9.79
					Jet fire	37.5Kw/m2	NR	NR	NR
						4Kw/m2	17.80	16.51	16.59
			Large	18.52kg/s & 3,600s	Flash fire	LFL (51062 ppm)	50.51	49.92	53.04
					Jet fire	37.5Kw/m2	55.60	34.57	33.50
						4Kw/m2	69.53	64.17	64.10
			Catastrophic Rupture	-	Flash fire	LFL (51062 ppm)	75.69	72.14	74.86
					Jet fire	37.5Kw/m2	75.65	51.71	49.95
						4Kw/m2	96.72	91.06	90.77
7	Interconnecting p/l from R-105 to V-104	Interconnecting P/L, E-107,	Small	0.054kg/s & 3,600s	Flash fire	LFL (51974.6 ppm)	1.75	1.00	2.24
					Jet fire	37.5Kw/m2	NR	NR	NR

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S.No	Node	Description	Accident Scenario	Release Rate & Duration	Event	Impact criteria	Consequence Distance(m) D 11m/s	B 3m/s	F 3m/s
		E-108,EA-101, E-109,V-104				4Kw/m2	NR	NR	NR
			Medium	1.344kg/s & 3,600s	Flash fire	LFL (51974.6 ppm)	6.98	9.22	10.10
					Jet fire	37.5Kw/m2	NR	NR	NR
						4Kw/m2	18.55	16.92	16.98
			Large	21.50kg/s & 3,600s	Flash fire	LFL (51974.6 ppm)	57.53	56.30	60.84
					Jet fire	37.5Kw/m2	57.82	29.81	30.68
						4Kw/m2	71.49	64.67	64.75
			Catastrophic Rupture	-	Flash fire	LFL (51974.6 ppm)	90.79	85.14	90.96
					Jet fire	37.5Kw/m2	78.81	46.44	45.80
						4Kw/m2	99.06	91.35	91.06
8	Interconnecting p/l from V-104 to PSA unit	Interconnecting P/L	Small	0.054kg/s & 3,600s	Flash fire	LFL (51974.6 ppm)	1.79	2.18	2.27
					Jet fire	37.5Kw/m2	NR	NR	NR
						4Kw/m2	NR	NR	NR
			Medium	1.344kg/s & 3,600s	Flash fire	LFL (51974.6 ppm)	7.12	9.38	10.27
					Jet fire	37.5Kw/m2	NR	NR	NR
						4Kw/m2	18.70	17.06	17.11
			Large	21.89kg/s & 3,600s	Flash fire	LFL (51974.6 ppm)	60.39	58.13	63.13
					Jet fire	37.5Kw/m2	58.17	58.17	30.06
						4Kw/m2	71.93	65.17	65.09
			Catastrophic Rupture	-	Flash fire	LFL (51974.6 ppm)	97.68	90.75	97.15
					Jet fire	37.5Kw/m2	79.24	46.77	46.13
						4Kw/m2	99.64	91.93	91.63
9	Interconnecting p/l from PSA Unit to product H2 to BL	Interconnecting P/L	Small	0.0212kg/s & 3,600s	Flash fire	LFL (40000 ppm)	3.41	4.63	5.06
					Jet fire	37.5Kw/m2	NR	NR	NR
						4Kw/m2	NR	NR	NR
			Medium	0.531kg/s & 3,600s	Flash fire	LFL (40000 ppm)	20.28	19.26	21.03
					Jet fire	37.5Kw/m2	NR	NR	NR
						4Kw/m2	19.74	20.66	20.71
			Large	8.49kg/s & 3,600s	Flash fire	LFL (40000 ppm)	62.25	54.60	62.96
					Jet fire	37.5Kw/m2	61.23	42.47	42.50
						4Kw/m2	70.98	74.10	73.85
			Catastrophic Rupture	-	Flash fire	LFL (40000 ppm)	131.43	113.11	128.61
					Jet fire	37.5Kw/m2	156.46	111.18	111.08
						4Kw/m2	195.96	203.72	202.18

Flammable Consequence Results for Naphtha

S.No	Node	Description	Accident Scenario	Release Rate & Duration	Event	Impact criteria	Consequence Distance(m) D 11m/s	B 3m/s	F 3m/s
1	Naphtha from BL to V-102	Interconnecting P/L, V-102	Small	0.276kg/s & 3600s	Flash fire	LFL (10055.5 ppm)	4.54	5.84	8.10
					Jet fire	37.5Kw/m2	8.15	9.80	9.80
						4Kw/m2	13.95	15.87	15.81
					Pool fire	37.5Kw/m2	NR	14.10	11.54
						4Kw/m2	NR	27.19	28.39
			Medium	6.891kg/s & 3600s	Flash fire	LFL (10055.5 ppm)	44.91	64.07	68.93
					Jet fire	37.5Kw/m2	35.34	41.81	41.67
						4Kw/m2	60.56	68.29	67.85
					Pool fire	37.5Kw/m2	NR	NR	NR
						4Kw/m2	84.71	82.44	80.56
			Large	110.25kg/s & 1476.63s	Flash fire	LFL (10055.5 ppm)	111.95	174.10	207.99
					Jet fire	37.5Kw/m2	99.96	109.16	108.58
						4Kw/m2	171.83	181.58	179.83
					Pool fire	37.5Kw/m2	NR	NR	NR
						4Kw/m2	260.29	228.39	223.26
					Explosion	0.3bar	NH	235	281
			Catastrophic Rupture	-	Flash fire	LFL (10055.5 ppm)	162.61	247.88	310.87
					Jet fire	37.5Kw/m2	141.36	163.18	160.33
						4Kw/m2	241.13	273.41	267.55
					Pool fire	37.5Kw/m2	NR	NR	NR
						4Kw/m2	317.95	266.44	262.33
					Explosion	0.3bar	NH	315	358
2	Naphtha from V-102 to E-101A/S	Interconnecting P/L,P-102A/S, E-101A/S	Small	0.877kg/s & 3,600s	Flash fire	LFL (10060.8 ppm)	6.64	9.61	11.63
					Jet fire	37.5Kw/m2	12.37	14.51	14.57
						4Kw/m2	21.66	23.39	23.39
			Medium	21.933kg/s & 3,600s	Flash fire	LFL (10060.8 ppm)	84.66	113.54	132.45
					Jet fire	37.5Kw/m2	52.94	61.86	61.86
						4Kw/m2	93.58	101.52	100.77
			Large	362.36kg/s & 3,600s	Flash fire	LFL (10060.8 ppm)	362.08	524.25	559.94
					Jet fire	37.5Kw/m2	169.17	206.21	205.23
						4Kw/m2	291.53	338.41	335.03
					Pool fire	37.5Kw/m2	NR	82.41	79.92
						4Kw/m2	NR	90.17	89.43
					Explosion	0.3bar	440	636	672
3	Interconnecting p/l from E-101A/S to R-101	Interconnecting P/L, R-101, E-102A/S	Small	0.862kg/s & 3,600s	Flash fire	LFL (10060.8 ppm)	6.58	9.39	11.52
					Jet fire	37.5Kw/m2	12.28	14.41	14.38
						4Kw/m2	21.50	23.23	23.11
			Medium	21.55kg/s & 3,600s	Flash fire	LFL (10060.8 ppm)	83.85	112.67	130.54
					Jet fire	37.5Kw/m2	52.62	61.43	61.21
						4Kw/m2	93.01	100.81	100.07
			Large	344.81kg/s & 3,600s	Flash fire	LFL (10060.8 ppm)	352.31	511.72	552.26
					Jet fire	37.5Kw/m2	165.90	202.27	201.32
						4Kw/m2	286.06	332.22	328.91
					Pool fire	37.5Kw/m2	NR	110.27	74.22
						4Kw/m2	NR	96.52	89.80
					Explosion	0.3bar	427.74	614.84	669.84
			Catastrophic Rupture	-	Flash fire	LFL (10060.8 ppm)	528.67	777.44	729.87
					Jet fire	37.5Kw/m2	231.36	282.43	281.01
						4Kw/m2	395.62	460.28	455.36
					Pool fire	37.5Kw/m2	125.14	NR	NR
						4Kw/m2	133.37	157.67	179.34
					Explosion	0.3bar	636.56	936.87	885.08
4	Interconnecting p/l from R-101	Interconnecting	Small	0.0588kg/s & 3,600s	Flash fire	LFL (53531.9 ppm)	1.21	1.33	1.36

