Chapter 7
Additional Studies
- Risk Assessment

7.1 Introduction

Risk Assessment (RA) study includes the consequences due to the accidental release of hazardous materials at the port site causing fire, explosion and toxic scenarios. The study comprises identification and quantification of risks associated with loading and unloading operations for petroleum products such as crude oil, motor spirit, kerosene, diesel, naphtha, and propylene in south oil jetty at the port. The possible release scenarios of the hazardous chemicals are examined to select credible incidents and damage potential of the incidents are modelled. The effects of the scenarios are presented in terms of heat radiations and pressure waves.

7.1.1 Objectives of the Study

Following are the objectives of the study:

- Study of past accident information to identify worst scenarios
- Hazard identification study through computation of Fire, Explosion and Toxicity Indices (FETI)
- Generation of credible and worst case scenarios for accidental release of hazardous material during processing, transportation, handling and storage
- Computation of damage distances through consequence analysis for various heat loads and pressure waves and at different atmospheric conditions
- Effect of damages due to the proposed facility on adjacent installations through damage contour plots
- Quantification of risk through individual and societal contours based on population data
- Assessment of individual and societal risk against the risk acceptability criteria relevant to the situation
- Recommendations for risk mitigation measures based on the study
- Preparation of Disaster Management Plan (DMP) comprising on-site and off-site emergency scenarios

7.1.2 Components of Risk Assessment

The normal components of a risk assessment study are:

- Hazard identification
- Consequence analysis
- Recommendations for risk mitigation
- Delineation of Disaster Management Plan (DMP)

7.2 Past Accident Data Analysis

Analysis of events arising out of the unsafe operations is one of the basic requirements for ensuring safety in any facility. The data required for such an analysis can be monitored or collected from the records of the past accidents. The analyzed data helps in formulation of the mitigation measures for upcoming facility in order to minimize occurrence of accidents. It is, therefore, important to collect the data methodically, based on potential incidents, sections involved, causes of failure and the preventive measures taken. Following are the details of few industrial accidents

West Pharmaceuticals, Kinston, USA, 29th January 2003:

An explosion and fire involving polyethylene dust killed 6 workers and injured 38 others at the USA-based West Pharmaceuticals (Kinston, NC) on 29th January 2003. Two firefighters were among those killed in a massive blast of which impact was felt over a large area; the burning debris triggered secondary fires up to 2 miles away. Some initiating event caused dust to become airborne above a suspended ceiling. There it contacted an ignition source leading to the explosion.

Qingdao Port, China, 22nd November 2013:

The oil pipeline at Qingdao port in eastern China was leaked which led to fire and explosion killing 47 persons. The pipeline, owned by China's largest oil refiner, Sinopec, got leaked for 15 minutes onto a street and into a sea. The spilled oil during clean up caught fire and exploded at two locations. More than 32,000 square feet of sea surface also got contaminated.

Kunshan Zhongrong Metal Products Co. Ltd., China, 2nd August, 2014:

A massive explosion occurred when a flame was lit in a metal polishing dust room of Kunshan Zhongrong Metal Products Co. Ltd., Jiangsu Province, China. The blast killed 75 people and more than 200 got injured with burns to their body and respiratory system. The company was involved in the business of metal plating and polishing products.

7.3 Failure Scenarios

A hazardous material can be safe if it is maintained at desired operating conditions during storage, operation and transportation. For the proposed facility, the failure of pipeline or any process equipment can be due to various failure causes which can be categorized as follows

External Interface Failure:

- Human activities such as excavation, drilling, etc. carried out in vicinity of the installation potentially cause damage to the installation. Other potential human related cause can be sabotage of the installation
- Natural calamity like floods, cyclones and earthquakes

Mechanical Failure:

- Improper selection of material of construction, defects in construction
- Operational causes like increase in pressure, temperature

Corrosion and other Failures:

- Internal Corrosion – Liquid fuel inside the pipeline
- External corrosion - Moisture in the ground and salinity of the soil
- Other failure causes include washout, ground movement or sabotage

Material Damage to the Pipelines:

- Minor damage: Damage not requiring repair
- Moderate damage: Damage requiring repair but not leading to release of hydrocarbons
- Major damage: Damage causing release of hydrocarbons

Leakage due to Failure of Pipeline Accessories:

- Failure of pipeline accessories like gaskets and flanges

7.4 Hazard Identification

Identification of hazards is an important step in risk assessment study as it leads to the generation of accidental scenarios. Once a hazard has been identified, it is necessary to evaluate the risk to plant personnel and neighbouring community arising due to handling of unidentified hazards. The following points are taken into account while identifying hazards

- Location of process unit facilities involving hazardous materials
- The types and design of process units
- The quantity of hazardous material that could be involved in an airborne release and
- The properties of the hazardous material

7.4.1 Fire and Explosion Index (FEI)

The Fire and Explosion Index (FEI) is useful in identifying hazardous materials and risks arising due to the handling of hazardous materials. The FEI estimates the global risk associated with a unit in which hazardous materials are processed and classifies the units according to their general level of risk. The FEI covers aspects related to the intrinsic hazard of materials, the quantities handled and operating conditions. This factor gives index value for the area which could be affected by an accident. The method for evaluation of FEI involves following stages.

- Selection of pertinent process unit which can have serious impact on overall safety of the plant
- Determination of Material Factor (MF): The factor for a given substance in the process unit gives intrinsic potential to release energy in case of fire or an explosion. Material Factor can be directly obtained from Dow's Fire and Explosion Index Hazard classification Guide of American Institute of Chemical Engineers, New York. The factor can also be evaluated from NFPA indices of danger, health, flammability and reactivity
- Determination of Unit Hazard Factor: The Unit Hazard Factor is obtained by multiplication of General Process Hazard (GPH) factor and Special Process Hazard (SPH) factor. The GPH factor is computed according to presence of exothermic reactions and loading and unloading operations. The penalties due to each of these reactions / operations are summed up to compute GPH factor. Similarly, the SPH factor can be evaluated for the operations close to flammable range or operating pressures different from atmospheric pressure. Penalties of these operations for both factors can be obtained from Dow's EFI index form.

Fire and explosion index is then calculated as the product of Material Factor (MF) and Unit Hazard Factor. The degree of hazards for the computed value of FEI is presented in **Table 7.1**.

Table 7.1 : Degree of Hazards Based on FEI

Sr. No.	FEI Range	Degree of Hazard
1	0 – 60	Light
2	61–96	Moderate
3	97 –127	Intermediate
4	128 – 158	Heavy
5	159 and Above	Severe

Source: Dow's F&EI Hazard Classification Guide, 7th Edition, AIChE Technical Manual (1994)

The preventive and protective control measures are recommended based on degree of hazard. Therefore, FEI highlights the efforts to be taken to reduce risks for a particular process unit. The FEI computed for various process equipments are presented in **Table 7.2**.

Table 7.2 : Fire and Explosion Index

Sr. No.	Unit Name	FEI	Category
1	Crude Oil	89	Moderate
2	Motor Spirit Regular	173	Severe
3	Aviation Turbine Fuel	31	Light
4	Motor Spirit Premium	122	Intermediate
5	High speed Diesel	43	Light
6	Propylene	130	Heavy
7	Naphtha	77	Moderate

7.5 Maximum Credible Accidents (MCA) Analysis

The MCA analysis encompasses defined techniques to identify the hazards and compute the consequent effects in terms of damage distances due to heat radiation, toxic releases, vapour cloud explosion etc. A list of probable or potential accidents of the major units in the facility arising due to use, storage and handling of the hazardous materials are examined to establish their credibility. Depending upon the effective hazardous attributes and their impact on the event, the maximum effect on the surrounding environment and the respective damage caused can be assessed. Flow chart of accidental release of hazardous chemicals is presented in **Figure. 7.1**.

Hazardous substances can cause damage on a large scale if they are accidentally released . The extent of the damage is dependent upon the nature of the release and the physical state of the material. In the present report the consequences for flammable hazards are considered and the damages caused due to such releases are assessed at different combinations of weather conditions to simulate worst possible scenario.

The following steps are involved in the MCA analysis:

- Identification of potential hazardous sections and representative failure cases
- Visualisation of release scenarios with recourse to consequence analysis
- Damage distance computations for the released cases

The flammable substances on release may cause fire and/or explosion causing possible damage to the surrounding area. The extent of damage depends upon the nature of the release. The release of flammable materials and subsequent ignition result in heat radiation wave or pressure waves depending upon the flammability and its physical state. Damage distances due to release of hazardous materials depend on atmospheric stability and wind speed. It is important to visualize the consequence of the release of such substances and the damage caused to the surrounding areas. Computation of damage distances are carried out at various atmospheric stability conditions for various wind velocities and the result is tabulated. Pasquill-Giffard atmospheric stability classes with corresponding weather conditions are listed in **Table 7.3**. The probable worst case scenarios for the proposed facility are listed below:

- Unloading arm failure for HSD / ATF pipeline
- Unloading arm failure for Naphtha / MS pipeline
- Failure of flanges in case of pipeline
- Partial failure of booster pump discharge in pipeline
- Catastrophic failure of pipelines at booster pump discharge
- Partial failure of flanges at the terminal

Table 7.3 Pasquill – Giffard Atmospheric Stability

Sr. No.	Stability Class	Weather Conditions
1	A	Very unstable – sunny, light wind
2	A/B	Unstable - as with A only less sunny or more windy
3	B	Unstable - as with A/B only less sunny or more windy
4	B/C	Moderately unstable – moderate sunny and moderate wind
5	C	Moderately unstable – very windy / sunny or overcast / light wind
6	C/D	Moderate unstable – moderate sun and high wind
7	D	Neutral – little sun and high wind or overcast / windy night
8	E	Moderately stable – less overcast and less windy night
9	F	Stable – night with moderate clouds and light / moderate wind
10	G	Very stable – possibly fog

