

# Fire Impact Assessment Of Flammable Fuel Storage In Heat Treatment Plant Using Fire Dynamic Simulator

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**Abstract-** Today we use highly durable materials in our day to day life. Some material used for manufacturing of mechanical components and infrastructure projects require high strength and durability. To make a component highly durable heat treatment is done to fulfil the requirement of particular needs of a component. The Heat Treatment process increases the strength of the material by modifying their metallurgical properties. In Heat Treatment facility, the fire hazards are comparatively high and even a single fire accident may be catastrophic due to the congested and complex layout of the facility. This study proposes a novel methodology for modelling the impact of a fire event in a Heat Treatment facility. Hazard identification and accident credibility assessment have been used to discover the most credible fire accident scenarios. These scenarios have been simulated using Computational Fluid Dynamics (CFD) code, Fire Dynamics Simulator (FDS). The results have then been compared to identify the most severe impact of the fire on personnel and assets using thermal radiation and risk levels. It has been found that the fire event in scenarios has a high potential to cause damage to adjacent assets. From this comparison, it is evident that the scenario in the fuel storage and transmission pipe lines in the combustion process have the highest risk of fire to both personnel and assets. The proposed methodology may be adapted further for safety measure design to mitigate or avoid the impacts of a fire event in any complex processing facility.

**Keywords-** Computational Fluid Dynamics (CFD), Fire Dynamics Simulator (FDS), Hazard identification.

## I. INTRODUCTION

Process facilities are usually equipped with diverse equipment, control systems and operating procedures. Any process deviations from normal operating conditions, due to errors in the interaction of equipment, human factor, management and organizational issues make process plants susceptible to process failures and or accidents. Some major accidents such as The Piper Alpha disaster, The Bhopal accident, The Ocean Ranger accident, The Cleveland accident, The Skikda accident, The BP Texas City disaster and The BP

Deepwater Horizon explosion are examples of such accidents. Some lessons were learned from each accident and safety regulations and designs have been upgraded. Despite upgrading for designs, operating and emergency procedures, previous accidents demonstrate that the processing plants are still vulnerable. Accidents in processing facilities are mainly associated with fire, explosions and toxic product releases.

Fire is the most frequent accident in process facilities and in the transportation of hazardous materials. Considering fire and explosion as the potential major accidents, fires account for 59.5% of these accidents in process industries. Because of the frequent occurrences of fire accidents in process facilities, there is always a need for an efficient means of combating potential fire accidents.

In recent years, many studies have been conducted considering the fire risk analysis and accident modelling. For modelling the impacts of fire, various models are available, namely semi-empirical models, integral models, zone models and CFD models. Analytical models cannot simulate obstacles and they do not represent the real condition of a system.

### 1.1 Definition

#### Heat Treatment

Process in which a metal is heated to a certain temperature and the cooled in a particular manner to alter its internal structure for obtaining desired degree of physical and mechanical properties such as brittleness, hardness, and softness.

#### Flammable Fuel

A flammable liquid is a combustible liquid that can easily catch fire. However, it is not the liquid itself that burns, but the vapor cloud above the liquid that will burn if the vapor's concentration in air is between the lower flammable limit (LFL) and upper flammable limit (UFL) of the liquid.

#### Methanol

A toxic, colourless, volatile flammable liquid alcohol, made chiefly by oxidizing methane.

### High Speed Diesel (HSD)

It is normally used as a fuel in medium and high-speed compression ignition engines (operating above 750 rpm) in commercial vehicles, stationary diesel engines, locomotives and pumps etc.

### Liquified Petroleum Gas (LPG)

It is a compressed gas that consists of flammable hydrocarbons (such as propane and butane) and is used especially as fuel or as raw material for chemical synthesis.

### Furnace

An enclosed structure in which material can be heated to very high temperatures.

### Blower

A mechanical device for creating a current of air used to dry or heat something.

### Fire

It is the rapid oxidation of a material in the exothermic chemical process of combustion, releasing heat, light, and various reaction products. The flame is the visible portion of the fire. If hot enough, the gases may become ionized to produce plasma. Depending on the substances alight, and any impurities outside, the colour of the flame and the fire's intensity will be different.

### Fire Elements

There are four elements needed to start and sustain a fire or a flame. These elements are classified in the “fire tetrahedron” and are:

1. Reducing agent (fuel)
2. Heat
3. Oxidizing agent (oxygen)
4. Chemical Reaction

### Fire Safety

Is set of practices intended to reduce the destruction caused by fire, Fire safety measures include those that are intended to prevent ignition of an uncontrolled fire, and those

that are used to limit the development and effects of a fire after it starts.

Fire safety measures include those that are planned during the construction of a building or implemented in structures that are already standing, and those that are taught to occupants of the building.

### Explosion

An explosion is a rapid increase in volume and release of energy in an extreme manner, usually with the generation of high temperatures and the release of gases. Supersonic explosions created by high explosives are known as detonations and travel via supersonic shock waves.

### Bleve

A boiling liquid expanding vapor explosion is an explosion caused by the rupture of a vessel containing a pressurized liquid above its boiling point.

### Computational Fluid Dynamics

CFD is a branch of fluid mechanics that uses numerical analysis and data structures to solve and analyse problems that involve fluid flows.

### Fire Dynamics Simulator

FDS is a computational fluid dynamics (CFD) model of fire-driven fluid flow. The software solves numerically a form of the Navier-Stokes equations appropriate for low-speed, thermally-driven flow, with an emphasis on smoke and heat transport from fires.

### Quantitative Risk Assessment Module (QRAM)

It is a hazard modelling program, which is used widely to plan for and respond to emergencies.

### DIKE

A long wall or embankment built to prevent flooding from the sea.

### Emergency Control Room (ECR)

A room used to coordinate the emergency procedures during an accident.

### Dispersion

It is a system in which particles are dispersed in a continuous phase of a different composition (or state), colloidal size range, dispersed throughout a continuous phase.

## II. LITERATURE SURVEY

A.Yu. Snegirev ET AL developed a simplified approach capturing major flame extinction mechanism has been formulated and calibrated against the measurement data for critical strain of laminar diffusion counter flow flames with fuel and (or) oxidizers stream diluted by nitrogen. This model correctly predicts the minimum extinguishing concentration of different inert diluents like argon, nitrogen, water vapor and carbon dioxide which is used for fire suppression. This proposed algorithm can be used for any practical fuel as the global kinetic model of fuel oxidation is calibrated using procedures developed in this project.

Dominik Hermann paper discusses the modelling challenges that need to be overcome when performing probabilistic precursor analysis. The events used to analyze are selected from the Organization for Economic Cooperation and Development (OECD) and Fire Incident Records Exchange (FIRE). He concludes that the Relative Risk Index (RRI) decrease when Bayesian model is used.