S.No	Node	Description	Accident Scenario	Release Rate & Duration	Event	Impact criteria	Consequence Distance(m) D 11m/s	B 3m/s	F 3m/s
	to R-103	P/L, R-102, R-103, E-104	Medium	1.469kg/s & 3,600s	Flash fire	LFL (53531.9 ppm)	5.13	5.91	6.30
					Jet fire	37.5Kw/m2	NR	NR	NR
						4Kw/m2	19.31	18.61	18.68
			Large	23.51kg/s & 563.07s	Flash fire	LFL (53531.9 ppm)	31.39	33.66	35.10
					Jet fire	37.5Kw/m2	58.85	45.72	45.46
						4Kw/m2	76.88	73.34	73.22
			Catastrophic Rupture	-	Flash fire	LFL (53531.9 ppm)	51.31	50.35	54.14
					Jet fire	37.5Kw/m2	82.85	63.56	63.19
						4Kw/m2	108.06	104.99	104.59
5	Interconnecting p/l from R-103 to R-104	Interconnecting P/L, R-104	Small	0.0603kg/s & 3,600s	Flash fire	LFL (53531.9 ppm)	1.24	1.36	1.40
			Medium	1.508kg/s & 3,600s	Flash fire	LFL (53531.9 ppm)	5.28	6.13	6.53
					Jet fire	37.5Kw/m2	NR	NR	NR
						4Kw/m2	19.61	18.88	18.95
			Large	24.13kg/s & 3,600s	Flash fire	LFL (53531.9 ppm)	33.47	35.12	36.27
					Jet fire	37.5Kw/m2	59.51	46.26	46.01
						4Kw/m2	77.80	74.26	74.13
			Catastrophic Rupture	-	Flash fire	LFL (53531.9 ppm)	54.43	53.43	56.60
					Jet fire	37.5Kw/m2	56.19	64.25	63.87
						4Kw/m2	65.28	106.26	105.84
6	Interconnecting p/l from R-104 to R-105	Interconnecting P/L, R-105, E-105, E-106	Small	0.0467kg/s & 3,600s	Flash fire	LFL (51365.3 ppm)	1.62	2.03	2.15
			Medium	1.167kg/s & 3,600s	Flash fire	LFL (51365.3 ppm)	6.52	8.73	9.60
					Jet fire	37.5Kw/m2	NR	NR	NR
						4Kw/m2	17.79	16.50	16.56
			Large	18.68kg/s &3,600s	Flash fire	LFL (51365.3 ppm)	50.09	49.39	52.66
					Jet fire	37.5Kw/m2	55.64	34.23	33.15
						4Kw/m2	69.53	64.10	64.02

S.No	Node	Description	Accident Scenario	Release Rate & Duration	Event	Impact criteria	Consequence Distance(m) D 11m/s	B 3m/s	F 3m/s
			Catastrophic Rupture	-	Flash fire	LFL (51365.3 ppm)	75.34	71.90	74.71
					Jet fire	37.5Kw/m2	75.75	50.75	49.59
						4Kw/m2	96.73	90.93	90.64
7	Interconnecting p/l from R-105 to V-104	Interconnecting P/L, E-107, E-108,EA-101, E-109,V-104	Small	0.054kg/s & 3,600s	Flash fire	LFL (51974.6 ppm)	1.75	2.14	2.24
			Medium	1.344kg/s & 3,600s	Flash fire	LFL (51974.6 ppm)	6.98	9.22	10.10
					Jet fire	37.5Kw/m2	NR	NR	NR
						4Kw/m2	18.55	16.92	16.98
			Large	21.50kg/s & 3,600s	Flash fire	LFL (51974.6 ppm)	57.53	56.30	60.84
					Jet fire	37.5Kw/m2	57.82	29.81	30.68
						4Kw/m2	71.49	64.67	64.75
			Catastrophic Rupture	-	Flash fire	LFL (51974.6 ppm)	90.79	85.14	90.96
					Jet fire	37.5Kw/m2	78.81	46.44	45.80
						4Kw/m2	99.06	91.35	91.06
8	Interconnecting p/l from V-104 to PSA unit	Interconnecting P/L	Small	0.054kg/s & 3,600s	Flash fire	LFL (51974.6 ppm)	1.79	2.18	2.27
					Jet fire	37.5Kw/m2	NR	NR	NR
						4Kw/m2	NR	NR	NR
			Medium	1.344kg/s & 3,600s	Flash fire	LFL (51974.6 ppm)	7.12	9.38	10.27
					Jet fire	37.5Kw/m2	NR	NR	NR
						4Kw/m2	18.70	17.06	17.11
			Large	21.89kg/s & 3,600s	Flash fire	LFL (51974.6 ppm)	60.39	58.13	63.13
					Jet fire	37.5Kw/m2	58.17	58.17	30.06
						4Kw/m2	71.93	65.17	65.09
			Catastrophic Rupture	-	Flash fire	LFL (51974.6 ppm)	97.68	90.75	97.15
					Jet fire	37.5Kw/m2	79.24	46.77	46.13
						4Kw/m2	99.64	91.93	91.63
9	Interconnecting p/l from PSA Unit to product H2 to BL	Interconnecting P/L	Small	0.0212kg/s & 3,600s	Flash fire	LFL (40000 ppm)	3.41	4.63	5.06
					Jet fire	37.5Kw/m2	NR	NR	NR