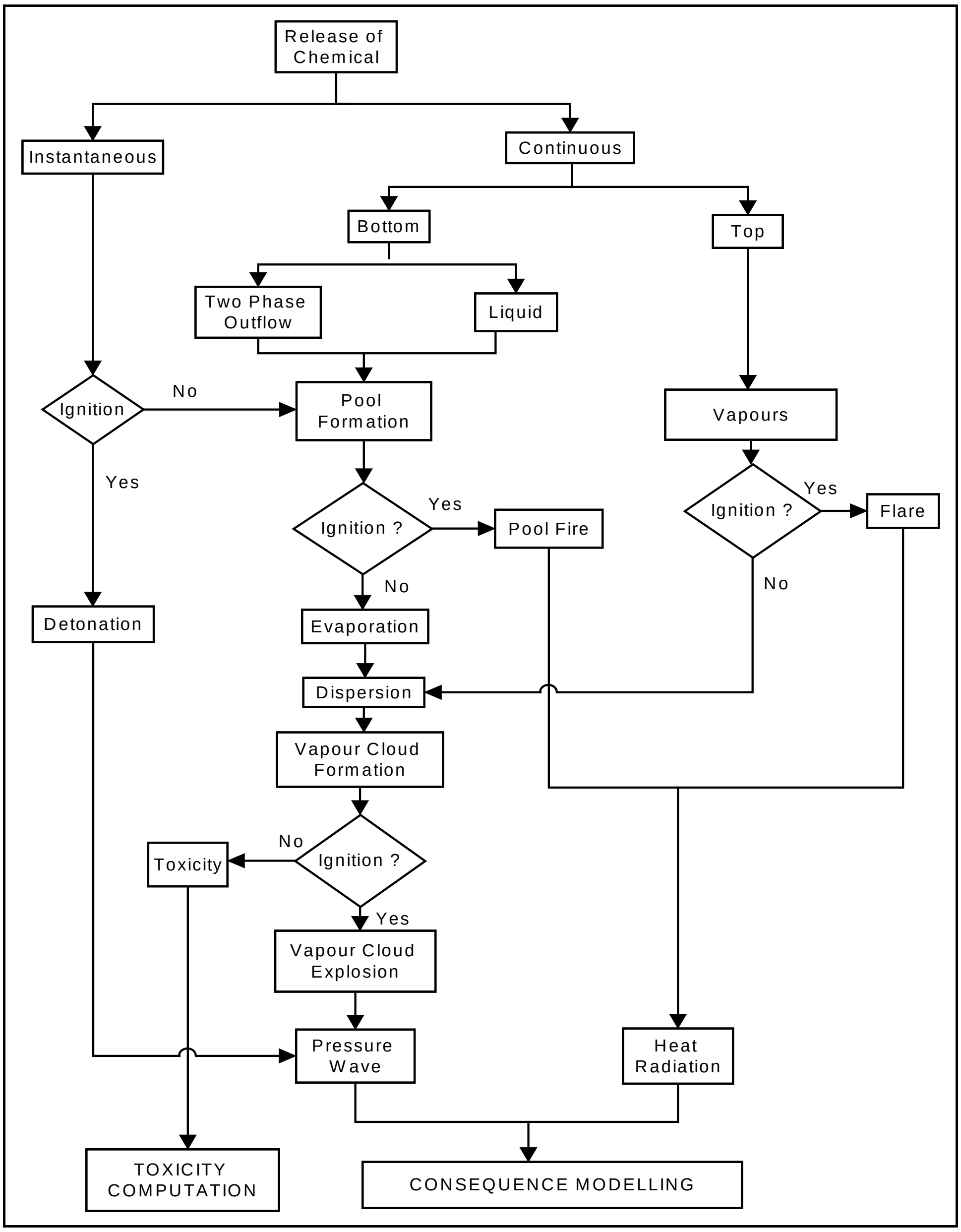

Figure 7.1 : Accidental Release of Chemicals: A Scenario

7.5.1 Fire and Explosion Scenarios

Combustible materials within their flammable limits may ignite and burn if exposed to an ignition source of sufficient energy. On process plants, this normally occurs as a result of a leakage or spillage. Depending on the physical properties of the material and the operating parameters, the combustion of material in a plant may take on a number of forms like jet fire, flash fire, pool fire, vapour cloud explosion and BLEVE.

Jet Fire:

Jet fire occurs when flammable material of a high exit velocity ignites. In process industries this may be due to equipment failure or an accidental. Ejection of flammable material from a vessel, pipe or pipe flange may give rise to a jet fire and in some instances the jet flame could have substantial "reach". Depending on wind speed, the flame may tilt and impinge on pipeline, equipment or structures. The thermal radiation from these fires may cause injury to people or damage equipment some distance from the source of the flames.

Flash Fire:

A flash fire is the non-explosive combustion of a vapour cloud resulting from a release of flammable material into the open air, which after mixing with air, ignites. A flash fire results from the ignition of a released flammable cloud in which there is essentially no increase in combustion rate. The ignition source could be electric spark, a hot surface, and friction between moving parts of a machine or an open fire.

Flash fire may occur due to its less vapour temperature than ambient temperature. Hence, as a result of a spill, they are dispersed initially by the negative buoyancy of cold vapour and subsequently by the atmospheric turbulence. After the release and dispersion of the flammable fuel the resulting vapour cloud is ignited and when the fuel vapour is not mixed with sufficient air prior to ignition, it results in diffusion fire burning. Therefore the rate at which the fuel vapour and air are mixed together during combustion determines the rate of burning in the flash fire.

The main dangers of flash fire are radiation and direct flame contact. The size of the flammable cloud determines the area of possible direct flame contact effects. Radiation effects on a target depend on several factors including its distance from the flames, flame height, flame emissive power, local atmospheric transitivity and cloud size. Most of the time, flash combustion lasts for no more than a few seconds.

Pool Fire:

Releases of hydrocarbons in the absence of immediate ignition would form an unconfined pool, which on ignition would result in a pool fire. Radius of pool depends upon mass flow rate, ambient temperature; heat of vaporization of material released, vapour pressure of material released and discharge duration. Emissive power generated from the pool surface depends upon pool burning rate, heat of combustion of release material, atmospheric transitivity and area of pool.

The pool fire being either tank or bund fire consists of large volumes of flammable material at atmospheric pressure burning in an unconfined space. The flammable material will be consumed at the burning rate depending on factors including the prevailing winds. During combustion heat will be released in the form of thermal radiation. Temperature close to the flame centre will be high but will reduce rapidly to tolerable temperatures over a relatively short distance. Any plant building or persons close to the fire or within the intolerable zone will experience burn damage with the severity depending on the distance from the fire and the time exposed to the heat of the fire. In the event of a pool fire the flames will tilt according to the wind speed and direction. The flame length and tilt angle affect the distance of thermal radiation generated.

Vapour Cloud Explosion:

The Vapour Cloud Explosion (VCE) begins with a release of a large quantity of flammable vaporizing liquid or gas from a storage tank, transport vessel or pipeline producing a dangerous overpressure. These explosions follow a well-determined pattern. There are basically four features, which must be present for an effective vapour cloud explosion to occur with an effective blast. These are:

- First, the release material must be flammable and at a suitable condition of temperature and pressure which depends on the chemical. The materials which come under this category, range from liquefied gases under pressure (e.g. butane, propane); ordinary flammable liquids (e.g. cyclohexane, naphtha) to non-liquefied flammable gases (e.g. ethylene, acetylene)
- Second, before the ignition, a cloud of sufficient size must have been formed. Normally ignition delays of few minutes are considered the most probable for generating the vapour cloud explosions
- Third, a sufficient amount of the cloud must be within the flammable range of the material to cause extensive overpressure
- Fourth, the flame speed determines the blast effects of the vapour cloud explosions, which can vary greatly
- The flammable content of a gas cloud is calculated by three-dimensional integration of the concentration profiles, which fall within the flammable limits. If the gas cloud ignites, two situations can occur, namely non-explosive combustion (flash fire) and explosive combustion (flash fire followed by explosion)

BLEVE:

If the liquid is stored under pressure at a temperature above its boiling point, the initial physical explosion that breaks the receptacle produces a sudden decompression giving rise to a massive evaporation of the saturated liquid. This kind of evaporation is known as BLEVE. The explosion is of great destructive power due to the high increase in pressure caused by the sudden incorporation of liquid into the gas phase. The ignition of BLEVE produces a mass of gases at high temperature known as 'fireball' with significant thermal effects. Historically, BLEVEs have been produced with some frequency and have almost caused human casualties.

Lower and Upper Flammability Limit:

In case of any spillage and leakages of hydrocarbons / flammable material, probability of getting ignited is depending on whether the air borne mixture is in the flammable region. The lower flammability limit corresponds to minimum proportion of combustible vapour in air for combustion. The upper flammability limit corresponds to maximum proportion of combustible vapour in air for combustion and the concentration range lying between the lower and the upper limit is called as flammable range.

7.5.2 Models for the Calculation of Heat load and Shock Waves

If a flammable gas or liquid is released, damage resulting from heat radiation or explosion may occur on ignition. Models used in this study for the effects in the event of the ignition of a gas cloud will be discussed in succession. These models calculate the heat radiation or peak overpressure as a function of the distance from the torch, the ignited pool or gas cloud. The physical significance of the various heat loads is depicted in **Table 7.4**.

Table 7.4 : List of Damages Envisaged at Various Heat Loads

Sr. No.	Heat loads (kW/m^2)	Type of Damage Intensity	
		Damage to Equipment	Human Injury
1	37.5	Damage to process equipment	100% lethality in 1 min. 1% lethality in 10 sec
2	25.0	Minimum energy required to ignite wood	50% Lethality in 1 min. Significant injury in 10 sec
3	19.0	Maximum thermal radiation intensity allowed on thermally unprotected equipment	--
4	12.5	Minimum energy required to melt plastic tubing	1% lethality in 1 min
5	4.0	--	First degree burns, causes pain for exposure longer than 10 sec
6	1.6	--	Causes no discomfort on long exposures
Source: Techniques for assessing industrial hazards by world bank			

7.5.3 Model for Pressure Wave

A pressure wave can be caused by gas cloud explosion. The following damage criteria are assumed as a result of the peak overpressure:

- ♦ 0.03 bar overpressure wave is taken as the limit for the occurrence of wounds as a result of flying fragments of glass
- ♦ Following assumptions are used to translate an explosion in terms of damage to the surrounding area:
  - Within the contour area of the exploding gas cloud, Casualties are due to burns or asphyxiation. Houses and buildings in this zone will be severely damaged

- In houses with serious damage, it is assumed that one out of eight persons present will be killed as a result of the building collapse. Within the zone of a peak over pressure of 0.3 bar the risk of death in houses is 0.9 × 1/8 = 0.1125, and in the zone with a peak over pressure of 0.1 bar the probability of death is 0.1 × 1/8 = 0.0125, i.e. one out of eighty people will be killed

The significance of the peak over pressures 0.3 bar, 0.1 bar, 0.03 bar and 0.01 bar are depicted in **Table 7.5.**

Table 7.5 : Damage Criteria for Pressure Waves

Human Injury		**Structural Damage**	
Peak Over Pressure (bar)	**Type of Damage**	**Peak Over Pressure (bar)**	**Type of Damage**
5-8	100% lethality	0.3	Heavy (90% damage)
3.5-5	50% lethality	0.1	Repairable (10% damage)
2-3	Threshold lethality	0.03	Damage of Glass
1.33-2	Severe lung damage	0.01	Crack of windows
1-1.33	50% Eardrum rupture	-	-
Source: Marshall, V.C. (1977)’ How lethal are explosives and toxic escapes’.			