DwiArini ET AL research is to study fire induced smoke movement in basement of the building. They erected a replica of the basement in 1:8 scale for the experiment. They adopted Froude number for calculation as they assumed that the smoke movement and temperature distribution is mainly caused by buoyant force from fire source. They concluded that the weak buoyancy of smoke result in accumulation of smoke in location of fire source itself, which led to significant increase of temperature.

Qiang Liu ET AL simulated and studied the aspect of tank rupture and leakage by numerical simulation, which can be further applied to safe design and accident consequence analysis of oil storage tank. They developed a CFD based model to simulate the dike over topping after catastrophic rupture of oil tank. As a result of their research they concluded that the rupture occurred at bottom of tank will cause quicker spill and more overtopping of oil than that in other positions.

TilBaalispang ET AL study proposes a novel methodology for modelling the impact of fire in a Floating Liquefied Natural Gas facility. Hazard identification and accident credibility assessment have been used to discover the fire scenarios, which have been simulated using Computational Fluid Dynamics and Fire Dynamics Simulator.

The result has been compared to identify most severe impact of fire on personnel and assets by thermal radiation.

Wolfram Jahn thesis proposes and studies a method to use measurement of the real events in order to steer and accelerate fire simulations. The aim of this proposed model is to provide fire development forecasting with a positive lead time i.e., the forecast of future events is ready before those events takes place.

### 2.1 Objective

simulating it virtually and to make the industry realise that even a simple permissible violation may lead to severe loss, even though there is no such previous incident occurred.

## III. METHODOLOGY

1. Fire Risk Assessment
2. The Most Credible Accident Scenario (MCAS) identification.
3. CFD simulation of identified credible accident scenarios.
4. FDS for fire simulation to calculate Heat Release Rate (HRR).
5. To evaluate Dispersion, Fire and Explosion spread radius by using QRA Module.
6. Assessment to evaluate impact on Human and Structural or Assets.

## LAYOUT OF METHODOLOGY

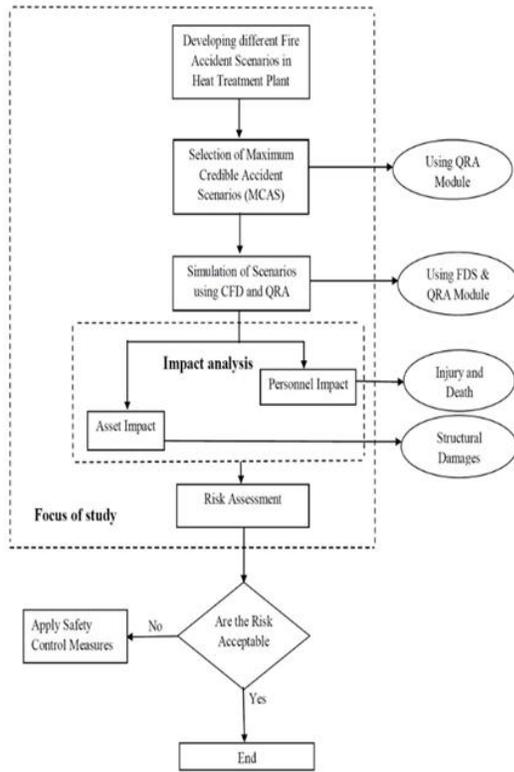


Fig.1 Overall framework of the developed methodology of fire impact assessment in HTP

Table1.Fire risk assessment (FRA)

FIRE RISK ASSESSMENT (FRA)							RISK SCORE	
Site:			Thiruvudikkam				14.37	
Department:			Heat Treatment					
Machine / Area:			Flammable Fuel Storage					
S.NO	Location	Hazard Description	Potential Hazards (What can cause harm to you or others while performing the step?)	Safe Practices or Controls (What method is currently in place to keep the hazard from hurting you or others?)	RESIDUAL RISK			Current Risk Total
					P	C	PxC	
<b>SOURCES OF IGNITION (Check, inspect and control)</b>								
1	LPG Storage Area	Electrical fittings, pumps and generators	Fire Hazard - i. Spark may produce due to usage of Electrical fittings. ii. Heat generated from pump and generator operation	Simple inspection, Visual audit	2	5	10	10
								Periodic inspection and maintenance of electrical fittings by a competent person. Fire partition wall must be erected to separate pump and generator area Install Gas detection system to identify leakage Ensure that all electrical circuits are not subject to overload. Installation of automatic fire detection and suppressing unit Ensure that sootier outlets are not overloaded.
2	Methanol Storage Area	Manual Handling of methanol	i. Spill Hazard- manual handling of methanol in barrels using forklift. ii. Fire Hazard- due to heat produced by pump.	Simple inspection, Visual audit	3	5	15	15
		Hot work process	Fire Hazard- Ignition from Hot work source	Temporarily Barricade used	3	5	15	15
								Avoid Manual handling of Methanol Spark arrestor provided in electrical fittings. Properly maintain pump to reduce heat generation Work Instructions to be developed.
3	HSD Storage Area	No dike provided and stacking of other flammable materials inside the boundary of HSD storage yard	i. Spill Hazard- leakage from valves of storage tanks. ii. Fire Hazard- Spark may be produced from electrical light post or metal ladders stored inside the yard	Simple inspection, Visual audit	2	5	10	10
								Periodic inspection and maintenance of electrical fittings by a competent person. Periodic maintenance of valves of storage Tank Installation of automatic fire detection and suppressing unit Avoid stacking of flammable and combustible metal inside the yard
4	Furnace Area	Heat Radiation	Fire Hazard- Ignition from environment, Hot work source	N/A	2	5	10	10
								Provide fire resistant wall to separate furnace area and fuel storage area