S.No	Node	Description	Accident Scenario	Release Rate & Duration	Event	Impact criteria	Consequence Distance(m) D 11m/s	B 3m/s	F 3m/s
						4Kw/m2	NR	NR	NR
			Medium	0.531kg/s & 3,600s	Flash fire	LFL (40000 ppm)	20.28	19.26	21.03
					Jet fire	37.5Kw/m2	NR	NR	NR
						4Kw/m2	19.74	20.66	20.71
			Large	8.49kg/s & 3,600s	Flash fire	LFL (40000 ppm)	62.25	54.60	62.96
					Jet fire	37.5Kw/m2	61.23	42.47	42.50
						4Kw/m2	70.98	74.10	73.85
			Catastrophic Rupture	-	Flash fire	LFL (40000 ppm)	131.43	113.11	128.61
					Jet fire	37.5Kw/m2	156.46	111.18	111.08
						4Kw/m2	195.96	203.72	202.18

Flammable Consequence Results for Natural gas

S.No	Node	Description	Accident Scenario	Release Rate & Duration	Event	Impact criteria	Consequence Distance(m) D 11m/s	B 3m/s	F 3m/s
1	NG from BL to E-101A/S	Interconnecting P/L, E-101A/S	Small	0.113kg/s & 3600s	Flash fire	LFL (44000 ppm)	2.39	2.72	2.92
			Medium	2.82kg/s & 3600s	Flash fire	LFL (44000 ppm)	10.50	13.62	14.90
					Jet fire	37.5Kw/m2	23.03	19.34	29.39
						4Kw/m2	29.90	29.58	29.64
			Large	46.66kg/s & 3600s	Flash fire	LFL (44000 ppm)	95.62	87.93	96.99
					Jet fire	37.5Kw/m2	53.17	67.61	67.66
						4Kw/m2	76.73	115.68	115.10
			Catastrophic Rupture	-	Flash fire	LFL (44000 ppm)	210.51	182.36	201.74
					Jet fire	37.5Kw/m2	142.35	118.96	118.67
						4Kw/m2	200.10	216.50	214.55
2	Interconnecting p/l from E-101A/S to R-101	Interconnecting P/L, R-101, E-102A/S	Small	0.0696kg/s & 3,600s	Flash fire	LFL (43534.9 ppm)	1.75	2.11	2.04
			Medium	1.74kg/s & 3,600s	Flash fire	LFL (43534.9 ppm)	7.24	9.10	9.91
					Jet fire	37.5Kw/m2	17.62	14.83	14.80
						4Kw/m2	23.10	22.93	22.99
			Large	27.83kg/s & 3,600s	Flash fire	LFL (43534.9 ppm)	50.13	50.08	52.38
					Jet fire	37.5Kw/m2	68.77	54.89	54.99
						4Kw/m2	91.07	91.59	91.26
			Catastrophic Rupture	-	Flash fire	LFL (43534.9 ppm)	74.35	70.96	73.59
					Jet fire	37.5Kw/m2	94.50	76.14	76.15
						4Kw/m2	127.99	132.25	131.48
3	Interconnecting p/l from R-101 to R-103	Interconnecting P/L, R-102, R-103, E-104	Small	0.0532kg/s & 3,600s	Flash fire	LFL (43737.8 ppm)	1.41	1.68	1.76
			Medium	1.33kg/s & 3,600s	Flash fire	LFL (43737.8 ppm)	5.78	7.43	8.10
					Jet fire	37.5Kw/m2	13.43	12.12	11.80
						4Kw/m2	19.94	19.89	19.95
			Large	21.29kg/s & 3,600s	Flash fire	LFL (43737.8 ppm)	39.62	40.73	42.46
					Jet fire	37.5Kw/m2	61.59	49.15	49.21

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S.No	Node	Description	Accident Scenario	Release Rate & Duration	Event	Impact criteria	Consequence Distance(m) D 11m/s	B 3m/s	F 3m/s
						4Kw/m2	81.02	80.99	80.76
			Catastrophic Rupture	-	Flash fire	LFL (43737.8 ppm)	59.55	57.63	60.21
					Jet fire	37.5Kw/m2	57.78	68.41	68.46
						4Kw/m2	79.81	117.27	116.67
4	Interconnecting p/l from R-103 to R-104	Interconnecting P/L, R-104	Small	0.054kg/s & 3,600s	Flash fire	LFL (45562.1 ppm)	1.52	1.80	1.88
			Medium	1.34kg/s & 3,600s	Flash fire	LFL (45562.1 ppm)	6.09	8.06	8.75
					Jet fire	37.5Kw/m2	NR	NR	NR
						4Kw/m2	19.94	19.63	19.70
			Large	21.48kg/s & 3,600s	Flash fire	LFL (45562.1 ppm)	44.40	44.29	46.05
					Jet fire	37.5Kw/m2	61.45	48.55	48.61
						4Kw/m2	79.94	78.95	78.74
			Catastrophic Rupture	-	Flash fire	LFL (45562.1 ppm)	65.21	62.43	64.56
					Jet fire	37.5Kw/m2	84.84	67.34	67.34
						4Kw/m2	112.58	113.84	113.30
5	Interconnecting p/l from R-104 to R-105	Interconnecting P/L, R-105, E-105, E-106	Small	0.0428kg/s & 3,600s	Flash fire	LFL (48485 ppm)	1.87	2.33	2.45
			Medium	1.07kg/s & 3,600s	Flash fire	LFL (48485 ppm)	7.29	10.37	11.53
					Jet fire	37.5Kw/m2	NR	NR	NR
						4Kw/m2	17.91	16.69	16.76
			Large	17.14kg/s & 3,600s	Flash fire	LFL (48485 ppm)	53.67	52.87	54.49
					Jet fire	37.5Kw/m2	55.13	38.05	37.25
						4Kw/m2	69.63	65.10	65.00
			Catastrophic Rupture	-	Flash fire	LFL (48485 ppm)	78.03	72.69	75.74
					Jet fire	37.5Kw/m2	76.78	54.09	53.32
						4Kw/m2	96.70	92.58	92.26
6	Interconnecting p/l from R-105 to V-104	Interconnecting P/L, E-107, E-108,EA-101,	Small	0.054kg/s & 3,600s	Flash fire	LFL (49492.6 ppm)	1.98	2.39	2.49
			Medium	1.26kg/s & 3,600s	Flash fire	LFL (49492.6 ppm)	7.68	10.67	11.83
					Jet fire	37.5Kw/m2	NR	NR	NR
		E-109,V-104				4Kw/m2	18.74	17.22	17.28
			Large	20.17kg/s & 3,600s	Flash fire	LFL (49492.6 ppm)	63.76	61.56	65.62
					Jet fire	37.5Kw/m2	57.73	34.42	33.36
						4Kw/m2	71.91	66.09	65.99
			Catastrophic Rupture	-	Flash fire	LFL (49492.6 ppm)	96.21	89.10	93.50
					Jet fire	37.5Kw/m2	78.23	51.22	50.07
						4Kw/m2	99.57	93.51	93.19
7	Interconnecting p/l from V-104 to PSA unit	Interconnecting P/L	Small	0.054kg/s & 3,600s	Flash fire	LFL (49414.7 ppm)	2.03	2.43	2.53
			Medium	1.26kg/s & 3,600s	Flash fire	LFL (49414.7 ppm)	7.86	10.93	12.18
					Jet fire	37.5Kw/m2	NR	NR	NR
						4Kw/m2	18.89	17.36	17.42
			Large	20.41kg/s & 3,600s	Flash fire	LFL (49414.7 ppm)	67.15	64.13	68.87
					Jet fire	37.5Kw/m2	37.16	34.78	33.72
						4Kw/m2	72.35	66.53	66.44
			Catastrophic Rupture	-	Flash fire	LFL (49414.7 ppm)	102.66	93.36	98.53
					Jet fire	37.5Kw/m2	78.61	51.66	50.50
						4Kw/m2	100.13	94.13	93.81
8	Interconnecting p/l from PSA Unit to product H2 to BL	Interconnecting P/L	Small	0.0212kg/s & 3,600s	Flash fire	LFL (40000 ppm)	3.41	4.63	5.06
					Jet fire	37.5Kw/m2	NR	NR	NR
						4Kw/m2	NR	NR	NR
			Medium	0.531kg/s & 3,600s	Flash fire	LFL (40000 ppm)	20.28	19.26	21.03
					Jet fire	37.5Kw/m2	NR	NR	NR
						4Kw/m2	19.74	20.66	20.71
			Large	8.49kg/s & 3,600s	Flash fire	LFL (40000 ppm)	62.25	54.60	62.96
					Jet fire	37.5Kw/m2	61.23	42.47	42.50
						4Kw/m2	70.98	74.10	73.85
			Catastrophic Rupture	-	Flash fire	LFL (40000 ppm)	131.43	113.11	128.61
					Jet fire	37.5Kw/m2	156.46	111.18	111.08
						4Kw/m2	195.96	203.72	202.18