7.5.4 Computation of Damage Distances

Damage distances for the accidental release of hazardous materials have been computed at 2F, 3D and 5D weather conditions. In these conditions, 2, 3 and 5 are wind velocities in m/s and F and D are atmospheric stability classes. These weather conditions have been selected to accommodate worst case scenarios to get maximum effective distances. DNV based **PHAST 6.51**, software has been used to carry out consequence analysis. The computed damage distances for units are described in **Table 7.6**.

Table 7.6 : Computed Damage Distances for Units

Pipeline	Source Strength (kg/sec)	Leak Size (mm)	Weather	Damage Distance (m)									
				Jet Fire			Pool Fire			Flash Fire at LFL conc.	VCE Over pressure		
				37.5 kW/m²	12.5 kW/m²	4.0 kW/m²	37.5 kW/m²	12.5 kW/m²	4.0 kW/m²		0.3 bar	0.1 bar	0.03 bar
Crude Oil	9.67	25mm	2F	13	28	47	-	56	88	13	34	47	84
			3D	18	31	52	-	72	106	9	32	43	75
			5D	19	30	49	-	162	198	9	30	40	68
	38.68	50mm	2F	19	43	72	-	83	133	26	68	96	170
			3D	24	42	71	-	89	146	26	66	91	160
			5D	32	51	84	-	149	208	23	61	82	138
	1385.27	Line Rupture	2F	45	91	149	-	221	363	14	60	110	244
			3D	53	92	152	-	217	378	10	75	140	315
			5D	66	106	176	-	225	413	19	65	120	268
Motor Spirit Regular	11.17	25mm	2F	11	35	59	-	-	-	14	34	49	88
			3D	19	35	58	-	-	-	11	33	46	81
			5D	22	34	56	-	-	-	10	31	42	72
	44.71	50mm	2F	18	59	102	-	-	-	30	70	100	180
			3D	31	60	99	-	-	-	28	68	96	170
			5D	36	57	96	-	-	-	27	73	96	157
	1601.18	Line Rupture	2F	221	609	1071	-	159	277	3525	3660	3689	3974
			3D	268	612	1021	-	146	281	2217	2374	2398	2728
			5D	298	582	933	-	147	295	2116	2283	2348	2756

Pipeline	Source Strength (kg/sec)	Leak Size (mm)	Weather	Damage Distance (m)									
				Jet Fire			Pool Fire			Flash Fire at LFL conc.	VCE Over pressure		
				37.5 kW/m²	12.5 kW/m²	4.0 kW/m²	37.5 kW/m²	12.5 kW/m²	4.0 kW/m²		0.3 bar	0.1 bar	0.03 bar
Aviation Turbine Fuel (ATF)	11.97	25mm	2F	11	33	56	-	-	-	15	35	50	90
			3D	18	33	56	-	-	-	12	33	47	83
			5D	21	33	53	-	-	-	11	32	43	74
	47.89	50mm	2F	18	56	97	58	70	86	32	71	102	184
			3D	30	57	95	64	67	69	30	69	98	176
			5D	35	55	91	-	-	-	29	74	98	162
	1715.16	Line Rupture	2F	106	267	454	-	226	368	910	1016	1036	1122
			3D	130	269	439	-	216	378	394	497	524	639
			5D	163	291	472	-	229	419	256	408	426	695
Motor Spirit Premium (MSP)	11.17	25mm	2F	13	34	58	-	-	-	15	34	49	88
			3D	19	34	58	-	-	-	12	33	45	79
			5D	21	34	55	-	-	-	11	31	42	72
	44.71	50mm	2F	20	59	101	-	-	-	29	69	99	178
			3D	31	59	98	-	-	-	27	67	95	168
			5D	36	56	94	-	-	-	28	73	95	156
	1474.08	Line Rupture	2F	217	574	998	-	179	310	2930	3072	3118	3444
			3D	264	587	973	-	167	316	1951	2095	2162	2535
			5D	294	568	909	-	165	332	1876	2098	2155	2628

Pipeline	Source Strength (kg/sec)	Leak Size (mm)	Weather	Damage Distance (m)									
				Jet Fire			Pool Fire			Flash Fire at LFL conc.	VCE Over pressure		
				37.5 kW/m²	12.5 kW/m²	4.0 kW/m²	37.5 kW/m²	12.5 kW/m²	4.0 kW/m²		0.3 bar	0.1 bar	0.03 bar
High Speed Diesel (HSD)	13.37	25mm	2F	-	12	20	-	83	118	11	45	59	98
			3D	8	15	25	-	133	173	9	33	46	81
			5D	10	16	25	-	321	366	9	32	43	74
	53.48	50mm	2F	5	19	33	-	125	182	34	81	112	195
			3D	11	19	32	-	122	185	29	78	106	182
			5D	15	24	38	-	343	414	23	73	97	160
	1915.28	Line Rupture	2F	22	43	72	-	234	369	29	93	165	361
			3D	25	42	71	-	224	376	19	80	150	339
			5D	31	49	80	-	241	417	36	141	253	553
Propylene	16.20	25mm	2F	-	23	52	-	-	-	3	-	-	-
			3D	-	25	50	-	-	-	3	-	-	-
			5D	-	27	47	-	-	-	4	-	-	-
	64.81	50mm	2F	-	39	90	-	-	-	7	40	60	114
			3D	-	42	87	-	-	-	7	29	48	99
			5D	-	46	83	-	-	-	7	27	44	89
	168.90	Line Rupture	2F	37	120	320	-	-	-	507	598	622	879
			3D	9	135	309	-	-	-	43	180	270	520
			5D	15	155	299	-	-	-	49	224	308	533

Pipeline	Source Strength (kg/sec)	Leak Size (mm)	Weather	Damage Distance (m)									
				Jet Fire			Pool Fire			Flash Fire at LFL conc.	VCE		
											Over pressure		
				37.5 kW/m²	12.5 kW/m²	4.0 kW/m²	37.5 kW/m²	12.5 kW/m²	4.0 kW/m²		0.3 bar	0.1 bar	0.03 bar
Naphtha	11.01	25mm	2F	12	34	58	-	-	-	13	34	48	85
			3D	19	34	57	-	-	-	10	32	45	78
			5D	21	33	54	-	-	-	9	31	42	71
	44.03	50mm	2F	19	58	100	-	-	-	28	69	97	175
			3D	31	59	97	-	-	-	26	67	94	166
			5D	35	56	93	-	-	-	25	62	84	143
	1576.96	Line Rupture	2F	173	453	783	-	232	384	2094	2224	2286	2585
			3D	210	460	758	-	220	394	1309	1479	1531	1868
			5D	267	509	815	-	224	426	1300	1584	1602	2032

7.6 Sources and Triggers of Dust Explosions

A dust explosion occurs due to rapid combustion of flammable particulates suspended in air. The dust of any solid material that can burn in air can trigger massive explosion and the intensity of explosion increases with the degree of sub-division of the material. If the degree of sub-division is higher or the particle size is smaller, the explosion will be more rapid and huge, till a limiting stage is reached when particles too fine in size tend to lump together. The flash fire would occur if the dust cloud is unconfined. In case of confined dust cloud, the heat of combustion develops higher levels of overpressure which may result in higher flame propagation across the dust cloud. These events results into explosion. In addition to particle size, the intensity of an explosion depends on the rate of energy release due to combustion relative to the degree of confinement and heat losses.

The requirement of oxygen for combustion is fulfilled by atmospheric air. The dust explosion of volatile materials may occur in three steps which may follow each other in very quick succession — devolatization (where volatiles are let off by the particle or the particles are vapourized), gas phase mixing of fuel (released by dusts) and oxidant (usually air), and gas phase combustion.

7.6.1 Operations Involving Dusts

The following operations in which dusts are generated or handled

- Size reduction
- Conveying—manual or mechanical
- Settling operations
- Screening operations
- Mixing and blending operations
- Storages and Packaging

7.6.2 Dust as a Risk Factor

Dust comprises small solid particles which remains airborne before settling on their own. The dust of flammable material when comes in contact with ignition source triggers an explosion. Dust explosions have different characteristics than gas explosions and can in some cases be much more devastating. If a gas/air mix is ignited, the force of the resulting explosion causes the gas cloud to dissipate rapidly and thus dilutes the gas/air mix to a concentration lower than that necessary for further combustion. Thus, if no further gas is added, the explosion is over after several milliseconds.

The **Figure 7.2** shows the distribution of various ignition sources responsible for triggering dust explosion. It can be noticed that 30 % of explosions are caused due to mechanical sparks whereas 8 % of explosions are due to open fire. Each of static electricity, friction and smolder spots are responsible for 9 % of explosions. The other ignition sources like welding, hot surfaces contribute around 6 % of explosions.