5	General Maintenance	Any heat generating processes like welding, cutting etc	Fire Hazard- Ignition from environment, Hot work source	Suitable fire fighting equipment available nearby	2	4	8	Ensure equipment is used in accordance with manufacturer's recommendations and properly maintained Avoid hot work process near the fuel storage area	8
6	Fuel Storage Yard	Material Handling Equipment	Fire Hazard- Spark produced from ignition of equipment	N/A	2	4	8	Install spark arrestor in equipment operating in the vicinity of fuel storage Suitable fire fighting equipment available nearby	8
		Lightning Protection	Damage to structure by lightning	No protection	1	5	5	Adequate lightning protection on structures	5
		Surveillance	Trespassing	Areas are controlled by security fencing, CCTV, intruder alarms, have controlled	1	2	2	Intruder alarms should be installed	2
		Maintenance Activities	Fire Hazard- Ignition from environment, Hot work source	Work permit procedure in place	2	3	6	Fire protection must be done before carrying out maintenance work	6
		Self combustion of materials	Fire Hazard- Ignition from environment, Hot work source	If materials at risk of self combustion are stored for longer than 3 months, additional measures are in place including monitoring & turning of the piles. There is a clear method in place to record & manage the storage of all waste on site	1	3	3	Safe waste disposal system must be implemented	3
<b>COMBUSTIBLE MATERIALS FUEL SOURCES (Remove, reduce and control)</b>									
7	Fuel Storage Yard	Horsekeeping	Fire Hazard- ignition of waste accumulated	There is good general housekeeping	1	3	3	Cleaning shifts, site inspections	3
		Any flammable or highly flammable materials or substances on site. E.g. some solvents, paints, oils and	Fire Hazard- ignition of flammables	The use of flammable materials and substances are avoided. All flammable substances required for maintenance activities are stored in flammable cabinets	1	3	3	Completely remove the flammable material	3
		Is any waste/welfare rubbish stored externally (e.g. waste skips, bins, etc.)	Fire Hazard- ignition of waste accumulated	Waste skips are kept locked and stored away from buildings and plant.	1	3	3	Industrial waste stored externally	3
		Orphaned Cylinder Store	i. Fire Hazard- ignition of waste accumulated ii. Roll over of cylinders	No proper Cylinder store location.	1	2	2	Cylinder store away from building and pedestrian routes Cylinder storage near bores and needs to be moved	2
<b>SOURCES OF OXYGEN (Reduce)</b>									
8	HTP	Reduce the potential sources of oxygen to a fire	Oxygen source help in fire hazard	N/A	2	4	8	Periodic maintenance of valves and oxygen cylinders	8
<b>CONTAINING AND MITIGATING (Control)</b>									
		Automatic detection	Fire Hazard- Spread of fire	NA	3	4	12	Fire alarm not currently connected to a remote monitoring centre service schedule in place and it is being followed. Sufficient number of suitable smoke/heat detectors/alarms located in all common areas	12
				NA					

9	HTP and Fuel Storage Area	Means of alarm sound	Increase casualty- if no proper alarm system installed	There is adequate means of raising alarm sound	3	4	12	Emergency call points in place Fire alarm in pre-sort may not be fully available due to surrounding noise	12												
		Means of fighting fire	Fire Hazard- Spread of fire	Fire suppression systems have been fitted in factory (Fire Hydrant) Fire suppression systems are regularly maintained and serviced (Fire Hydrant)	3	4	12	Sprinklers to be installed in the HTP and Fuel Storage Yard	12												
	Means of escape	Stamped Hazard- chaos during evacuation	Sufficient numbers of fire escape routes Escape is available in more than one direction Everyone can escape without assistance Exits are easily identified There is a dedicated assembly point located in a safe area Emergency team is prepared	2	4	8	Make sure Escape routes are free from obstruction There is adequate emergency lighting Additional signage to be installed	8													
<b>INFORMATION / TRAINING FOR WORKERS &amp; OTHERS</b>																					
10	HTP and Fuel Storage Area	INFORMATION / TRAINING	Miss Communication	workers know the identity of those persons nominated to implement the emergency action plan	2	2	4	Monthly training and 6 month once fire drills should be conducted	4												
		INFORMATION / TRAINING	Miss Communication	Fire Action Notices clearly displayed throughout the Premises (where relevant) suitable & regular fire safety training given to workers and full details of this training recorded.	2	2	4	Monthly training and 6 month once fire drills should be conducted	4												
<b>Risk to Persons on the Premises</b>																					
11	HTP and Fuel Storage Area	Person at risk	Increase casualty	Every person are trained and know the exit Wheel chairs are available	2	2	4	Make assistance for disabled workers	4												
<table border="1" style="width: 100%;"> <tr> <th>Degree of Risk</th> <th>Risk Rating Score</th> </tr> <tr> <td>Very High Risk</td> <td>20 to 25</td> </tr> <tr> <td>High Risk</td> <td>12 to 19</td> </tr> <tr> <td>Medium Risk</td> <td>8 to 11</td> </tr> <tr> <td>Low Risk</td> <td>5 to 7</td> </tr> <tr> <td>Very Low Risk</td> <td>1 to 4</td> </tr> </table>										Degree of Risk	Risk Rating Score	Very High Risk	20 to 25	High Risk	12 to 19	Medium Risk	8 to 11	Low Risk	5 to 7	Very Low Risk	1 to 4
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FIRE HAZARDS AND THEIR ELIMINATION OR CONTROL

1. SOURCES OF FUEL

1.1 Are there any highly flammable substances in the premises?	<input checked="" type="checkbox"/> Yes	<input type="checkbox"/> No
1.2 Control Measures	<ul style="list-style-type: none"> <li><input type="checkbox"/> Replace them with safer alternatives</li> <li><input type="checkbox"/> Remove or significantly reduce any highly flammable substances</li> <li><input checked="" type="checkbox"/> Keep them in fire resisting stores</li> <li><input checked="" type="checkbox"/> Separate them from heat sources by use of fire resisting construction</li> <li><input type="checkbox"/> Keep minimum quantity in workroom</li> <li><input type="checkbox"/> Ensure all containers are kept closed when not in use</li> <li><input type="checkbox"/> Other (state here)</li> </ul>	
1.3 Are flammable liquids or gases used or stored in areas without adequate Ventilation?	<input type="checkbox"/> Yes	<input checked="" type="checkbox"/> No
1.4 Control Measures	<ul style="list-style-type: none"> <li><input type="checkbox"/> Improve ventilation</li> <li><input type="checkbox"/> Other (state here)</li> </ul>	
1.5 Are there quantities of combustible material stored or in use in the premises. E.g. Fuel, Lubrication oil etc?	<input checked="" type="checkbox"/> Yes	<input type="checkbox"/> No
1.6 Control Measures	<ul style="list-style-type: none"> <li><input type="checkbox"/> Replace stocks of combustible materials with non-combustibles</li> <li><input type="checkbox"/> Reduce stocks of readily combustible materials to a minimum</li> <li><input checked="" type="checkbox"/> Separate such materials from heat sources or by fire resisting construction</li> <li><input type="checkbox"/> Other (state here)</li> </ul>	
1.7 Are quantities of combustible waste allowed to accumulate in the premises such as Paper, cardboard, wood shavings, dust?	<input type="checkbox"/> Yes	<input checked="" type="checkbox"/> No
1.8 Control Measures	<ul style="list-style-type: none"> <li><input type="checkbox"/> Improve the arrangements for the disposal of waste</li> <li><input type="checkbox"/> Improve the general housekeeping</li> <li><input type="checkbox"/> Ensure staff are aware of the standard of housekeeping required</li> <li><input type="checkbox"/> Give specific additional training to the staff responsible</li> <li><input type="checkbox"/> Other (state here)</li> </ul>	