Flammable Consequence Results for RF Gas

S.No	Node	Description	Accident Scenario	Release Rate & Duration	Event	Impact criteria	Consequence Distance(m) D 11m/s	B 3m/s	F 3m/s
1	RFG from BL to E-101A/S	Interconnecting P/L,E-101A/S	Small	0.1124kg/s & 3600s	Flash fire	LFL (33243.2 ppm)	2.81	3.66	3.86
			Medium	2.81kg/s & 3600s	Flash fire	LFL (33243.2 ppm)	14.87	18.87	20.91
					Jet fire	37.5Kw/m2	22.92	7.23	19.42
						4Kw/m2	29.83	29.60	29.66
			Large	46.41kg/s & 3,600s	Flash fire	LFL (33243.2 ppm)	136.57	115.62	125.04
					Jet fire	37.5Kw/m2	84.30	67.70	67.78
						4Kw/m2	113.50	116.17	115.58
			Catastrophic Rupture	-	Flash fire	LFL (33243.2 ppm)	272.04	224.62	249.99
					Jet fire	37.5Kw/m2	142.59	119.24	118.96
						4Kw/m2	200.99	217.65	215.68
					Explosion	0.3bar	NH	NH	294.33
2	Interconnecting p/l from E-101A/S to R-101	Interconnecting P/L, R-101, E-102A/S	Small	0.0704kg/s & 3,600s	Flash fire	LFL (33243.2 ppm)	2.13	2.50	2.65
			Medium	1.76kg/s & 3,600s	Flash fire	LFL (33243.2 ppm)	8.83	11.94	13.25
					Jet fire	37.5Kw/m2	17.73	15.03	15.03
						4Kw/m2	23.19	23.11	23.11
			Large	28.14kg/s & 3,600s	Flash fire	LFL (33243.2 ppm)	60.45	57.49	59.91
					Jet fire	37.5Kw/m2	69.10	55.16	55.37
						4Kw/m2	91.76	92.52	92.18
			Catastrophic Rupture	-	Flash fire	LFL (33243.2 ppm)	84.91	79.12	83.29
					Jet fire	37.5Kw/m2	95.01	76.72	76.73
						4Kw/m2	129.11	133.70	132.90
3	Interconnecting p/l from R-101 to R-103	Interconnecting P/L, R-102, R-103, E-104	Small	0.0552kg/s & 3,600s	Flash fire	LFL (33243.2 ppm)	1.86	2.08	2.23
			Medium	1.38kg/s & 3,600s	Flash fire	LFL (33243.2 ppm)	7.15	9.79	11.03
					Jet fire	37.5Kw/m2	14.81	12.80	12.67
						4Kw/m2	20.30	20.30	20.36
			Large	22.09kg/s & 3,600s	Flash fire	LFL (33243.2 ppm)	48.75	47.65	50.04

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S.No	Node	Description	Accident Scenario	Release Rate & Duration	Event	Impact criteria	Consequence Distance(m) D 11m/s	B 3m/s	F 3m/s
					Jet fire	37.5Kw/m2	62.49	49.98	50.11
						4Kw/m2	82.51	82.72	82.48
			Catastrophic Rupture	-	Flash fire	LFL (33243.2 ppm)	69.34	65.36	69.90
					Jet fire	37.5Kw/m2	86.58	69.61	69.66
						4Kw/m2	116.80	119.86	119.21
4	Interconnecting p/l from R-103 to R-104	Interconnecting P/L, R-104	Small	0.0524kg/s & 3,600s	Flash fire	LFL (46325.4 ppm)	1.56	1.84	1.91
			Medium	1.311kg/s & 3,600s	Flash fire	LFL (46325.4 ppm)	6.23	8.15	8.96
					Jet fire	37.5Kw/m2	NR	NR	NR
						4Kw/m2	19.63	19.17	19.24
			Large	20.98kg/s & 3,600s	Flash fire	LFL (46325.4 ppm)	44.56	44.60	46.18
					Jet fire	37.5Kw/m2	60.61	47.46	47.78
						4Kw/m2	78.27	76.61	76.43
			Catastrophic Rupture	-	Flash fire	LFL (46325.4 ppm)	65.39	62.53	64.34
					Jet fire	37.5Kw/m2	83.57	65.74	65.74
						4Kw/m2	109.98	110.22	109.72
5	Interconnecting p/l from R-104 to R-105	Interconnecting P/L, R-105, E-105, E-106	Small	0.0427kg/s & 3,600s	Flash fire	LFL (48574.1 ppm)	1.87	2.34	2.45
			Medium	1.067kg/s & 3,600s	Flash fire	LFL (48574.1 ppm)	7.30	10.40	11.57
					Jet fire	37.5Kw/m2	NR	NR	NR
						4Kw/m2	17.87	16.63	16.69
			Large	17.08kg/s &3,600s	Flash fire	LFL (48574.1 ppm)	53.68	52.86	54.43
					Jet fire	37.5Kw/m2	55.09	37.51	36.62
						4Kw/m2	69.43	64.79	64.70
			Catastrophic Rupture	-	Flash fire	LFL (48574.1 ppm)	77.96	72.95	75.70
					Jet fire	37.5Kw/m2	76.64	53.57	52.75
						4Kw/m2	96.39	92.11	91.80
6	Interconnecting p/l from R-	Interconnecting	Small	0.045kg/s & 3,600s	Flash fire	LFL (49592.3 ppm)	1.79	2.24	2.34