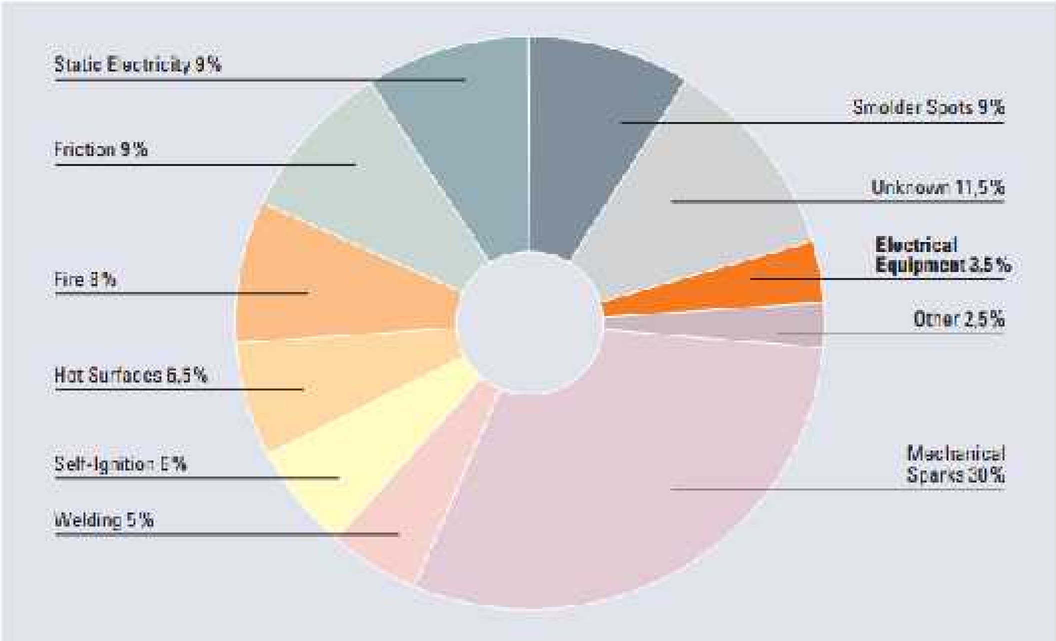

Figure 7.2 : Ignition Sources of Dust Explosions

The dust explosions in the port facility have caused serious industrial accidents resulting in multiple fatalities and severe structural damage. A dust cloud of any flammable material will explode when:

- The concentration of dust in air falls within the explosive limits.
- A source of ignition of the required energy is present.
- The dust must have a particle size distribution that will allow the propagation of flame
- The atmosphere into which the dust is dispersed as a cloud or suspension must contain sufficient oxidant to support combustion;

7.7 Risk Mitigation Measures

The risk mitigation measures to minimize occurrence of hazardous event have been incorporated in this section. Specific recommendations for particular facility as well as general recommendation are presented

7.7.1 Specific Recommendations

Following are specific recommendations based on the outcome of MCA analysis:

7.7.1.1 Loading and Unloading Arms

Before the start of the loading operations, all valve settings should be inspected. All the information regarding cargo should be available with the operation in-charge. The following precautions must be observed:

- Loading operation must start at a low rate. During this initial stage, the cargo line, manifold, connections, drain points etc. must be checked for leakages

- The loading rate should be increased slowly once it is satisfied that there is no leak in the system and filling pipe in the tank is covered
- At least one deck officer and one crew member must be on duty and available throughout the cargo loading operation. The deck officer has the responsibility to carry out the loading operation in accordance with the instructions received from the Chief-Officer. Some cargoes loaded in hot climates are chilled and cause bulkheads to sweat on loading. Therefore, careful attention should be given to sequences of loading
- During the loading operation, a detailed cargo log has to be kept ready
- Loading single product in more than one tank simultaneously may increase the risk of an overflow, therefore, the operation in-charge must ensure that fully loaded tanks are properly isolated from tanks still being loaded
- When nearing completion of loading, the shore should be notified and the loading rate should be reduced slowly

7.7.1.2 Handling of High Vapour Pressure Cargoes

High vapour pressure cargoes should be carefully handled as it generates large amount of vapour during loading or unloading operations. The high vapour pressure petroleum cargo once loaded into an empty tank evolutes gas rapidly, therefore, loading rate should not be very high. Therefore, during loading of high vapour pressure cargoes, efforts should be made to discharge and completely strip a tank in one operation The high vapour pressure cargo includes crude oil, aviation fuel, light distillate feedstock, motor gasoline etc.

7.7.1.3 Completion of Loading and Final Measurements

When loading is completed, the final loading measurements need to be done. In order to clear the shore and vessel’s cargo line free from products, the lines are blown from the shore. Cargos sensitive to oxygen are given a nitrogen blanket following the loading. Following precautions need to be taken at the completion of loading operations:

- Manifold valve for the loading operations must be closed
- In cases where the shore line is emptied by either blowing or pigging the product into the ship tank, it must ensure that the tanks have sufficient space to accommodate the quantity in the shoreline
- During blowing or pigging, care must be taken not to over-pressurize or overflow the tank.
- Shore hoses or arms must be disconnected only after they are drained of cargo residues and relieved of any pressure
- Personnel engaged in hose disconnection must wear proper personal protective equipment.

7.7.1.4 Pipeline

- Pipeline should be provided with high integrity three-layer polyethylene coating to protect it from external corrosion
- All welds should be radiographed and hydrostatic testing of the pipeline should be performed at a pressure upto 1.4 times the design pressure of the pipeline system. The test pressure should be held for a minimum period of 30 minutes to ensure complete structural integrity of the pipeline.
- Piping shall be opened at proper locations by removing valves at flanged locations to permit visual inspection.
- When erratic corrosion or erosion conditions are noted in areas accessible for visual examination, radiographic examination or ultrasonic testing shall be performed to determine thickness.
- Welds, heat-affected areas adjoining welds, points of restraint cracking, hydrogen attack and caustic embrittlement shall be inspected for cracks.
- For spot checks, dye-penetrate or magnetic particle inspection should be used
- Hammer testing shall also be carried out to supplement visual and ultrasonic inspection
- Regular patrolling of the pipelines should be carried out especially when the transfer operation is in progress. This will help in identifying any activity that have the potential to cause pipeline damage or to identify small leaks whose effects are too small to be detected by instruments.
- Pipeline failures due to third party activity can be reduced by ensuring that the members of the public, surrounding population, and the district administration are aware of the pipeline.
- The entire stretch of the underground pipeline is proposed to be cathodically protected. Regular readings of pipe to soil potentials should be taken to ensure that rapid corrosion is not taking place locally.
- Prior to the transfer of hydrocarbons from the port to the storage terminal, water draw off should be done to minimize internal corrosion
- Positive blinding of the lines may be carried out by using spectacle blinds both at the port and the terminal.
- At locations where the pipelines / pipe racks are close to traffic movement, adequate crash guards must be provided.

7.7.1.5 Flammable Oil Storages

Following are mitigation measures for the storage of flammable materials like naptha, gasoline, HSD, etc.

- Shut off and isolation valves should be easily approachable in emergencies

- Escape routes should be provided at strategic locations and should be easily accessible
- Necked flame, welding, hot surfaces or any other ignition source should not be permitted in storage area
- Gas and hydrocarbon detector should be provided in storage area to detect leakage
- The fire proofing material/coating resistant to weather effects such as chalking and erosion having adequate adhesion, strength and durability should be applied
- The separation /space between the storage tanks in the storage areas should be according to the OISD guidelines and sufficient to escape in case of any emergency
- The inspection and checking of firefighting facilities should be done periodically
- All storage facility have been provided with water spray cooling system and foam pourer system
- A wind direction pointer should be installed at storage site, so that in an emergency the wind direction can be directly seen and downwind population cautioned
- Signboards including phone numbers, no smoking signs and type of emergencies should be increased to cover all the locations of the plant

7.7.1.6 Propylene Spheres

- Pressure relief valves should be equipped on the top and at the centre of the spheres to release the excess pressure
- Fire protecting materials should be used to protect pressurized spheres against the effect of fire
- Spheres can be buried to avoid the pressurized explosions like BLEVE and UVCE
- Fire fighters should be trained with respect to the basic properties of containers and decisions to be taken regarding exposures and evacuations
- Loading points should have quick shut off valves
- All flanged joints in loading header and loading points shall be provided with jumper wires
- If any leak appears, the valve should be immediately closed and corrective measure should be taken
- Automatic shut down valves based on mass flow meter reading should be installed
- Thermal relief valve in each section is recommended to release pressure in case of malfunctioning of any of the shutdown valves

- Water sprinklers system should be provided on tank shell including the top cover
- Fire hydrant and monitor nozzle installation should be provided
- Ignition sources should be avoided near the propylene sphere
- Filling/Transfer operations should be stopped immediately in the event of
  - Uncontrolled leakage
  - Fire occurring in the vicinity
  - Lightening and thunder storm
- If leak is not ignited, water spray may be used in dispersing gas or vapor
- Use adequate ventilation to keep gas and vapor concentrations below occupational exposure and flammability limits. Use explosion-proof equipment and lighting in classified/controlled areas
- Use goggles and face shield, wear apron, insulating gloves while handling hazardous material

7.7.1.7 Coal

- The temperature of the coal stockpile should be monitored at the centre of the stock. The temperature at the side, top or corners of the stock should not be measured as temperature at the centre is always higher than at any other locations
- Hatch top wheels and associated equipment should be greased to ensure that no sparks are caused during opening and closing of the container
- Electrical cables, cargo hold lights and any other electrical instruments within cargo holds should be checked for insulation damage to ensure that they are safe for use in an atmosphere containing explosive gases
- Extra monitoring is necessary if coal is loaded in holds adjacent to hot areas
- No smoking policy should be strictly implemented on the ship and hot work should not be allowed in the vicinity of coal cargo compartments
- The coal containing compartment should be adequately ventilated
- The gases may escape the cargo compartment to adjacent stores, mast houses, etc. These spaces should also be monitored on a regular basis
- If any suspected problem is observed during the passage, the shipper should be immediately contacted to inform or seek any clarification
- Cargo temperature as well as methane content should be monitored. Necessary instruments should be installed for this
- Wear suitable protective clothing. Keep away from incompatibles such as oxidizing agents

7.7.1.8 Iron Ore

- ♦ Iron ores are heavy cargoes which occupy a small area for a large weight. The top of the tank should have sufficient strength to carry iron ores
- ♦ The loading and unloading operations of iron ore produces significant amount of dust. The enclosed conveyor belt should be used to minimize dust formation
- ♦ If iron ore is kept lying open, its moisture content increases due to absorption from air or rain. The moisture content should be well controlled as per the standard laboratory test
- ♦ Use appropriate tools to put the spilled material in a convenient waste disposal container
- ♦ The water should be spread on the contaminated surface and it should be disposed off according to local and regional authority requirements
- ♦ Use a shovel to put the material into a convenient waste disposal container