3.1 Fire Risk Assessment Check List

Employer or other responsible person			
Name of Premises	XXXX		
Address	XXXX		
Post Code		Telephone no	
Name of Assessor(s)	-		
Date of Assessment	18-09-2017	Date of Review	18-01-2018

FACILITY GENERAL INFORMATION

Property Use	MANUFACTURING OF GEAR BOX		
No of floors	N/A	No of floors below ground	N/A
Approx area in m <sup>2</sup> of footprint of building		Age of building	14 YEARS
Brief details of construction	INDUSTRIAL SHED WITH ADMINISTRATION BUILDING		

BUILDING OCCUPANTS GENERAL INFORMATION

Occupancy Profile: Maximum Number of persons, in the most highly occupied compartment to be effected by an uncontrolled fire within 30 minutes, assuming no evacuation.	WEEKDAYS		WEEKENDS	
	0000 to 0400	50-70	0000 to 0400	50-70
	0400 to 0800	50-70	0400 to 0800	50-70
	0800 to 1200	50-70	0800 to 1200	50-70
	1200 to 1600	50-70	1200 to 1600	50-70
	1600 to 2000	50-70	1600 to 2000	50-70
	2000 to 2400	50-70	2000 to 2400	50-70

3.3. MAXIMUM CREDIBLE ACCIDENT SCENARIO (MCAS)

The central criterion that constitutes a credible accident.

3.3.1. Maximum Credible Accident Scenario For Dispersion

- i. Flash vaporization of CLG/Methanol/HSD storage tanks forming gas puff.
- ii. Rupture of CLG/Methanol/HSD tanks on site and rapid evaporation.
- iii. Main pipeline rupture induces flash puff.
- iv. Pipeline leak leads to slow and steady vaporization of cryogenic liquid pool.

- v. Rupture of storage tanks leads to slow and steady pool evaporation dispersion under DF stability.
- vi. Flash evaporation of externally heated storage tank forming gas puff.

**3.3.2. Maximum Credible Accident Scenario For Fire**

- i. CLG/Methanol/HSD main pipe leak leads to free spread Pool Fire
- ii. Cryogenic liquid Pool Fire
- iii. Main pipe rupture leads to Jet Fire.
- iv. Tank rupture flash vaporization forming gas cloud puff immediate edge ignition lead to Fire Ball.
- v. Main pipe leak flash puff immediate edge ignition lead to Fire Ball.

**3.3.3. Maximum Credible Accident Scenario For Explosion**

- i. CLG/Methanol/HSD tank rupture at stored temperature flash vaporization forming gas cloud delayed internal ignition leads to BLEVE.
- ii. Tank rupture free spread liquid pool on rapid vaporization of cryogenic delayed ignition leads to explosion.
- iii. Mechanical explosion scenario.
- iv. Main pipe rupture flash puff delayed internal ignition leading to explosion.

**3.4. FIRE DYNAMICS SIMULATION**

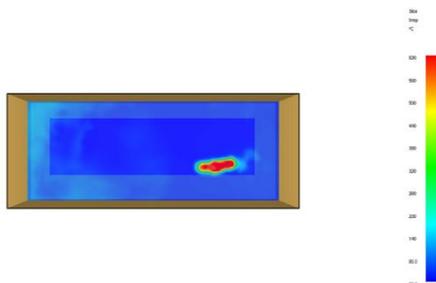


Fig.2. Simulation I for 10 Seconds of fire spread

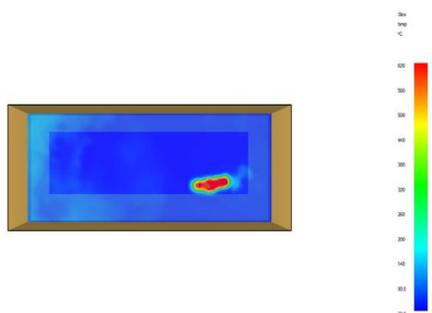


Fig.3. Simulation II for 21 Seconds of fire spread

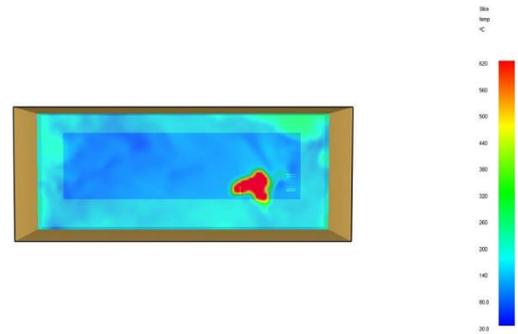


Fig.4. Simulation III for 40 Seconds of fire spread

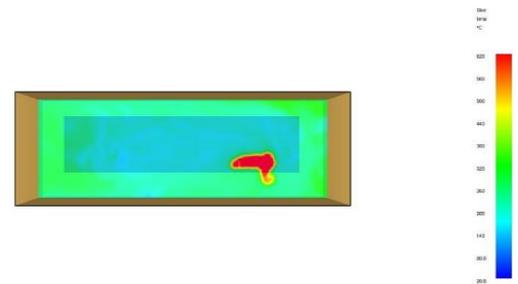


Fig.5. Simulation IV for 80 Seconds of fire spread

**IV. RESULT AND DISCUSSIONS**

**RESULT**

The simulation results are given below for different Flammable Fuels.

**4.1. IMPACT ASSESSMENT**

The severity of the affliction depends upon the area struck.

**4.1.1. Impact of Dispersion Of LPG**

Table 2.Impact of Dispersion Of LPG

MCAS	Dist. in (m)	Time in (Sec)	Dosage in (mg)	Fatality %	Injury %
SCENAR IO 1	2.1	0.53	620117.581	100	0
	232.68	58.2	619.95	0	26.38
SCENAR IO 2	2.1	0.53	569.6392	74.91	25.09
	66.7	16.53	0.6221	0	20.73
SCENAR IO 3	2.1	0.53	9556.0219	100	0
	89.91	22.49	0.19	0	2.71
SCENAR IO 4	2.1	0.53	3422.5532	100	0
	111.2	27.82	1.4007	0	40.64

	4				
SCENAR IO 5	2.1	0.53	569.6352	74.91	25.09
	66.07	16.53	0.6221	0	20.73
SCENAR IO 6	2.1	0.53	46410769.84	100	0
	849.22	212.41	2.7639	0	16.65

