RISK ASSESSMENT STUDY

1.0 Risk Assessment

Hazard analysis involves the identification and quantification of the various hazards (unsafe conditions) that exist in the plant. On the other hand, risk analysis deals with the identification and quantification of risks, the plant equipment and personnel are exposed to, due to accidents resulting from the hazards present in the plant.

Risk analysis follows an extensive hazard analysis. It involves the identification and assessment of risks on the neighboring population are exposed to as a result of hazards present. This requires a thorough knowledge of failure probability, credible accident scenario, vulnerability of population etc.

In the sections below, the identification of various hazards, probable risks in the proposed copper refinery project, maximum credible accident analysis, consequence analysis are addressed which gives a broad identification of risks involved in the plant. Based on the risk estimation for fuel and chemical storage Disaster Management Plan (DMP) has been prepared.

1.1 Approaches to the Study

Risk involves the occurrence or potential occurrence of some accidents consisting of an event or sequence of events. The risk assessment study covers the following:

- Identification of potential hazard areas;
- Identification of representative failure cases;
- Visualization of the resulting scenarios in terms of fire (thermal radiation) and explosion;
- Assess the overall damage potential of the identified hazardous events and the impact zones from the accidental scenarios;
- Assess the overall suitability of the site from hazard minimization and disaster mitigation points of view;
- Furnish specific recommendations on the minimization of the worst accident possibilities; and
- Preparation of broad Disaster Management Plan (DMP), On-site and Off-site Emergency Plan, including Occupational and Health Safety Plan.

1.2 Hazard Identification

Identification of hazards in the proposed copper refinery plant is of primary significance in the analysis, quantification and cost effective control of accidents involving chemicals and process. A classical definition of hazard states that hazard is in fact the characteristic of system/plant/process that presents potential for an accident. Hence, all the components of a system/plant/process need to be thoroughly examined to assess their potential for initiating or propagating an unplanned event/sequence of events, which can be termed as an accident. The following two methods for hazard identification have been employed in the study:

- Identification of major hazardous units based on Manufacture, Storage and Import of Hazardous Chemicals Rules, 1989 of Government of India (GOI Rules, 1989); and
- Identification of hazardous units and segments of plants and storage units based on relative ranking technique, viz. Fire-Explosion and Toxicity Index (FE&TI).

1.3 Classification of Major Hazardous Units

Hazardous substances may be classified into three main classes namely flammable substances, unstable substances and toxic substances. The ratings for a large number of chemicals based on flammability, reactivity and toxicity have been given in NFPA Codes 49 and 345 M. The fuel and chemical storage for proposed project is given in **Table-1** and the hazardous characteristics of the major flammable materials as employed in different process units are listed in **Table-2.**

TABLE-1
CATEGORY WISE SCHEDULE OF STORAGE FACILITIES

Sr. No.	Material	UOM	Storage Capacity	Classification
1	H_2SO_4 (Sulphuric Acid)	Ton	1,50,000	Corrosive
2	Furnace Oil	Ton	4,000	Flammable
3	HSD	KL	1,000	Flammable
4	LPG	Ton	400	Flammable
5	Oxygen (Liquid)	Ton	1,000	Flammable
6	Coal/pet coke	Ton	100	Flammable
7	Met Coke	Ton	100	Flammable
8	H_3PO_4 (Phosphoric Acid)	Ton	30,000	Corrosive
9	H_2SiF_6 (Hydro Fluro Silicic Acid)	Ton	4,000	Corrosive

TABLE-2
PROPERTIES OF FUELS

Chemical	Codes/ Label	TLV	FBP	MP	FP	UEL	LEL
			°C			%	
Furnace Oil	Flammable	5mg/m^3	400	338	32.96	7.5	0.6
HSD	Flammable	5mg/m^3	369	338	32.96	7.5	0.6
LPG	Flammable	1000 ppm	-	-	104.4	9.5	1.9

TLV : Threshold Limit Value
FBP : Final Boiling Point
MP : Melting Point
FP : Flash Point
UEL : Upper Explosive Limit
LEL : Lower Explosive Limit

1.4 Identification of Major Hazard Installations Based on GOI Rules, 1989

Following accidents in the chemical industry in India over a few decades, a specific legislation covering major hazard activities has been enforced by Govt. of India in 1989 in conjunction with Environment Protection Act, 1986. This is referred here as GOI rules 1989. For the purpose of identifying major hazard installations the rules employ certain criteria based on toxic, flammable and explosive properties of chemicals.