7.7.1.9 Lime Stone

- ♦ Limestone is not combustible or flammable. However, its reaction with acids may rupture containers. Therefore, limestone stockpiles should be kept away from acids and other incompatible material
- ♦ For large spills of lime stones, use dry methods to collect spilled materials
- ♦ Evacuate downwind area during cleaning up operation to minimize dust exposure. Store spilled materials in dry, sealed plastic or non-aluminum metal containers
- ♦ The limestone stockpiles should be kept away from moisture and rainfall, so that quality of limestone is not degraded

7.7.2 General Recommendations

Following are general recommendations to be followed:

- ♦ Surrounding population (includes all strata of society) should be made aware of the safety precautions to be taken in the event of any mishap within the plant. This can effectively be done by conducting the safety training programs
- ♦ Buildings possibly subjected to external blast waves should be made of reinforced concrete. The windows should be made of blast resistant glass with strong frame
- ♦ Air intakes should not be placed at grounds level, to prevent combustible dense gas from entering into building
- ♦ Buildings possibly subjected to internal explosion should have a strong frame structure supporting roof and intermediate floors. The walls should

be open. If a solid wall is needed, use low weight wall panels to facilitate early explosion venting

- Safety escape routes should be provided at strategic locations and should be easily accessible
- Grating and vent panels should be provided to minimize dominant eeffects
- Critical switches and alarm should be always kept in line
- Fire extinguishers should be tested periodically and should be always kept in operational mode
- Fire detectors should be installed near those units which handle large amount of explosive material and operate under high temperature and pressure
- Periodical mock drills should be conducted so as to check the alertness and efficiency of the DMP and EPP and records should be maintained
- Proper training should be given to staff to handle any emergency situation
- Signboard including phone numbers, no smoking signs and type of emergencies should be installed at various locations

7.7.2.1 Electricity Hazard

- All electrical equipments shall be provided with proper earthing. Earthed electrode shall periodically tested and maintained
- Emergency lighting shall be available at all critical locations including the operator's room to carry out safe shut down of the plant, ready identification of fire fighting facilities such as fire water pumps and fire alarm stations
- All electrical equipments shall be free from carbon dust, chemical deposits, and grease
- Use of approved insulated tools, rubber mats, shockproof gloves and boots, tester, fuse tongs, discharge rod, safety belt, hand lamp, wooden or insulated ladder and not wearing metal ring and chain
- Flame and shock detectors and central fire annunciation system for fire safety should be provided
- Temperature sensitive alarm and protective relays to make alert and disconnect equipment before overheating
- Danger from excess current due to overload or short circuit should be prevented by providing fuses, circuit breakers and thermal protection
- Carbon dioxide, halon or dry chemical fire extinguishers are to be used to extinguish electrical fires

7.7.2.2 Personal Protective Equipment (PPE)

Personal Protective Equipment (PPE) provides additional protection to workers exposed to workplace hazards in conjunction with other facility controls and safety systems. The PPE is considered to be a last resort that is above and beyond the other facility controls and provides the worker with an extra level of personal protection. The **Table 7.7** presents general examples of occupational hazards and types of PPE available for different purposes. Recommended measures for use of PPE in the workplace include:

- Active use of PPE if alternative technologies, work plans or procedures cannot eliminate or sufficiently reduce a hazard or exposure
- Identification and provision of appropriate PPE that offers adequate protection to the worker, co-workers, and occasional visitors, without incurring unnecessary inconvenience to the individual
- Proper maintenance of PPE, including cleaning when dirty and replacement when damaged or worn out. Proper use of PPE should be part of the recurrent training programs for employees
- Selection of PPE should be based on the type of hazards to be handled

Table 7.7 : Details of Personal Protective Equipment

Objective	Workplace Hazards	Suggested PPE
Eye and face protection	Flying particles, molten metal, liquid chemicals, gases or vapours, light radiation	Safety glasses with side-shields, protective shades, etc.
Head protection	Falling objects, inadequate height clearance, and overhead power cords	Plastic helmets with top and side impact protection
Hearing protection	Noise, ultra-sound	Hearing protectors (ear plugs or ear muffs)
Foot protection	Failing or rolling objects, points objects. Corrosive or hot liquids	Safety shoes and boots for protection against moving and failing objects, liquids and chemicals
Hand protection	Hazardous materials, cuts or lacerations, vibrations, extreme temperatures	Gloves made of rubber or synthetic material (Neoprene), leather, steel, insulation materials, etc.
Respiratory protection	Dust, fogs, fumes, mists, gases, smokes, vapours	Facemasks with appropriate filters for dust removal and air purification (chemical, mists, vapours and gases). Single or multi-gas personal monitors, if available
	Oxygen deficiency	Portable or supplied air (fixed lines). Onsite rescue equipment
Body / leg protection	Extreme temperatures, hazardous materials, biological agents, cutting and laceration	Insulating clothing, body suits, aprons etc. of appropriate materials

7.7.2.3 Occupational Health Hazards

Following are measures to tackle occupational health hazards:

- Detect the possible onset of an occupational disease
- Monitor personal exposure with the help of biological monitoring
- Check the effectiveness of preventive and control measures on regular basis
- Where there is potential for exposure to substances poisonous by ingestion, suitable arrangements are to be made for provision of clean eating areas where workers are not exposed to the hazardous or noxious substances
- Adequate supplies of potable drinking water should be provided from a fountain with an upward jet or with a sanitary means of collecting the water for the purposes of drinking
- Water supplied to areas of food preparation or for the purpose of personal hygiene (washing or bathing) should meet drinking water quality standards
- Periodic medical hearing checks should be performed on workers exposed to high noise levels
- Preventing spread of communicable diseases through food handlers
- Provisions should be made to provide orientation training to all new employees to ensure they are apprised of the basic site rules of work at / on the site and of personal protection and preventing injury to fellow employees
- Contractors that have the technical capability to manage the occupational health and safety issues of their employees should be hired, extending the application of the hazard management activities through formal procurement agreements
- Two ambulances and full fledge first aid treatment facilities should be available at all times

7.7.2.4 Falling Objects

- Provide safety helmets to protect workers below against falling objects
- Barriers like a toe boards or mesh guards should be provided to prevent items from slipping or being knocked off the edge of a structure
- Secure objects to the structure like lashing of scaffold boards
- Ensure that there are no loose objects and all tools are properly secured
- Create an exclusion zone beneath areas where work is taking place
- Danger areas should be clearly marked with suitable safety signs indicating that access is restricted to essential personnel wearing hard hats while the work is in progress.

7.7.3 Mitigation for Dust Explosion

7.7.3.1 Process Modification

The most obvious and fool-proof way to prevent dust explosions is to replace existing processes with the ones which do not deal with combustible dusts. Safe process design to prevent or reduce dust explosion hazard involve use of production, treatment, transportation and storage operations where dust cloud generation is kept at a minimum. Following four elements associated with inherently safe design may reduce the risk of accidents.

- ♦ Minimize (intensification): use smaller quantities of hazardous materials when the use of such materials cannot be avoided
- ♦ Substitute (substitution): replace a hazardous substance with one that is less hazardous or a hazardous process route with one that does not involve hazardous material
- ♦ Moderate (attenuation/limitation of effects): use hazardous material in their least hazardous forms or identify options that involve less severe operating conditions
- ♦ Simplify (simplifications/error tolerance): design processes and equipment to eliminate opportunities for errors by identifying ways to eliminate excessive use of add-on safety features and protective devices

The recommendations for process modifications are described below:

- ♦ Use nitrogen as a conveying gas instead of air
- ♦ Use nitrogen sealing in silos
- ♦ Fill silos using a cyclone to reduce dust cloud dispersion
- ♦ Carefully control the particle size
- ♦ Reduce electrostatic problems with silos and bag filters by checking the relative potential of metal construction parts
- ♦ Control moisture in pipes and silos
- ♦ Use lower mass flow rates
- ♦ Use online monitoring of the electric field of compacted powders in silos
- ♦ Keep the dust concentration below the minimum explosible concentration
- ♦ Design and test explosion blocks in conveying pipes

7.7.3.2 Preventing Flammable Dust Suspensions

It is difficult to keep the flammable dust cloud concentrations below certain levels in order to prevent an explosion, because the minimum explosive concentration is usually far below the economic operational conditions. The following measures may be effective:

- In cases where high dust concentration may be unavoidable, it would be appropriate to work with smaller piles of dust than with large one.
- Situations such as the free fall of dust from a height into a hopper, which may encourage dust cloud formation, should be avoided.
- The dust removal process must be done at a early stage for process considerations permit in order to avoid dust suspensions.
- Equipments handling flammable dusts should be appropriately designed to minimize the accumulation of dusts. Cleaning of dusts collected in places like ducts should be facilitated as often as permissible.

Safe housekeeping practices can be implemented to limit the presence of dust to controlled locations thereby reducing the potential for the formation of hazardous dust clouds. The NFPA 654 guidelines on housekeeping practices should be followed. It is recommended that all penetrations of floors, walls, ceilings, and partitions defining such barriers be dust tight. The surfaces where dust might accumulate be designed and constructed to minimize dust accumulations and to facilitate cleaning (for example, interior window ledges can be sloped, beams can be boxed in, and concrete walls can be painted to limit dust adherence). The spaces that may be inaccessible for cleaning may be sealed. The localized dust collection systems should be installed to limit dust migration. Such systems, however, must be carefully designed, operated, and maintained to control their own inherent dust explosion hazards.

One of the most effective ways of limiting the spread of dust through a facility is to keep it inside the equipment. Proper design, maintenance, and operation of equipment to minimize dust emissions is, therefore, of prime importance. Unsafe housekeeping such as vigorous sweeping or the use of steam or compressed air to blow down equipment in dusty areas may lead to the formation of combustible dust clouds.