O 6			88		
	3226.5	807.01	6.8224	0	14.91

**4.1.2 Impact of Explosion Of LPG**

Table 3. Impact of Explosion of LPG

MCAS	Dist.i n (m)	Over Pressu re in (psi) invert	Fatalit y %	Ear drum Ruptur e%	Structu ral Damag e %	Glas s Bre ak %
SCENAR IO 1	77.114	17.95	10.49	96.40	100	100
	836.630	0.83	0	0.33	0.52	87.04
SCENAR IO 2	8.230	18.04	11	96.45	100	100
	107.29	0.83	0	0.33	0.52	87.13
SCENAR IO 3	8.230	18.04	11	96.45	100	100
	107.29	0.83	0	0.33	0.52	87.13
SCENAR IO 4	8.230	18.04	11	96.45	100	100
	107.29	0.83	0	0.33	0.52	87.13

**4.2.1. Impact of Dispersion of Methanol**

Table 4. Impact of Dispersion of Methanol

MCAS	Dist. in (m)	Time in (Sec)	Dosage in (mg)	Fatalit y %	Injur y %
SCENAR IO 1	2.1	0.53	515.0745	93.81	6.19
	88.07	22.03	0.5936	0	27.35
SCENAR IO 2	2.1	0.53	489.2216	90.36	9.64
	86.59	21.66	0.5799	0	26.72
SCENAR IO 3	2.1	0.53	205.5792	43.17	56.3
	67.6	16.91	0.3653	0	16.22
SCENAR IO 4	2.1	0.53	4.792	0	88.39
	67.6	16.91	0.3653	0	16.22
SCENAR IO 5	2.1	0.53	4.792	0	88.39
	67.6	16.91	0.3653	0	16.22
SCENAR IO	2.1	0.53	1661595396.74	100	0

**4.2.2. Impact of Fire of Methanol**

Table 5. Impact of Fire of Methanol

MCAS	Dist.i n (m)	IHR in (kW/m <sup>2</sup> )	Dose in (kWh/m <sup>2</sup> )	Fatalit y %	Injur y %
SCENAR IO 1	71.1	37.82	47.29	100	0
	290.7	2.26	2.42	0	1.13
SCENAR IO 2	71.1	37.82	47.29	100	0
	290.7	2.26	2.42	0	1.13
SCENAR IO 3	58.73	37.69	49.35	100	0
	239.53	2.27	2.52	0	1.23
SCENAR IO 4	19.83	31.29	42.63	78.67	21.33
	75.43	2.16	2.59	0	0.17
SCENAR IO 5	224.49	37.53	47.19	100	0
	930.49	2.26	2.42	0	1.13

**4.3.1. Impact of Dispersion of High-Speed Diesel (HSD)**

Table 6. Impact of Dispersion of High-Speed Diesel (HSD)

MCAS	Dist. in (m)	Time in (Sec)	Dosage in (mg)	Fatalit y %	Injur y %
SCENAR IO 1	2.1	0.53	2296.4541	91.55	8.45
	72.26	18.06	2.0616	0	21.75
SCENAR IO 2	2.1	0.53	2296.4541	91.55	8.45
	72.26	18.06	2.0616	0	21.75
SCENAR IO 3	2.1	0.53	2296.4541	91.55	8.45
	72.26	18.06	2.0616	0	21.75
SCENAR IO 4	2.1	0.53	2296.4541	91.55	8.45

	72.2	18.06	2.0616	0	21.75
SCENARI O 5	2.1	0.53	2296.4541	91.55	8.45
	72.2	18.06	2.0616	0	21.75
SCENARI O 6	2.1	0.53	2296.4541	91.55	8.45
	72.2	18.06	2.0616	0	21.75

**4.3.2. Impact of Fire of High-Speed Diesel (HSD)**

Table 7. Impact of Fire of High-Speed Diesel (HSD)

MCAS	Dist.in (m)	IHR in (kW/m <sup>2</sup> )	Dose in (kWh/m <sup>2</sup> )	Fatalit y %	Injur y %
SCENARI O 1	37.21	38.19	52.25	100	0
	152.81	2.26	2.63	0	1.13
SCENARI O 2	512.62	37.56	47.67	100	0
	2089.02	2.26	2.38	0	1.13
SCENARI O 3	43.62	34.34	40.99	91.23	8.77
	171.62	2.22	2.31	0	0.75
SCENARI O 4	37.21	38.19	52.25	100	0
	152.81	2.26	2.63	0	1.13
SCENARI O 5	793.84	37.52	46.68	100	0
	3243.84	2.26	2.39	0	1.13

**4.4. RECOMMENDATIONS**

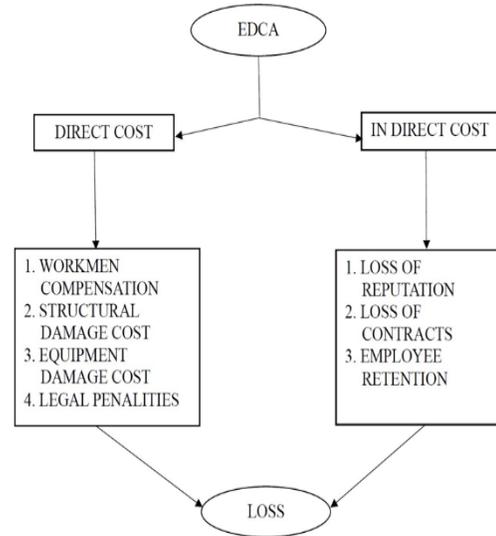
- i. Storage of LPG in bullets instead of cylinders
- ii. Installation of gas detectors
- iii. Installation of automatic fire detection and suppression system
- iv. Provision of dike for liquid fuel storage tank
- v. Provision of spark arrestor in all electrical equipment's used in the storage yard
- vi. Periodic maintenance of mechanical fittings used in fuel transfer system

**4.5. COST BENEFIT ANALYSIS**

It is a systematic approach to estimate the strengths and weaknesses of alternatives (for example in transactions, activities, functional business requirements or projects investments). It is used to determine options that provide the best approach to achieve benefits while preserving savings.

The CBA is also defined as a systematic process for calculating and comparing benefits and costs of a decision, policy (with particular regard to government policy) or (in general) project.