S.No	Node	Description	Accident Scenario	Release Rate & Duration	Event	Impact criteria	Consequence Distance(m) D 11m/s	B 3m/s	F 3m/s
	105 to V-104	P/L, E-107, E-108, EA-101, E-109,V-104	Medium	1.128kg/s & 3,600s	Flash fire	LFL (49592.3 ppm)	7.01	9.61	10.66
					Jet fire	37.5Kw/m2	NR	NR	NR
						4Kw/m2	17.59	16.17	16.23
			Large	18.06kg/s & 3,600s	Flash fire	LFL (49592.3 ppm)	55.11	53.90	57.16
					Jet fire	37.5Kw/m2	55.24	31.68	31.68
						4Kw/m2	68.50	62.68	62.69
			Catastrophic Rupture	-	Flash fire	LFL (49592.3 ppm)	81.98	76.77	80.58
					Jet fire	37.5Kw/m2	75.14	47.91	46.73
						4Kw/m2	95.09	88.75	88.48
7	Interconnecting p/l from V-104 to PSA unit	Interconnecting P/L	Small	0.051kg/s & 3,600s	Flash fire	LFL (49503.1 ppm)	2.02	2.43	2.53
			Medium	1.27kg/s & 3,600s	Flash fire	LFL (49503.1 ppm)	7.86	10.94	12.19
					Jet fire	37.5Kw/m2	NR	NR	NR
						4Kw/m2	18.84	17.28	17.34
			Large	20.04kg/s & 3,600s	Flash fire	LFL (49503.1 ppm)	67.11	64.09	68.82
					Jet fire	37.5Kw/m2	57.99	34.06	33.02
						4Kw/m2	72.12	66.17	66.18
			Catastrophic Rupture	-	Flash fire	LFL (49503.1 ppm)	101.46	93.25	98.34
					Jet fire	37.5Kw/m2	78.54	50.87	49.67
						4Kw/m2	99.78	93.57	93.25
8	Interconnecting p/l from PSA Unit to product H2 to BL	Interconnecting P/L	Small	0.0212kg/s & 3,600s	Flash fire	LFL (40000 ppm)	3.41	4.63	5.06
					Jet fire	37.5Kw/m2	NR	NR	NR
						4Kw/m2	NR	NR	NR
			Medium	0.531kg/s & 3,600s	Flash fire	LFL (40000 ppm)	20.28	19.26	21.03
					Jet fire	37.5Kw/m2	NR	NR	NR
						4Kw/m2	19.74	20.66	20.71
			Large	8.49kg/s & 3,600s	Flash fire	LFL (40000 ppm)	62.25	54.60	62.96
					Jet fire	37.5Kw/m2	61.23	42.47	42.50

S.No	Node	Description	Accident Scenario	Release Rate & Duration	Event	Impact criteria	Consequence Distance(m) D 11m/s	B 3m/s	F 3m/s
						4Kw/m2	70.98	74.10	73.85
			Catastrophic Rupture	-	Flash fire	LFL (40000 ppm)	131.43	113.11	128.61
					Jet fire	37.5Kw/m2	156.46	111.18	111.08
						4Kw/m2	195.96	203.72	202.18

Toxic Consequence Results for LPG

S.No	Node	Description	Accident Scenario	Release Rate & Duration	Event	Impact criteria	Consequence Distance(m) D 11m/s	B 3m/s	F 3m/s
1	Interconnecting p/l from R-103 to R-104	Interconnecting P/L,R-103, R-104	Small	0.0603kg/s & 3,600s	Toxicity	3% lethality	50	50	50
			Medium	1.508kg/s & 3,600s			100	100	75
			Large	24.13kg/s & 3,600s			250	225	125
			Catastrophic Rupture	-			300	225	125
2	Interconnecting p/l from R-104 to R-105	Interconnecting P/L, R-105, E-105, E-106	Small	0.0463kg/s & 3,600s	Toxicity	3% lethality	50	50	50
			Medium	1.158kg/s & 3,600s			150	125	100
			Large	18.52kg/s & 3,600s			350	250	150
			Catastrophic Rupture	-			425	325	175
3	Interconnecting p/l from R-105 to V-104	Interconnecting P/L, E-107, E-108, EA-101, E-109,V-104	Small	0.054kg/s & 3,600s	Toxicity	3% lethality	50	50	50
			Medium	1.344kg/s & 3,600s			200	175	150
			Large	21.50kg/s & 3,600s			500	350	300
			Catastrophic Rupture	-			650	450	350
4	Interconnecting p/l from V-104 to PSA unit	Interconnecting P/L	Small	0.054kg/s & 3,600s	Toxicity	3% lethality	50	50	50
			Medium	1.344kg/s & 3,600s			200	175	150
			Large	21.89kg/s & 3,600s			575	375	375
			Catastrophic Rupture	-			725	475	425

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Toxic Consequence Results for Naphtha

S.No	Node	Description	Accident Scenario	Release Rate & Duration	Event	Impact criteria	Consequence Distance(m)		
							D 11m/s	B 3m/s	F 3m/s
1	Naphtha from V-102 to E-101A/S	Interconnecting P/L,P-102A/S, E-101A/S	Medium	21.94kg/s & 3,600s	Toxicity	3% lethality	125	125	200
			Large	362.35kg/s & 3,600s			475	675	950
2	Naphtha from BL to V-102	Interconnecting P/L, V-102	Small	0.276kg/s & 3600s	Toxicity	3% lethality	NR	NR	NR
			Medium	6.891kg/s & 3,600s			75	100	100
			Large	110.25kg/s & 1,476.63s			125	150	175
			Catastrophic Rupture	-			150	175	200
3	Interconnecting p/l from R-103 to R-104	Interconnecting P/L,R-104	Small	0.0603kg/s & 3,600s	Toxicity	3% lethality	50	50	50
			Medium	1.508kg/s & 3,600s			125	100	100
			Large	24.13kg/s & 3,600s			275	225	125
			Catastrophic Rupture	-			325	250	150
4	Interconnecting p/l from R-104 to R-105	Interconnecting P/L, R-105, E-105, E-106	Small	0.0467kg/s & 3,600s	Toxicity	3% lethality	25	25	25
			Medium	1.167kg/s & 3,600s			150	125	100
			Large	18.68kg/s &3,600s			375	250	150
			Catastrophic Rupture	-			450	325	175
5	Interconnecting p/l from R-105 to V-104	Interconnecting P/L, E-107, E-108,	Small	0.054kg/s & 3,600s	Toxicity	3% lethality	25	25	25
			Medium	1.344kg/s & 3,600s			200	175	150
			Large	21.50kg/s & 3,600s			500	350	300
		EA-101, E-109, V-104	Catastrophic Rupture	-			650	450	350
6	Interconnecting p/l from V-104 to PSA unit	Interconnecting P/L	Small	0.054kg/s & 3,600s	Toxicity	3% lethality	50	50	50
			Medium	1.344kg/s & 3,600s			200	175	150
			Large	21.89kg/s & 3,600s			575	375	375
			Catastrophic Rupture	-			725	475	425