7.7.3.3 Elimination of Ignition Sources

The ignition sources, which are traceable to routine operations or worker habits such as smoking, open flames, open light (bulbs), welding, cutting, and grinding, can be eliminated by sufficient staff training and enforcement of discipline. The ignition sources that originate in the process itself involve factors such as open flames, hot surfaces, self-heating, smoldering nests and exothermic decomposition, heat from mechanical impacts, exothermic decomposition of dust via mechanical impacts, and electric sparks and electrostatic discharges. As these ignition conditions are inherent in the actual process, the hazard can be reduced by employing the right precautionary measures like regular cleaning of accumulated dust at the process site, earthing of equipment that may develop charges, inspection of odd noises; and strict adherence to the process operation norms.

The minimum hot-surface temperature for ignition of a dust cloud varies with scale as well as the geometry of the hot surface in relation to the dust cloud. Consequently, results from small scale laboratory tests ought not to be directly applied in design of large-scale industrial plants. Development of numerical models for dynamic simulation of hot-surface ignition processes would be helpful in this regard. The parameters influencing the minimum energy required for igniting a dust cloud by an electric spark include voltage and current characteristics across the spark gap, spark gap geometry and electrode material, as well as all the dust cloud parameters. The latter include particle material and particle size/shape distributions, dust moisture content, dust concentration, and the dynamic state of the dust cloud with respect to the spark gap. Minimum ignition energies (MIE) of clouds of a given dust material decreases strongly with the fineness of the dust.

7.7.3.4 Inerting

Inerting refers to ways and means by which the oxygen concentration in a process area or a vessel is reduced by adding an inert gas to a level at which the dust cloud can no longer propagate a self-sustaining flame. Such inerting would slow down or totally prevent the dust explosion from taking shape, thereby reducing the explosion hazard. Inerting is also practiced, though much less frequently, by mixing a combustible dust with a non-combustible one.

Use of Inert Gases:

The gases commonly used for inerting of hazardous dusts are nitrogen, carbon dioxide, water vapour and rare gases. Selecting a suitable gas depends on various factors the principle one being the reactivity (or rather the lack of it) of a gas with the dust for which it is used. For example, CO_2, which is otherwise a useful inerting gas for several dusts, cannot be used with aluminum dust as it reacts violently with it. At high temperatures, nitrogen reacts strongly with magnesium dust and hence cannot be used in process involving the latter. Other factors are the availability and cost of supply of the relevant gas.

In situations where nitrogen or carbon dioxide is incompatible with some powders, it is advisable to use rare gases. Applying water spray or increasing the relative humidity in the work area are the practical ways of inerting the dusts during open operations such as shredding. In inerting, the system is slightly evacuated and then flushed with the inert gas until the original pressure is regained. This is repeated until the desired level of inerting is accomplished. If a high pressure system is being used, the inert gas may simply be pumped into the process vessels until the desired pressure is reached. Once inerting has been done, care must be taken that no air leaks into the process. If a new gas is introduced with the feed, it should also be inerted. Often partial inerting is used where total inerting may be too costly; this does not eliminate the chance of explosion, but limits it substantively.

Use of Particulate or Liquid Inertants:

Use of solid/liquid inertants can be achieved for prevention of dust explosion or mitigation/control of dust explosion. Non-gaseous inertants must be added to an otherwise explosible dust in sufficient quantity to render the latter non-explosible. Non-gaseous inertant should be quickly released in adequate quantities in a process vessel, as soon as dust in that vessel catches fire to prevent the flame from propagating further.

Use of non-gaseous inertants in dust explosion prevention is limited and is principally done where rock dust (calcium carbonate, with or without magnesium carbonate) is often sprayed to reduce the explosion hazard posed by coal dust. The rock dust acts as a thermal inhibitor by absorbing heat from the flame front of an explosion. This quenches the flame and arrests its propagation. Smaller particles of rock dust are more effective than larger particles though very fine particles suffer from the disadvantage that agglomeration can occur.

7.7.3.5 Preventive Steps for Specific Dusts/Operations

It is very difficult to prevent formation of an atmosphere which is not susceptible to explosion hazard, in processes involving carbonaceous dusts. In theory, an explosive atmosphere can be avoided by reducing the oxygen concentration using inerting techniques. In practice, however, the very nature of the given process using carbonaceous dust may preclude inerting. For such situations, the only options are avoiding ignition sources or using explosion proof equipment. If a mixer is closed, the circumferential speed of the mixing element need not be limited. Circumferential speeds up to 10 m/s can be tolerated during filling and emptying with a mixer not filled to less than 70% of its volume, provided that the minimum ignition temperature of the processed product lies above the limit values.

Precautions during Dust Separation:

Dust separation may cause electrostatic charging which must be inhibited by the following measures:

- Grounding of all conductive parts
- Use of electrically conducting filler material
- Ensuring that all inner walls on which dust can impact at high speed do not have any insulating inner coatings with a high electrical break down strength

7.7.3.6 Safety Codes

A number of safety codes for the dust/vapour explosion are classified depending on the type of industry or operations. National Fire Protection Association (NFPA) codes are segregated as:

- Combustible metals and metal dusts (NFPA 65, 480, 481).
- Explosion protection systems (NFPA 68, 69).
- Handling and conveying of dusts, vapour, and gases (NFPA 91, 650, 654, 655).
- Prevention of sulphur fires and explosions (NFPA 655).
- Prevention of fires and explosions in wood processing and woodworking facilities (NFPA 664).

7.7.4 Oil Spill Response Plan

Spills of oil to land require immediate response action to stop the source of the discharge and to limit the spread of material. Immediate response actions and notification procedures shall be developed. Attention must be paid to fire and safety hazards. For terrestrial areas, selection of appropriate control and containment techniques is dependent on the:

- Nature of the substrate,

- Slope of the terrain,
- Amount of product, and
- Time available to implement the response action.

The quantity and time parameters reflect the reality of constructing a barrier of appropriate size in the time available. These factors can only be judged in the field at the time of the incident. Should it be impossible to implement the desired method at a desired location due to a lack of time or access, a new control point would be selected further down the slope. If containment is still impossible and human safety is in question, the threatened area would need to be evacuated.

7.8 Approaches to Disaster Management Plan

Chemicals occupy an important segment of our economy and are also the source of large benefits to the society. In recent years, there has been a rapid increase in the number, variety and complexity of the chemicals being used in the industry and in our daily life. However, many of these chemicals are toxic, highly reactive, explosive or inflammable or have a combination of these characteristics and all these are classed as hazardous chemicals. Such chemicals are potential hazardous not only to the human beings, flora and fauna but also to all forms of property and our environment as a whole. Thus, extreme care is essential in handling such chemicals in any form and at all stages of manufacture, processing, treatment, package, storage, transportation, use, collection, destruction, conversion or sale.

Dust explosion is initiated by the rapid combustion of flammable particulates suspended in air. Any solid material that can burn in air will do so with a violence and the speed that increases with the degree of sub-division of the material. Particles having diameter less than 76 µm are referred as dust. More than 70 % of dusts processed in industry are combustible. This implies that majority of industrial plants that have dust-processing equipment are susceptible to dust explosions.

Several agencies of the Government, both at the central and state levels, such as the Directorate of Explosives, the Inspectorate of Factories and Port and Transport Authorities are entrusted with the responsibility of ensuring safe handling and management of hazardous chemicals under acts and rules made for the purpose. In spite of these measures, the possibility of accidents cannot be ruled out. Human errors and mechanical, electrical, instrumental or system failures have, on occasions, led to severe disasters. Accidents occurred at Bhopal, Mexico and other parts of the world have made people concerned with the dangers of chemical accidents. Occurrence of such accidents makes it essential that the central and state Governments as well as the local authorities are fully prepared to mitigate the sufferings and meet the eventualities resulting from any unfortunate occurrence of chemical accidents in our country. The existing Disaster Management Plan (DMP) can be extended for the proposed facility.

The management of disaster for major hazards is significant and is now a part of planning process as required by MoEFCC. Although all process and operating parameters are integrated for safety, it is important to plan for emergency handling so as to face it when it strikes. Planning for emergencies has to also take place in dust storage and handling operations.

The emergency planning exercises for on-site and off-site scenarios required for preparing a DMP are different; however they should complement each other. This study has focused on the possible hazards confined within the premises and the corresponding action plan (On-site plan). The responsibilities and actions expected from the Government departments during an emergency are also listed (Off-site Plan).When the disaster cannot be prevented, preparedness is very important in disaster risk management because being prepared for any disaster can reduce the adverse effect (casualty, loss of property) of it at least to some extent.

7.8.1 Disaster

Disaster is a sudden occurrence of hazard with a magnitude which could disturb the normal pattern of life in the facility and/or in vicinity causing extensive damage to life and/or property. The Disaster Management Plan (DMP) presents a clear organizational structure and elaborates the duties to be performed by individuals (including outside agencies) when situation demands, so as to reduce the probability/severity of community suffering and property damage. The activities among other things also include providing help in arranging for food, shelter, clothing, medical attention and other life sustaining requirements.

7.8.2 Causes of Disaster

Various causes that can lead to the above-referred disaster are as follows:

(a) In-plant emergencies due to deficiencies in system / malfunctioning / improper handling in:

- Operations
- Maintenance
- Equipment failure
- Design

(b) Natural calamities like

- Cyclone/Storm/Gale/Flood
- Lightning
- Earthquake

(c) Deliberate acts of man like

- Sabotage
- Riot
- War

(d) Projectile hitting the facility

7.8.3 Different Phases of Disaster

Warning Phase

Many disasters are preceded by some sort of warning. For example, with the aid of satellites and network of weather stations, many meteorological disasters like cyclones, hurricanes and floods can be predicted and preventive actions can be taken to eliminate / reduce their effect.

Period of Impact Phase:

This is the period when the disaster actually strikes and very little can be done to reduce the effects of disaster. The period of impact may last for a few seconds (like fire, dust explosion, gas leak) or may prolong for days. This is the time to bring the action plan in force. The coordinators in organization structure will perform the responsibilities assigned to them. Needless to emphasize that prompt and well organised rescue operations can save valuable lives.

Rescue Phase:

The rescue phase starts immediately after the impact and continues until necessary measures are taken to rush help and combat with the situation.

Relief Phase

In this phase, apart from organization and relief measures internally, depending on severity of the disaster, external help should also be summoned to provide relief measures like evacuations to a safe place and providing medical help, food, shelter clothing etc. This phase will continue till normalcy is restored.