**4.5.1. Expected Damage Cost Analysis (EDCA)**

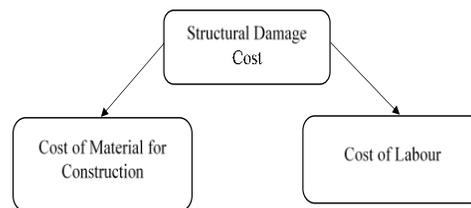


**Fig.6 Expected Damage Cost Analysis**

**4.5.2. Calculation of Workmen Compensation**

- i. Fatality = 50% of Total monthly income x Relevant Factor
- ii. Permanent Total Disablement = 60% of Total monthly income x RF
- iii. Permanent Partial Disablement = 40% of Total monthly income x RF
- iv. Temporary Disablement = 25% of Total monthly income till recovery

**4.5.3. Structural Damage Cost**



**Fig.7 Structural Damage Cost**

**4.5.4. Equipment Damage Cost**

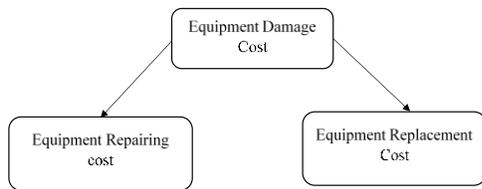


Fig.8 Equipment Damage Cost

4.5.5. LEGAL COST

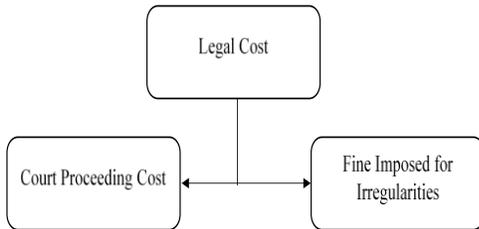


Fig.9 Legal Cost

4.5.6. Overall Loss Incurred Due to Accident

It is sum of all the direct and in direct cost involved in the accident (Compensation to workers + Structural Damage cost + Equipment Damage cost + Legal cost + Loss of Orders + Loss of Production).

**EXAMPLE SCENARIO:** Accident involving 2-Fatalities and 6-Injuries

Employee details	Age	Disablement	Salary
Employee 1	22		30,000.00
Employee 2	24		50,000.00
Employee details	Age	Disablement	Salary
Employee (PTD)	3	20	15,000.00
Employee (PTD)	4	26	25,000.00
Employee (PPD)	5	18	20,000.00
Employee (TD)	6	37	30,000.00
Employee (TD)	7	40	40,000.00
Employee (TD)	8	48	50,000.00

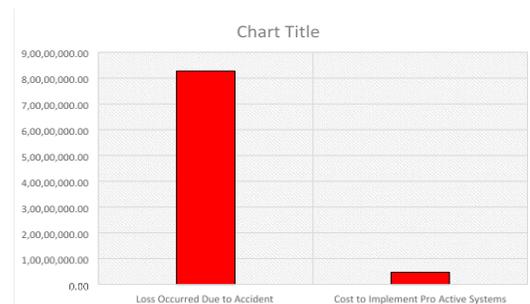
- i. Workmen Compensation Payable is Rs.1,57,55,180.00 (8 Workers)
- ii. Structural Damage cost is Rs.1,20,00000.00 (Affected area is 100mts)
- iii. Equipment Damage cost is Rs.5,00,00,000.00
- iv. Legal Cost is Rs.50,00,000.00

4.5.7. Cost Analysis for Implementation of Recommendations

- i. Cost of erection of LPG bullet - 4 to 5 Lakhs
- ii. Cost of installation of gas detector around the storage yard – 1 to 2 Lakhs
- iii. Setting of integrated emergency control room – 2 to 3 Lakhs
- iv. Installation of automatic fire detection and suppression system – 15 to 30 Lakhs
- v. Provision for dike for liquid fuel storage to contain leakage – 2 Lakhs
- vi. Installation of spark arrestors in all electrical equipment’s – 2 to 3 Lakhs
- vii. Maintenance Cost of all systems per year – 1 to 2 Lakhs

4.5.8. Cost Comparison of Loss Occurred Due to Accident And Implementation Of Pro-Active System

Fig.10 Cost Comparison Chart



V. CONCLUSION

The fire impact assessment is done for Flammable Fuel Storage in Heat Treatment Plant using Fire Dynamics Simulator in order to calculate Heat Release Rate (HRR) evolved during fire accident. The HRR obtained from Fire Dynamics Simulator is used as an input in Advanced Quantitative Risk Assessment Module (QRAM) to evaluate the Dispersion, Fire and Explosion Radius of the accident for the Maximum Credible Accident Scenario (MCAS). The recommendations are made to mitigate the accidents are proposed and cost comparison of losses incurred due to accident and implementation of mitigation system are done.

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## ANNEXURE I

## MATERIAL SAFETY DATA SHEET (MSDS)

**Product Name:** Methanol

**(i) Product Synonyms:** Methyl Alcohol, Methyl Hydrate, Wood Alcohol

**(ii) General Use:** Methanol has wide industrial use as a solvent and is extensively employed as a paint and varnish remover, as a chemical intermediate, and in the preparation of stains, enamels, plastics, and films. It is used to manufacture formaldehyde and methyl esters of organic and inorganic acids; chemical synthesis;

automotive antifreeze; denaturant for ethyl alcohol; dehydrator for natural gas, It is also used as a fuel.

**(iii) Product Description:** Clear, colourless, flammable, poisonous, mobile, highly polar liquid with slight alcohol odour, miscible with water, alcohol, ether, ketones and most other organic solvents. Burns with a nonluminous, bluish flame.

**(iv) Composition / Information on ingredients:**

Ingredient	Weight %	CAS Registry
Methanol	98	67-56-1
Water	1.8	7732-18-5

**(v) OSHA Hazardous Components (29 CFR 1910.1200):** Exposure Limits 8 hrs.

TWA (ppm).

Component	OSHA PEL	ACGIH TLV
Methanol	200 ppm	200 ppm
Water	N/A	N/A

**(vi) Potential Health Effects:**

**#Eye contact:** Methanol can seriously impair vision and may cause blindness. Immediate signs and symptoms include the following: vapours are slightly uncomfortable and splashes very irritating; irritation with painful burning or stinging sensation; watering of eyes; inflammation of the eyelids; eyes are sensitive to and painful in the light.

**#Skin contact:** Direct skin contact with methanol may cause irritation, dermatitis, erythema, and scaling. Methanol is highly volatile and will produce a feeling of cold. Alcohols remove oils from the skin, which becomes dry and eventually develops cracks or dermatitis. Methanol which can be absorbed by the skin, causes headache, fatigue, and reduction of visual acuity.

**#Inhalation:** Sign and symptoms of acute poisoning include slight irritation of the nose and eyes; head feels hot and face is flushed; excitability and talkativeness; drunken behaviour; staggering and lack of coordination; headache; mental confusion and visual disturbance; tiredness.

**#Ingestion:** Signs and symptoms of acute poisoning are gastrointestinal irritation; head feels hot and face is flushed; excitability and talkativeness; drunken behaviour; staggering and lack of coordination; headache; mental confusion and visual disturbance; tiredness.