Toxic Consequence Results for Natural gas

S.No	Node	Description	Accident Scenario	Release Rate & Duration	Event	Impact criteria	Consequence Distance(m)		
							D 11m/s	B 3m/s	F 3m/s
1	Interconnecting p/l from R-103 to R-104	Interconnecting P/L,R-104	Small	0.054kg/s & 3,600s	Toxicity	3% lethality	25	25	25
			Medium	1.34kg/s & 3,600s			125	100	75
			Large	21.48kg/s & 3,600s			275	200	100
			Catastrophic Rupture	-			275	200	125
2	Interconnecting p/l from R-104 to R-105	Interconnecting P/L, R-105, E-105, E-106	Small	0.0428kg/s & 3,600s	Toxicity	3% lethality	25	25	25
			Medium	1.07kg/s & 3,600s			150	100	100
			Large	17.14kg/s & 3,600s			350	250	150
			Catastrophic Rupture	-			425	325	125
3	Interconnecting p/l from R-105 to V-104	Interconnecting P/L, E-107, E-108,EA-101, E-109,V-104	Small	0.054kg/s & 3,600s	Toxicity	3% lethality	25	25	25
			Medium	1.26kg/s & 3,600s			175	150	125
			Large	20.17kg/s & 3,600s			500	325	250
			Catastrophic Rupture	-			625	400	275
4	Interconnecting p/l from V-104 to PSA unit	Interconnecting P/L	Small	0.051kg/s & 3,600s	Toxicity	3% lethality	50	50	50
			Medium	1.26kg/s & 3,600s			175	150	125
			Large	20.41kg/s & 3,600s			525	350	300
			Catastrophic Rupture	-			650	425	325

Toxic Consequence Results for RF Gas

S.No	Node	Description	Accident Scenario	Release Rate & Duration	Event	Impact criteria	Consequence Distance(m)		
							D 11m/s	B 3m/s	F 3m/s
1	Interconnecting p/l from R-103 to R-104	Interconnecting P/L,R-104	Small	0.0524kg/s & 3,600s	Toxicity	3% lethality	50	50	50
			Medium	1.311kg/s & 3,600s			125	100	100
			Large	20.98kg/s & 3,600s			275	200	100
			Catastrophic Rupture	-			275	175	125
2	Interconnecting p/l from R-104 to R-105	Interconnecting P/L, R-105, E-105, E-106	Small	0.0427kg/s & 3,600s	Toxicity	3% lethality	50	50	50
			Medium	1.067kg/s & 3,600s			150	100	100
			Large	17.08kg/s &3,600s			325	225	150
			Catastrophic Rupture	-			400	325	150
3	Interconnecting p/l from R-105 to V-104	Interconnecting P/L, E-107, E-108, EA-101, E-109,V-104	Small	0.045kg/s & 3,600s	Toxicity	3% lethality	50	50	50
			Medium	1.128kg/s & 3,600s			150	125	125
			Large	18.06kg/s & 3,600s			375	275	175
			Catastrophic Rupture	-			450	350	200
4	Interconnecting p/l from V-104 to PSA unit	Interconnecting P/L	Small	0.051kg/s & 3,600s	Toxicity	3% lethality	50	50	50
			Medium	1.27kg/s & 3,600s			200	175	150
			Large	20.04kg/s & 3,600s			500	350	300
			Catastrophic Rupture	-			650	425	325

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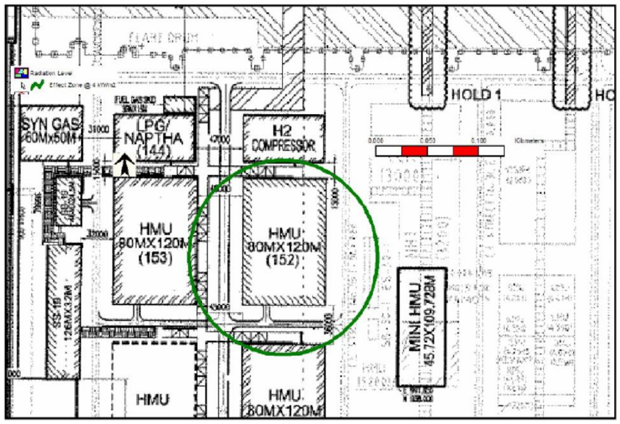
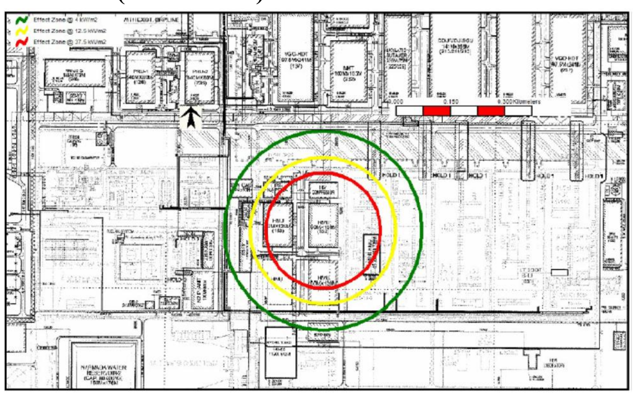
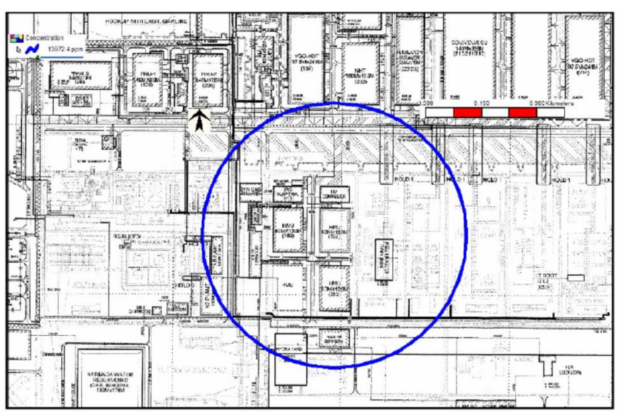
Pool fire - large leak from the E-101A/S (LPG as feed)



Jet fire - large leak from the E-101A/S (LPG as feed)



Flash fire - large leak from the E-101A/S



IX. PHA Scope Comprehensiveness

9.1 Non-Routine Mode of Operation

The biggest and most dangerous gap in PHA performance is the failure to include non-routine mode of operation. More than 80% of process facilities do not perform PHAs for non-routine mode of operation. Yet, a paper published by the Process Improvement Institute (PII) which reviewed 47 major process safety incidents occurring from 1987 to 2010 revealed that almost 70% of all moderate to major incidents occurred during non-routine mode of operation. This figure was even confirmed by a poll sent to over 50 of PII's clients. Discussing this issue with another safety consulting company, which leads PHAs on a regular basis, also confirmed that this is a major issue in most process facilities, despite the fact that performing PHAs for all modes of operation is an OSHA PSM requirement according to OSHA's 29 CFR 1910.119. What makes this issue even more dangerous, is that common PHA methodologies employed for continuous mode of operation only identifies 5-10% of the potential hazardous scenarios for non-routine mode of operation. This risk becomes even more evident when factoring the number of shutdown/startups performed by each facility each year, the fact that during startup/shutdown operations most safeguards proposed to reduce risk during continuous operation are bypassed, and that the reliance on operator actions is substantially increased greatly increasing human error and reducing reliability. This results in the increased probability of a major incident occurring by 30-50 times.