Rehabilitation Phase:

This is the final and the longest phase. It includes rebuilding damaged property, estimating the damages, payment of compensation, etc. Help from revenue/insurance authorities need to be obtained to assess the damage, quantum of compensation to be paid etc.

7.8.4 Objectives of DMP

The purpose of DMP is to give an approach to detail organizational responsibilities, actions, reporting requirements and support resources available to ensure effective and timely management of emergencies associated to production and operations in the site. The overall objectives of DMP are to:

- Identify natural and human induced hazards and provide guidance towards rapid and timely disaster prevention, preparedness, response and recovery.
- Ensure safety of people, protect the environment and safeguard commercial considerations
- Immediate response to emergency scene with effective communication network and organized procedures
- Obtain early warning of emergency conditions so as to prevent impact on personnel, assets and environment

- Safeguard personnel to prevent injuries or loss of life and evacuate them from a facility when necessary
- Provide a framework of coordinated arrangements for the emergency management operational procedures in the event of disaster or emergency

7.8.5 Key Elements of DMP

Following are the key elements of Disaster Management Plan:

- Basis of the plan
- Accident/emergency response planning procedures
- On-site Disaster Management Plan
- Off-site Disaster Management Plan

7.8.5.1 Basis of the Plan

Identification and assessment of hazards is crucial for on-site emergency planning and it is therefore necessary to identify what emergencies could arise in production of various products and their storage. Hazard analysis or consequence analysis gives the following results.

- Hazards from spread of fire or release of flammable and toxic chemicals from storage and production units
- Hazards due to formation of pressure waves due to vapor cloud explosion of flammable gases and oil spill hazards

7.8.5.2 Emergency Planning and Response Procedures

Emergency rarely occurs; therefore activities during emergencies require coordination of higher order than for planned activities carried out according to fixed time schedule or on a routine day-to-day basis. To effectively coordinate emergency response activities, an organizational approach to planning is required. The important areas of emergency planning are organization and responsibilities, procedures, communication, transport, resource requirements and control centre. The offsite emergency requires additional planning over and above those considered under onsite plans, which should be properly integrated to ensure better coordination.

The emergency planning includes anticipatory action for emergency, maintenance and streamlining of emergency preparedness and ability for sudden mobilization of all forces to meet any calamity.

7.8.5.3 On-site Disaster Management Plan

Purpose:

The purpose of the DMP is to provide an overview of how PPT addresses the risks and impacts of natural hazards through a collaborative approach to the prevention of, preparedness for, response to and recovery from emergencies.

- To protect persons and property of processing equipments in case of all kinds of accidents, emergencies and disasters

- To inform people and surroundings about emergency if it is likely to affect them
- To inform authorities including helping agencies (doctors, hospitals, fire, police transport etc.) in advance and also at the time of actual happening
- To identify, assess, foresee and work out various kinds of possible hazards, their places, potential and damaging capacity and area in case of above happenings. Review, revise, redesign, replace or reconstruct the process, plant, vessels and control measures if so assessed.

Reporting Procedure:

- In the event of fire / explosion /excess gas release in port facility, the person seeing the incident will follow the laid down procedure in the port facility and report as follows:
- Will dial from the nearest telephone
- Will state his name and exact location of the emergency
- Will contact respective plant officers / emergency coordinator on duty
- Person reporting the accident will remain near the location to guide emergency crew arriving at the scene
- In case fire/emergency, person should activate the nearest available push button type instrument, which will automatically sound an alarm in the fire control room indicating the location of the fire.

OR

- He will inform the telephone operator and also inform the nearest control room on field telephone/VHF set/ superphone.

Communication System:

- On the receipt of the call, the telephone operator will sound the fire alarm and indicate the area involved:

- Fire or gas leakage	-	Normal Fire Siren
- Emergency / Evacuation	-	High-pitched Wailing Siren
- All clear	-	Continuous Fire Siren

- Alarms will be followed by an announcement over public address system. In case of failure of alarm system, communication will be by telephone operator who will make announcement in industrial complex through public address system, which should be installed. Walkie-talkie and pager systems using predetermined codes of communication are very useful during emergency. If everything fails, a messenger will be used for sending the information.

Warning System and Control:

- The control centers will be located at an area of minimum risk or vulnerability in the premises concerned, taking into account the wind direction, areas, which might be affected by fire/explosion, etc.

Emergency Services:

- The emergency services include the fire-fighting system, first aid center and hospital services. Alternate sources of power supply for operating fire pumps, communication with local bodies, fire brigade etc. will also be clearly identified. Adequate number of external and internal telephone connections shall be installed.

Infrastructure:

Following infrastructure and operational system shall be provided in the proposed facility to meet any emergencies.

Emergency Control Room:

Emergency control room shall be located in the area away from accident / fire prone places of and shall be provided with the following facilities:

- Master plan of the port
- Layout of plant and equipment
- Portable gas detectors
- First-aid boxes
- Gas masks
- Telephone line with STD facility
- Loud hailers
- Emergency lighting system
- Stretchers, Ambulance
- Transport facility

Assembly Points:

- Assembly points are to be set up farthest from the locations of likely hazardous events, where pre-designated persons from the works, contractors and visitors would assemble in case of emergency. Up-to-date list of pre-designated employees of various departments (shift-wise) must be available at these points so that roll call could be taken. Pre-designated persons would take charge of these points and mark presence as the people come into it.

Fire Protection System:

The fire protection system for the proposed port facility shall consist of

- Hydrant system for all the areas of the port facility

- Automatic High Velocity (HV) water spray system for the various transformers and storage tanks
- Deluge system for cable vault/galleries
- Portable carbon dioxide (CO_2) extinguishers in for the control room
- Portable hand appliances of suitable types/ capacities for extinguishing small fires in selected areas of the plant
- The system will comply with the requirements of the Tariff Advisory Committee (TAC) of Insurance Association of India.

Evacuation Plan - by Road:

In case of emergency, the evacuation by roads can be through existing NH5A. It alternate evacuation by road can be through PPL township and IOCL township. These roads are highlighted in **Figure. 7.3**. Necessary evacuation arrangement can be made through discussions with IOCL.

Figure 7.3 : Evacuation Plan by Road

Evacuation Plan - by Water:

The proposed plan of evacuation by water from Paradip is through the proposed cruise terminal and the nearest location via water is Cuttack (upto Zobra Barrage) along Mahanadi river. Using water mode during Tsunami/ floods are not recommended. The usage of water during emergencies may be taken with caution. The proposed cruise terminal location and the water evacuation route are provided in the **Figure. 7.4**. The summary of the water evacuation plan are:

- Capacity – 1,000 to 2,000
- No of trips – 1 trip per day

- Not reliable mode of transport during disaster (flood/ tsunami)
- Can be used as an alternate source during emergency

Proposed Cruise Terminal Location

Figure 7.4 : Evacuation Plan by Water

Evacuation Plan - by Air:

There is no airport nearby the project area, however, there is a helipad located inside Paradip Port as shown in the **Figure. 7.5**. The helipad shall be used to transport important persons/ iindustrialist in case of emergency. As the evacuation is through use of helicopters, the maximum capacity is restricted to 6-10.

Escape route to Cruise Terminal and Helipad

Helipad

Figure 7.5 : Evacuation Plan - by Air

Evacuation Plan - by Rail:

The nearest area by rail evacuation shall be to Cuttack. Necessary coordination between the railway zonal headquarters in Bhubaneswar and Paradip Port for deployment special trains shall be carried during emergency by PPT. It is expected that about 1000 to 1500 person per trip would be evacuated and the number of trips per day would be at least 3. The evacuation route planned by rail is provided in **Figure. 7.6**.

Figure 7.6 : Evacuation Plan - by Rail

7.8.5.4 Off-site Disaster Management Plan

An unexpected emergency could cause serious damage to people, livestock and property in the surrounding area. This naturally calls for the necessity of evolving a comprehensive off-site emergency preparedness program so as to combat any such possible eventuality. Many agencies are involved in combating an emergency in off-site scenario. These include Government departments like revenue, public health, fire services, police, civil defense, home guards, medical services and other voluntary organization. Thus, handling an emergency requires an organized multi-disciplinary approach. The off-site emergency plan should aim at reducing the probability and severity of the sufferings of the people and the damage to property by clearly identifying the role of all agencies involved in combating an emergency. The scope of the offsite plan is to

- ♦ Protect the inhabitation around the hazardous areas against exposure to fire, toxic gases by providing alternate and safe shelter and evacuating them, if necessary
- ♦ Ensure their subsistence during the stay in camp
- ♦ To protect and safeguard the property and belongings of the evacuated sections of the population until their return
- ♦ To take adequate measures for their rehabilitation.

Sectorial Division of Emergency Planning Zone:

The Emergency Planning Zone has to be been divided into convenient sectors, as detailed below:

Depending upon the prevailing wind direction at the time of the emergency and the assessed extent of fire / explosion hazard, the protection measures will be implemented first in the sector downwind. Sectors adjacent to this sector on either side will come next. Based on subsequent changes in the extent and degree of release of hazardous material and the wind direction, protective measures will be introduced in zones further downwind.

Management Plan for Natural Disasters:

The management plan to tackle emergencies arising due to natural disasters like earthquake, flood. cyclone etc. is detailed below

Earthquake:

Paradip (Mahanadi delta) comes under earthquake risk zone-III (Moderate Damage Risk Zone) as shown in the **Figure. 7.7**. Hence, prompt actions in managing earthquake are important in minimizing its effect. All structures at project site shall be designed with appropriate/internationally accepted safety margins. The structural mitigation in earthquake prone areas includes seismic retrofits of property and the securing of items inside a building to enhance household seismic safety. It may include the mounting of furniture and other equipment to the walls.

Figure 7.7 : Earthquake Zones of Odisha

Flood:

Following are measures to be taken in case of floods:

- Focus resources on minimizing the spread of water into other areas of the plant
- Protect property and records by removing items from floors and /or covering with water resistant coverings.
- Attempt to move items of value to "higher ground" if possible.
- Evacuate personnel as needed. Utilize the fire alarm system if an immediate evacuation is required.
- Mitigation measures can be structural or non-structural. Structural measures use technological solutions, like flood levees. Non-structural measures include legislation, land-use planning (e.g. the designation of nonessential land like parks to be used as flood zones), and insurance.
- The response phase includes the mobilization of the necessary emergency services and first responders in the flood area. This is likely to include a first wave of core emergency services, such as fire-fighters, police and

ambulance crews. They may be supported by a number of secondary emergency services, such as specialist rescue teams.