**(vii) First Aid Measures:**

**# Eyes:** Remove the victim from the source of contamination and take him to the nearest eye wash, shower, or other source of clean water. Gently rinse the affected eye(s) with clean, lukewarm water for at least 15 minutes. Have the victim lie or sit down and tilt his head back. Hold the eyelid(s) open and pour water slowly over the eyeball(s) at the inner corners, letting the water run out of the outer corners. Ask the victim to look up, down and side to side as you rinse in order to better reach all parts of the eye(s). If the victim cannot tolerate light, protect his eye(s) with a clean, loosely tied handkerchief or strip of clean, soft cloth or bandage. Seek medical attention immediately.

**# Skin:** Remove the victim from the source of contamination. Remove clothing, shoes, socks, and jewellery from the affected areas. Be careful not to get any of the chemical on your skin or clothing. Wash the affected area with tepid water. Dry the skin gently with a clean, soft towel. Seek medical attention immediately.

**# Inhalation:** Remove the victim from the contaminated area while protecting yourself from exposure by wearing an appropriate respirator. Put a similar respirator on the victim. Remove contaminated clothing and equipment, while wearing gloves, being careful not to contaminate yourself. Administer CPR if necessary. Seek medical attention immediately.

**# Ingestion:** Remove the victim from the contaminated area to a quiet, well ventilated area. Call a poison control centre, inform them of the chemical swallowed and follow their advice. Seek medical attention immediately.

**Extinguishing Media** Use dry chemical alcohol foam, or carbon dioxide; water spray may be ineffective as an extinguishing agent, but water should be used to keep fire-exposed containers cool.

**Special Fire** Vapours are slightly heavier than air and may flow along

Surfaces Fighting Procedures to ignition sources.

Water may be ineffective in "in-depth methanol fires".

Fire fighters should use self-contained breathing apparatus and protective clothing.

**(ix) Accidental Release Measures:**

**# Spill or Leak Procedures:** Eliminate all ignition sources. Stop spill source. If spill is small use absorbent material to soak up spill. Dike large spill areas. Recover large spills by recovering the methanol or by diluting with water to reduce the fire hazard. Salvage the liquid by using a recommended absorbent material. Prevent methanol from entering sewers, drains, or waterways.

Always notify proper authorities of spills.

**(x) Waste Disposal Method:** Dispose of material in accordance with your local, state, federal or other applicable regulations.

**Physical and Chemical Properties:**

Appearance	Clear, Colourless liquid
Odour	Alcohol odour
Physical state	Liquid
Vapour pressure	(at 20°C ) 96 mmHg
Vapour density	(air = 1) 1.11
Melting point	-97.6°C
Boiling point	(at 760 mmHg) 64.5°C
Specific gravity	(water = 1) 0.7915 at 68°F
Evaporation rate	(Butyl Acetate = 1) 4.6
Percent volatile	100% (by volume)
Bulk density	6.63 lbs. per gallon
Solubility in water	Miscible
Solvent solubility	Solubility in alcohols, ketones, esters, and halogenated hydrocarbons - Miscible
Molecular weight	32.04
Chemical formula	CH <sub>3</sub> OH
Chemical family	Alcohols

**Product Name:** Liquefied Petroleum Gas (LPG)

**(i) Product Synonyms:** LPG, Propane, Butane, Propylene, Puro fax, Bottled Gas.

**(ii) General Use:** Domestic use for Cooking, Heating and Cutting in industries.

**(iii) Product Description:** Clear, colourless, odourless, flammable, poisonous, mobile. Burns with a nonluminous, bluish flame.

**(iv) Potential Health Effects:**

**(v) Effects of oxygen deficiency:**

# If oxygen is 16%: Breathing and pulse rate increased, impaired thinking and attention, reduced coordination.

# If oxygen is 14%: Abnormal fatigue upon exertion, emotional upset, faulty coordination, poor judgement.

# If oxygen is 12.5%: Very poor judgement and coordination, impaired respiration that can cause permanent hearing damage, nausea and vomiting.

# If oxygen is below 10%: Inability to perform various movements, loss of consciousness, convulsions, and death.

**(vi) First Aid Measures:**

# **Inhalation:** Remove the victim to fresh air area and provide the victim with artificial resuscitation.

# **Skin contact:** Remove the wetted clothes & wash the affected area with plenty of water.

**(vii) Accidental Release Measures:**

# **Spill or Leak Procedures:** Eliminate all ignition sources. Shut off leaks if possible, warn everybody that air mixture is explosive. Always notify proper authorities of leakage.

Flash Point	-104 - 60°C
Auto-Ignition temperature	466.1°C Propane, 405°C butane
Fire and Explosion Hazards	LPG burns with a clean, clear flame.
Upper Explosive / Fire Limits	9.5%
Lower Explosive /	1.9%

Extinguishing Media - CO2, Dry Chemical Powder, Water Spray

Special Fire - Keep the containers cool by spraying water

Fighting Procedures - exposed to fire or heat  
Unusual Hazards  
If not cooled sufficiently, containers will explode in fire

**(viii) Handling and Storage:** Keep in tightly closed cylinders in a cool, well ventilated area, away from heat, flame, sparks.

**Product Name:** High Speed Diesel (HSD)

- i. **Product Synonyms:** Automotive Diesel Oil
- ii. **General Use:** Fuel in Automobiles and in furnace
- iii. **Product Description:** Yellowish brown, flammable, liquid and burns with orange flame.
- iv. **Potential Health Effects:**

**Mode of entry health effects**

Eyes contact	Irritation eyes watering.
Inhalation	Excessive inhalation Vapours cause rapid breathing, excitability, staggering, headache, fatigue, nausea and vomiting, dizziness, drowsiness, narcosis convulsions, coma.
Ingestion	Fatigue, nausea and vomiting, dizziness,

**V. First Aid Measures:**

# **Skin contact:** Flush with plenty of water. Remove soaked clothing.

**ANNEXURE II**

Table 8. Quantitative Risk Assessment Module Model Result

HAMS-GPS : Dispersion Module  
[Licensed to : Inbarasan (Chennai)] Date : Friday, November 03, 2017

Scenario : 1. Flash Vaporization of Compressed Liquefied Gas Tank (CLG) forming Gas Puff (SMOD-b6 Puff Dispersion QF)

Wind orientation selected : 5

Probit Equations :  
Fatality Probit (y) : -10 + 1(Ln)Conc A<sup>2</sup> x Time  
Injury Probit (y) : -5 + 1(Ln)Conc A<sup>2</sup> x Time