9.2 Facility Siting

Another common gap shared by many companies is also failing to include or consider facility siting (i.e., effect of potential explosions and toxic releases on nearby occupied buildings) in their PHA. Most facilities will do a good job in including all process nodes. However, they might fail to assess facility siting entirely. Addressing facility siting is a requirement in the USA and is driven by OSHA and EPA. Yet, some facilities perform this task separately without incorporating its findings in the facility's PHA studies. Auditors should verify incorporation of facility siting assessment findings in PHA recommendations. In addition, since facility siting assessment should be part of the PHA, auditors should ensure that facility siting studies are performed at least every 5 years and incorporated in PHA revalidations. This is extremely important not only because it reduces residual risk that went unidentified in previous PHAs, but also because building occupancy indices may change as well, which may result in significant change in the consequences and the level of risk assessed in the previous PHA studies. Auditors should also verify that temporary structures, such as portable buildings or trailers used during turnaround and inspection (T&I) for contractor occupancy, are only placed in safe zones defined in the facility siting assessment. During the BP Texas city incident, 15 contractors were fatally injured in trailers that were not placed in safe zones

9.3 Chemical Inventory

Chemicals stored in the process are not subject to being overlooked in a PHA study. However, chemicals used for maintenance usually are overlooked. Improper storage of flammable or toxic chemicals stored in warehouses and sheds can lead to major incidents. A well-known one is the incident that occurred in Tianjin, China 2015. The explosions which originated from chemicals stored in a storage warehouse had a power which exceeded 20 tons of TNT. So, depending on the quantity and nature of the stored chemicals, a facility might be completely wiped out. Had a quality PHA been performed on this chemical warehouse, the risk would have been greatly reduced.

Auditors should not only ensure that all chemical storage warehouses/buildings have been included in the PHA, but also maximum inventory reached for these chemicals should be verified through site verifications, inventory reports, and/or employee interviews. It is also vital to ensure that maximum chemical inventories are accounted for in PHA revalidations as well. A change in inventory may slip through existing gaps in the facility's MOC process, especially if the chemical inventory is managed by a different department which may not have an engineer or qualified person. This is often seen in big companies where material/chemical warehouses are managed independently. Furthermore, in general warehouses are often perceived as low risk and have poor PSM implementation monitoring.

9.4 Shared Processes

Special attention must be given to shared processes and connected boundaries between different units in a given facility. Performing PHAs on processes like utility lines and flare headers that are shared among several units in a facility can be neglected unintentionally. When ownership of process units is segregated and the responsibility of performing PHAs is assigned to several PHA teams, the teams might neglect performing PHAs on shared processes or miss sections as a result of differently defined boundaries between units. The auditor should verify first if references in PHA do in fact link to a performed PHA on the shared process. In addition, the auditor should verify that the boundaries of connecting process units are similarly defined and no section of the facility is overlooked.

9.5 Inherently Safer Design (ISD)

Utilizing the ISD principals to reduce risk should be a critical step in any PHA study. Although it is most effective during conceptual design and front-end engineering design (FEED), it should also be applied to reduce consequence severity for high consequence hazardous scenarios identified during initial PHA studies. Although ISD can be applied at any time during the facility's lifecycle, it makes more sense practically and financially to apply them during the design stage of the process. By now, ISD awareness should not be an issue and auditors should pursue and verify implementation of ISD principals.

X. Conclusion And Future Scope

10.1 Conclusion

After completion of the study, I found that A process hazard analysis (PHA) or evaluation is an organized and systematic approach to identifying and analyzing the potential hazards associated with the processing or handling of highly hazardous chemicals. It evaluates and analyses possible causes and consequences of fires, explosions, releases, and spills of dangerous and flammable chemicals by focusing on equipment, utilities, human actions and external factors. Activities documenting and tracking implementation of corrective actions or safety improvements are not part of a PHA report. However, the PSM Rule requires a documented, integrated system for managing and monitoring action items. This system must assure that action items and recommendations are addressed and documented in a timely manner. OSHA UAS has also issued the guidelines for PSM compliance.

As implied throughout the thesis, it is critical that the audit team use guidelines similar to the ones proposed in this study as part of an overall PSM audit. Focusing on auditing the quality of the PHA element alone will unquestionably assist in identifying gaps in implementation and company policies/standards. However, solving these identified gaps will require looking at the bigger picture, which only can be attained from auditing the whole safety management system (SMS). Implementation deficiencies in process safety information, incident investigation, training, and mechanical integrity for example, will definitely have cascading effects on PHA implementation. In addition, implementation deficiencies in PHA quality will also have cascading effects on other PSM elements such as mechanical integrity, operating procedures, emergency planning and response. Therefore, it is highly recommended that the users of these proposed guidelines incorporate them as part of an overall PSM audit. It is also highly recommended that users of these guidelines also use their findings to propose recommendations that focus on improving the SMS, eliminating the identified gaps, and updating the internal standards and procedures of the facility to ensure continuous improvement. It is most frustrating to find out that all the man-hours, money, and effort that went into performing the monumental task of auditing the whole SMS just to find that the audit report merely became a document hidden on a shelf collecting dust. Spending the time and money to perform this audit and use its findings to close the company's SMS gaps should be seen as an investment by the facility's executives. It will unquestionably save a lot of money and ensure business continuity on the long run.

10.2 Future Scope

The intent of this element is to define the requirements to conduct a Process Hazard Analysis (PHA) on each process covered by the PSM Program. This critical element identifies the process hazards, evaluates the consequences and defines appropriate control measures to eliminate or minimize the severity of the hazard.

The next step that follows developing these guidelines would be of course to test them in a pilot exercise at a chemical/hydrocarbon facility. Multiple pilots will help complete and refine these guidelines, and make them more practical to use. The natural step following those pilot exercises and improvement of guidelines is to use them to enhance the facility's internal standards and procedures in order to help close identified gaps, develop systems that assist in making the PHA element easier to audit and monitor with the goal of steering the facility for continuous improvement of PHA element implementation. To help assure that all hazards are identified and evaluated, PHA will be help to the following processes

- Oil & Gas Processing
- Rubber Processing
- Petrochemical
- Cement Processing
- Pharmaceutical
- Water Treatment Process

- Toxic or Pesticide Chemical Processing
- Hazardous Waste Treatment Process
- Textile Processing
- Other Chemicals and Process Industries