Floods are the most common and widespread of all natural disasters. The entire coastal belt of Odisha including Paradip is prone to storm surges as shown in the **Figure. 7.8**. Damages can also be caused due to flooding in the river Mahanadi. This problem becomes even more acute when floods coincide with high tides of Sea. Flood causes damage to houses, industries, public utilities and property resulting in huge economic losses, apart from loss of lives.

Figure 7.8 : Flood zones of Odisha

Cyclones and Severe Storms:

Following are measures to be taken in case of cyclones and severe storms:

- Land use management should provide protection from wind and storm surge
- Engineering of structures should withstand wind forces and water damage (including storm surge)
- Building should be constructed with higher wind-resistant capacity
- Securing of elements such as metal sheeting, roofing, and fences should be done to avoid severe damages
- Safety shelters are to be arranged to tackle cyclones and storms
- Cyclone and severe weather warning systems should be installed
- Community awareness regarding cyclone risk and evacuation plan should be properly addressed

The entire coastal belt along with Paradip is prone to cyclone as shown in the **Figure. 7.9**.

Figure 7.9 : Cyclone Prone Areas of Odisha

Tsunami:

Tsunami has very long wavelengths and travel through the ocean at more than 700 km/h. Sometimes there appears to be just one wave but often there are multiple waves travelling a few minutes apart. The first sign of the arrival of a tsunami may actually be the sea level falling and bays appearing to empty. However as the wave approaches shore and the water shallows, it slows down. The wave rapidly bunches up as the faster rear sections catch up with the slower front sections resulting in the wave growing in height the closer it gets to shore.

Tsunami is a natural disaster which cannot be prevented but the effects can be reduced by knowing all facts about it and being prepared for it. Some of the measures are:

- Construction of shelters
- Plantation of mangroves to save the coast line and reduce the damage as shown in the **Figure. 7.10**

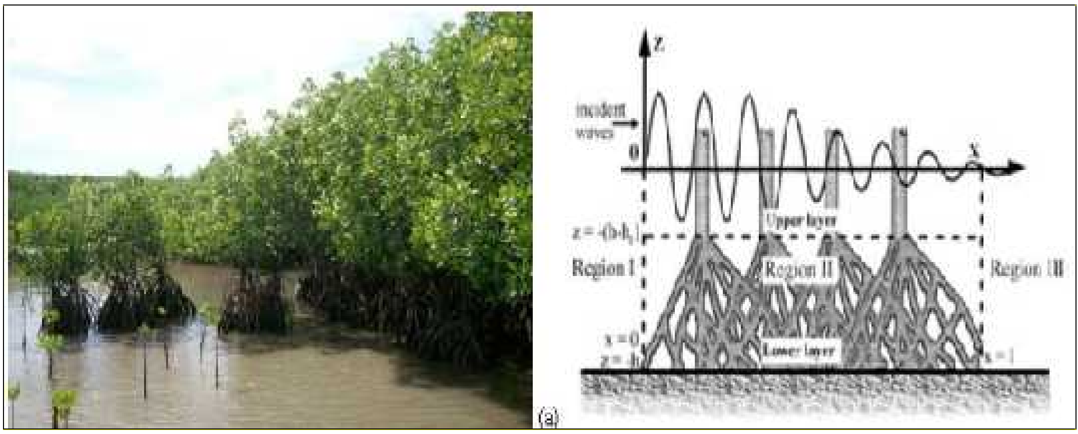

Figure 7.10 : Mangrove

- Development of a "Bio-Shield" - a narrow strip of land along coastline. Bio-Shield can be developed as coastal zone disaster management sanctuary, which must have thick plantation and public spaces for public awareness, dissemination and demonstration.
- Development of well-designed break waters as shown in the **Figure. 7.11** along the coast to provide necessary cushion against tsunami hazards.

Figure 7.11 : Breakwater

Heat Wave:

In recent years, excessive heat has caused more deaths than other weather events. A heat wave is a prolonged period of excessive heat, often combined with excessive humidity. Generally temperatures are 10 degrees or more above the average high temperature for the region during summer months, last for a long period of time and occur with high humidity as well.

The heat waves are seasonal and lasts from April to June, the chances of getting a heat stroke are high during this period. Heat stroke (also known as sunstroke) is a life-threatening condition in which a person's temperature control system stops working and the body is unable to cool itself.

Responsibilities of the Local Authorities:

For the local authorities and Govt. departments to fulfill their aims and responsibilities, in-hand information should be available to anticipate the development of believable accidents. Industrial operators should, therefore, provide appropriately structured input to assist the emergency management planning authorities in planning and operating off-site emergency procedures. The actions and responsibilities expected from concerned government department are listed below

Police Department:

- Warning and advice in the affected area. Use mike fitted van. Get ready with the message to be announced
- Regulating and diverting traffic
- Maintaining law and order in the area
- Ensuring security of the belongings of the evacuees

- Co-ordination with the transport authorities
- Co-ordination with civil defense and home guards
- Co-ordination with army, navy, air force as required
- Co-ordinate with state fire services
- Arrange for post-mortem of dead bodies
- Establish communication center

Medical Department:

- Set up temporary medical camp
- Ensuring medical facilities at the emergency site and neighborhood areas
- Arranging for casualties to be sent to government /private hospitals
- Co-ordinate the activities of primary health centers and municipal dispensaries to ensure required quantities of drugs and equipments
- Securing assistance of medical and paramedical personnel from nearby hospitals/institutions
- Temporary mortuary and identification of dead bodies

Revenue Department:

- Evacuation of personnel from the affected area
- Arrangements at rallying posts and parking yards
- Rehabilitation of evacuated persons
- Co-ordination with other agencies such as police, medical, animal husbandry, agriculture, electricity board, fire services, home guards - civil defense
- Nominate a press officer
- Establishing shelters for rescue, medical, fire fighting personnel, etc.

Fire Services Department:

- Assist in fire fighting - mobilize required fire engines
- Rendering assistance for fire fighting

Emergency Committee:

The PPT should form a committee for disaster management comprising officials as given in **Table 7.8.** The functioning of the committee is presented in **Figure. 7.12**.

Table 7.8 : Disaster Management Committee

Sr. No.	Name and Designation of Committee Members	Position
1	Chairman of PPT	Head
2	Chief Engineer	Member
3	Executive Engineer	Member
4	Executive Engineer (Port)	Member
5	Transport Officer	Member
6	Fire Officer	Member
7	Inspector	Member
8	Civil Defense Paradip	Member
9	NGO Representative	Member

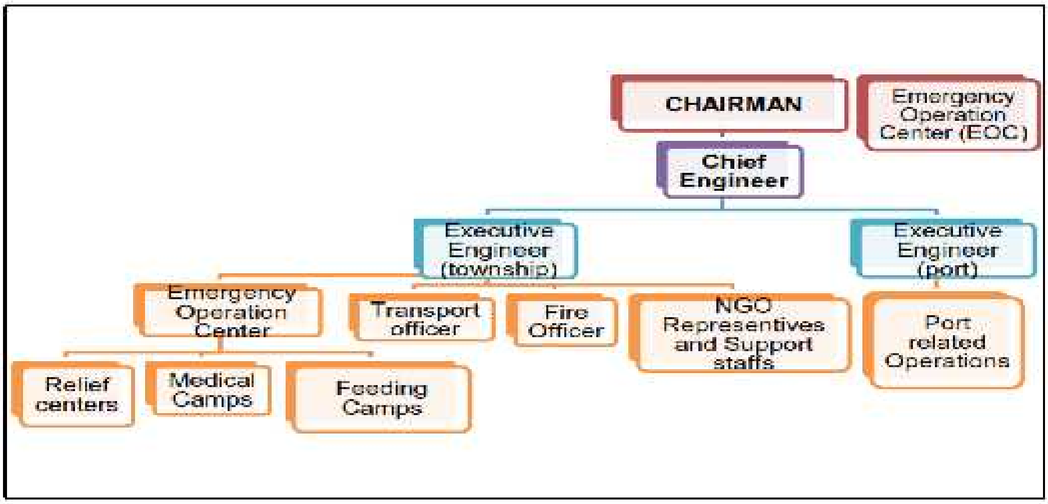

Figure 7.12 : Functioning of Disaster Management Committee

Post-Accident Activities:

Following activities are to be undertaken after accident had happened:

Accident Investigation:

The port facility will proceed in analyzing accidents and failures as per the following points:

- Evaluate the situation
- Protect life and property
- Keep the area safe
- Conduct a release survey
- Conduct pressure test of piping
- Perform meter and regulator checks
- Question persons on the scene
- Examine burn and debris patterns

- Record weather conditions
- Select samples of the failed facility or equipment or equipment for laboratory examination for the purpose of determining the causes of the failure and minimizing the possibility of recurrence
- Notify the appropriate Risk Management Office

Incident Reporting:

The officer of local Environment, Health and Safety shall within 72 hours of the closure of the incident, schedule a debriefing with all agencies concerned. This debriefing shall include, but not be limited to:

- Analysis of the incident including type of scenario, type of fire, impact distance, casualties and injuries etc.
- Problem areas identified
- Revisions to the emergency plan, if needed
- Factors that caused the incident
- Upon completion of the debriefing, open discussion for questions and answers should be allowed

Relief to Victims:

Post-incident activities include the relief to the victims. As per The Public Liability Insurance Act, the owner should pay specified amounts of money to the victims as interim relief. After proper assessment of the incident, the owner may invite applications for relief, conduct an enquiry into the claims and arrange payment of the relief amount to the victims.

Checklist for Capability Assessment:

The checklist will help in assessing the preparedness, prevention and response resources capabilities. The points included in the checklist are only indicative and there is a need to closely examine the local requirements while preparing the checklist. For good control and management of an incident, following are three important requisites

- Defined organization
- Effective means
- Trained people

The organization has to be properly structured for routine as well as emergency purposes with clear understanding of duties and responsibilities. The structure has to consider an execution and speedy implementation of the response plans; while at the same time, it should be flexible enough to tune itself to the fast changing situations. All plans and procedures for emergency handling should be established.