Probit Table and Absolute Fatality/Injury

Distance(m)	% Fatality	% Injury	Time (Sec)	Area (Ha)	Conc.(ppm) along X-axis	Dose (mg)	Absolute Fatality No.	Injury No.
2.1	100	0	0.53	0.217	950000	620177.581	217.000	0.000
78.96	0	100	19.75	0.510	10374.78	17.3301	0.000	510.000
155.82	0	100	38.97	0.726	1775.18	2.9653	0.000	726.000
232.68	0	26.38	58.20	0.900	619.95	1.0356	0.000	237.420
309.54	0	0	77.42	1.042	292.2	0.4881	0.000	0.000
386.4	0	0	96.65	1.160	163.33	0.2728	0.000	0.000
463.26	0	0	115.87	1.257	102.77	0.1717	0.000	0.000
540.12	0	0	135.09	1.335	69.53	0.1161	0.000	0.000
616.98	0	0	154.32	1.395	49.59	0.0828	0.000	0.000
693.84	0	0	173.54	1.438	36.83	0.0615	0.000	0.000
770.7	0	0	192.77	1.463	28.24	0.0472	0.000	0.000
847.56	0	0	211.99	1.471	22.22	0.0371	0.000	0.000
924.42	0	0	231.22	1.461	17.86	0.0298	0.000	0.000
1001.28	0	0	250.44	1.431	14.61	0.0244	0.000	0.000
1078.14	0	0	269.66	1.380	12.13	0.0203	0.000	0.000
1155	0	0	288.89	1.304	10.21	0.0171	0.000	0.000
1231.86	0	0	308.11	1.198	8.69	0.0145	0.000	0.000
1308.72	0	0	327.34	1.052	7.47	0.0125	0.000	0.000
1385.58	0	0	346.56	0.843	6.48	0.0108	0.000	0.000
1462.44	0	0	365.79	0.481	5.66	0.0095	0.000	0.000

Table 9. Fire Module

HAMS-GPS : Fire Module  
[Licensed to : Inbarasan (Chennai)] Date : Friday, November 03, 2017

Scenario : 1. CLG Liquid Main Pipe leak free spread Pool fire (SMOD-06a Fire module)

Wind orientation selected : 1

Probit Table and Absolute Fatality/Injury (At height of simulation)

Distance (m)	IHR (kW/m2)	Dose (Kwh/m2)	% Fatality	% Injury	Area (Ha)	Injury Type	Secondary Fire	Absolute Fatality No.	Injury No.
270.23	37.62	46.4	100	0	22.941	Fatal	Wood Ignited	22941.000	0.000
322.23	26.46	31.45	58.78	41.22	9.679	Signif.Injury	Wood Ignited	5683.316	3983.684
374.23	19.62	22.72	30.60	63.4	11.378	1st.deg.Burn	Wood Ignited	3481.668	7896.332
426.23	15.12	17.18	12.07	87.93	13.077	1st.deg.Burn	Wood Ignited	1578.394	11498.606
478.23	12.01	13.45	0	94.155	14.776	Pain	Unlikely	0.000	12434.745
530.23	9.77	10.81	0	73.38	16.474	Pain	Unlikely	0.000	12088.621
582.23	8.1	8.88	0	57.32	18.173	Pain	Unlikely	0.000	10416.764
634.23	6.83	7.43	0	45.10	19.872	Pain	Unlikely	0.000	8962.272
686.23	5.83	6.3	0	35.48	21.571	Pain	Unlikely	0.000	7653.391
738.23	5.04	5.42	0	27.88	23.270	Pain	Unlikely	0.000	6487.676
790.23	4.4	4.7	0	21.72	24.969	Pain	Unlikely	0.000	5423.267
842.23	3.87	4.12	0	16.62	26.668	Pain	Unlikely	0.000	4432.222
894.23	3.44	3.64	0	12.48	28.367	Pain	Unlikely	0.000	3540.202
946.23	3.07	3.24	0	8.92	30.066	Pain	Unlikely	0.000	2681.887
998.23	2.76	2.91	0	5.94	31.765	Pain	Unlikely	0.000	1886.841
1050.23	2.49	2.62	0	3.34	33.464	Pain	Unlikely	0.000	1117.698
1102.23	2.26	2.37	0	1.13	35.163	Pain	Unlikely	0.000	397.342
1154.23	2.06	2.16	0	0	36.862	Pain	Unlikely	0.000	0.000
1206.23	1.89	1.97	0	0	38.561	Pain	Unlikely	0.000	0.000
1258.23	1.74	1.81	0	0	40.260	Pain	Unlikely	0.000	0.000

\* IHR - Intensity of Heat / Thermal Radiation

Table 10. Explosion Module

HAMS-GPS : Explosion Module										
[Licensed to : Inbarasan (Chennai)]										
Date : Friday, November 03, 2017										
Scenario : 1. CLG Tank rupture at stored temp. Flash Vaporization forming Gas Cloud delayed internal ignition leading to BLEVE scenario (ChE module)										
Probit Table and Absolute Fatality/Injury (At height of simulation)										
Distance (m)	Over Pressure (psi)	Invert	%Fatality				Area (Ha)	Absolute		Wind orientation selected: 1
			Lung Rupture	% Ear Drum Rupture	% Structural Damage	% Glass Break		Fatality No.	Injury No.	
77.114	17.95	10.49	96.40	100.00	100.00	1.868	3.919	36.015		
117.089	6.64	0.00	58.41	98.11	100.00	2.439	0.000	28.492		
157.063	4.26	0.00	18.50	90.10	100.00	3.443	0.000	12.739		
197.038	3.18	0.00	9.05	70.83	100.00	4.447	0.000	8.049		
237.012	2.63	0.00	5.67	58.77	100.00	5.451	0.000	6.181		
276.987	2.24	0.00	3.82	21.32	100.00	6.455	0.000	4.932		
316.962	1.95	0.00	2.71	12.71	100.00	7.459	0.000	4.043		
356.936	1.73	0.00	2.01	8.06	99.06	8.463	0.000	3.402		
396.911	1.55	0.00	1.53	5.36	98.61	9.467	0.000	2.897		
436.885	1.40	0.00	1.20	3.71	98.02	10.471	0.000	2.513		
476.860	1.28	0.00	0.96	2.65	97.27	11.475	0.000	2.203		
516.834	1.18	0.00	0.78	1.95	96.34	12.479	0.000	1.947		
556.809	1.09	0.00	0.65	1.46	95.19	13.483	0.000	1.753		
596.783	1.02	0.00	0.54	1.12	93.79	14.487	0.000	1.565		
636.758	0.95	0.00	0.46	0.87	92.13	15.491	0.000	1.425		
676.732	0.97	0.00	0.49	0.95	92.70	16.495	0.000	1.617		
716.707	0.93	0.00	0.44	0.80	91.47	17.500	0.000	1.540		
756.681	0.89	0.00	0.40	0.69	90.12	18.503	0.000	1.480		
796.656	0.86	0.00	0.36	0.60	88.65	19.508	0.000	1.405		
836.630	0.83	0.00	0.33	0.52	87.04	20.511	0.000	1.354		

NOTE: Shock wave pressure is proportional to heat of combustion per Mole mass.