Bibliography

[1]. Burk, Arthur F., 1992. "Strengthen Process Hazards Reviews," Chemical Engineering
[2]. Progress, June 1992, pp. 90-94.
[3]. Center for Chemical Process Safety (CCPS), 1992. Guidelines for Hazard Evaluation
[4]. Procedures, Second Edition with Worked Examples; Publication G18; American Institute of Chemical Engineers, New York.7
[5]. Freeman, Raymond A., 1991. "Documentation of Hazard and Operability Studies,"
[6]. Plant/Operations Progress, July 1991, Vol. 10, No.3.
[7]. Hendershot, Dennis C., 1992. "Documentation and Utilization of the Results of Hazard
[8]. Evaluation Studies," prepared for presentation at the AIChE 1992 Spring National
[9]. Meeting, New Orleans, LA. Rohm and Haas Company, Bristol, PA.
[10]. Hummer, John J., John M. Googin, PhD, Michael W. Knazovich, Paul R. Wasilko, and
[11]. Janice West, 1992. "Report of Investigation of Accidental Release of Hydrogen Fluoride
[12]. from the Y-12 Plant Oak Ridge, Tennessee, January 24, 1992," Martin Marietta Energy
[13]. Systems, Inc., Oak Ridge, TN, March 1992.
[14]. King, Ralph, 1990. "Safety in the Process Industries," Butterworth-Heinemann, Ltd.1990.
[15]. Program Requirements," Washington, DC, January 1993.
[16]. Requirements for DOE Facilities," Washington, DC, July 1990 Cameron, I.T. and R. Raman, Process Systems Risk Management. Vol. 6. 2005: Academic Press.
[17]. Bridges, W. and T. Clark. How to efficiently perform the hazard evaluation (PHA) required for non-routine modes of operation (startup, shutdown, online maintenance). in 7th Global Congress on Process Safety. 2011.
[18]. U. S. Chemical Safety and Hazard Investigation Board, Williams Geismar Olefins Plant: Reboiler Rupture and Fire: Geismar, Louisiana: Incident Date: June 13, 2013: Two Fatalities, 167 Reported Injuries:. 2016.
[19]. U. S. Chemical Safety and Hazard Investigation Board, Chlorine release (16 medically evaluated, community evacuated): DPC Enterprises, L.P., Glendale, Arizona, November 17, 2003. 2003: Washington, D.C. p. 55.
[20]. U. S. Chemical Safety and Hazard Investigation Board, Chlorine release, July 20, 2003 (7 injured): contaminated antimony pentachloride exposure, July 29, 2003 (1 killed): hydrogen fluoride release, August 13, 2003 (1 exposed, 1 injured): Honeywell International, Inc., Baton Rouge, Louisiana 2005. p. 106.
[21]. Mannan, M.S., J. Makris, and H.J. Overman, Process Safety and Risk Management Regulations: Impact on Process Industry. Supplement 1 ed. Encyclopedia of Chemical Processing and Design, ed. R.G.A.a.J.J. McKetta. Vol. 69. 2002, New York: Marcel Dekker, Inc.
[22]. Litvak, A., Energy companies study the role of human behavior in safety. Pittsburgh Post-Gazette, 2014.
[23]. BP Texas City Final Investigation Report. 2007, U.S. Chemical Safety and Hazard Investigation Board.
[24]. Process safety management guidelines for compliance. 1992: [Washington, D.C.]: U.S. Dept. of Labor, Occupational Safety and Health Administration, 1992.
[25]. Kaszniak, M., Oversights and omissions in process hazard analyses: Lessons learned from CSB investigations. Process Safety Progress, 2010. 29(3): p. 264-269.
[26]. Moss, T., Auditing Offshore Safety Risk Assessments. Journal of Petroleum Technology, 1990. 42(10): p. 1241-1243.
[27]. Crawley, F. and B. Tyler, HAZOP: Guide to Best Practice (Third Edition). 2015: Elsevier.
[28]. Center for Chemical Process Safety, Guidelines for Risk Based Process Safety. 2007, Center for Chemical Process Safety/AIChE.
[29]. BC News, China explosions: What we know about what happened in Tianjin - BBC News. 2015.
[30]. Andrew Jacobs, J.C.H. and B. Chris, Behind Deadly Tianjin Blast, Shortcuts and Lax Rules. 2015.

[31]. Mortimer, C., Tianjin explosion: Gigantic crater left by Chinese factory explosion revealed in this picture. 2016.
[32]. Hyatt, N., Guidelines for process hazards analysis (PHA, HAZOP), hazards identification, and risk analysis. 2003: CRC press.
[33]. Dunjó, J., et al., Conducting HAZOPs in continuous chemical processes: Part I. Criteria, tools and guidelines for selecting nodes. Process Safety and Environmental Protection, 2011. 89: p. 214-223.
[34]. Center for Chemical Process Safety, Hazard Identification and Risk Analysis, in Guidelines for Auditing Process Safety Management Systems. 2011, John Wiley & Sons, Inc. p. 307-360.
[35]. Center for Chemical Process Safety, Guidelines for Defining Process Safety Competency Requirements. 2015, New York, US: American Institute of Chemical Engineers.
[36]. Center for Chemical Process Safety, Guidelines for Chemical Process Quantitative Risk Analysis. 2nd ed ed. CCPS guidelines series. 2000: New York: The Center, [2000].
[37]. Rushton, A.G., Quality Assurance of HAZOP. 1996, U.K. Health and Safety Executive: Sheffield, UK.
[38]. Beerens, H.I., J.G. Post, and P.A. Uijt de Haag, The use of generic failure frequencies in QRA: the quality and use of failure frequencies and how to bring them up-to-date. J Hazard Mater, 2006. 130(3): p. 265-70.
[39]. Moss, T.R. and J.E. Strutt, Data Sources for Reliability Design Analysis. Proceedings of the Institution of Mechanical Engineers, Part E: Journal of Process Mechanical Engineering, 1993. 207(1): p. 13-19.
[40]. LOPA – Layer of Protection Analysis. Process and HSE Engineering, 2011.
[41]. Lowrance, W.W., Of Acceptable Risk: Science and the Determination of Safety. 1976.
[42]. Shortreed, J., K. Dinnie, and D. Belgue. Risk criteria for public policy. in Proceedings of the First Biennial Conference on Process Safety and Loss Management. 1995.
[43]. Health and Safety Executive, Initial briefing to Societal Risk Technical Advisory Group. 2009, Research Report, RR703.
[44]. Duijm, N.J., Recommendations on the use and design of risk matrices. Safety Science, 2015. 76: p. 21-31.
[45]. Mannan, M.S., Personal Communication. 2017.
[46]. Suttinger, L.T. and C.L. Sossman, Operator Actions Within a Safety Instrumented Function. Conference: ISA 2002, Chicago, IL (US), 10/21/2002--10/24/2002; Other Information: PBD: 6 Sep 2002. 2002: Savannah River Site (US). Medium: ED; Size: vp.
[47]. Baybutt, P., Competency requirements for process hazard analysis (PHA) teams. Journal of Loss Prevention in the Process Industries, 2015. 33: p. 151-158.
[48]. Process safety management guidelines for compliance. 1994 (Reprinted). 1994: [Washington, D.C.]: U.S. Dept. of Labor, Occupational Safety and Health Administration, [1994].
[49]. Occupational Safety and Health Administration, OSHA Letter of Interpretation of PSM Standard, T.N.C. Robert Summers, Inc., Editor. 2001.
[50]. Mannan, M.S., Chemical Process Safety Lecture: HAZOPs. 2015.
[51]. Ralph, W., Personal Communication. 2017.