A systematic analysis of the fuels/chemicals and their quantities of storage has been carried out, to determine threshold quantities as notified by GOI Rules, 1989 and the applicable rules are identified. Applicability of storage rules is summarized in **Table-3.**

TABLE-3
APPLICABILITY OF GOI RULES TO FUEL STORAGE

Sr. No.	Chemical/ Fuel	Listed in Schedule	Total Quantity	Threshold Quantity (T) for Application of Rules	
				5,7-9,13-15	10-12
1	Furnace Oil	3 (1)	4000 T	25 MT	200 MT

2	HSD	3 (1)	1000 KL	25 MT	200 MT
3	LPG	3 (1)	400 T	25 MT	200 MT

1.5 Preliminary Hazard Analysis (PHA)

A preliminary hazard analysis is carried out initially to identify the major hazards associated with storages and the processes of the plant. This is followed by consequence analysis to quantify these hazards. Finally, the vulnerable zones are plotted for which risk reducing measures are deduced and implemented. Preliminary hazard analysis for fuel storage area and whole plant is given in **Table-4** and **Table-5**.

TABLE-4
PRELIMINARY HAZARD ANALYSIS FOR STORAGE AREAS

Unit	Phase-I	Phase-II	Total Capacity	Hazard Identified
Furnace Oil	2 x 1000 T	2 x 1000 T	4 x 1000 T	Fire/Explosion
HSD	1 x 500 KL	1 x 500 KL	2 x 500 KL	Fire/Explosion
LPG	2 x 100 T	2 x 100 T	4 x 100 T	Fire/Explosion

TABLE-5
PRELIMINARY HAZARD ANALYSIS FOR THE PROPOSED PROJECT IN GENERAL

PHA Category	Description of Plausible Hazard	Recommendation	Provision
Environ-mental factors	If there is any leakage and eventuality of source of ignition.	-	All electrical fittings and cables will be provided as per the specified standards. All motor starters will be flame proof.
	Highly inflammable nature of the chemicals may cause fire hazard in the storage facility.	A well designed fire protection including water sprinkler system, dry powder, CO_2 extinguisher will be provided.	Fire extinguisher of small size and big size will be provided at all potential fire hazard places. In addition to the above, fire hydrant network will also be provided.
	If there is any leakage in the duct and eventuality of source of emission SO_2	Periodical check-up of the wear and tear of the ducts and mechanical, Electrical and Instrumentation equipment.	-
	If there is a sudden trip of sulphuric acid plant main blower, the SO_2 gas in between smelter and SAP will become the eventuality of source of emission SO_2	Uninterrupted power supply.	If there is a sudden trip of sulphuric acid plant main blower, smelting will get stopped by trip interlock arrangement with sufficient back up arrangement to handle the gas trapped in the system.

- **Safety Measures in Storage Facilities**

Risk for storage units depends not on the extent of the consequence, but also on the probability of the failure of the safety measures and provisions provided. The safety measures to be provided in storage facilities in the proposed plant are given in **Table-6**.

TABLE-6
SUBSTANCE STORED AND SAFE GUARD

Substance Stored	Safe Guard
Sulphuric acid Phosphoric acid	• Bund wall will be constructed around the storage tanks for acid/ alkali spillage containment. • Collection pit / neutralization pit with pumping arrangement. • Buffer tank with equal capacity of maximum capacity of one tank. • Sufficient amount of neutralization agent.
Furnace oil High Speed Diesel (HSD)	Following fire fighting measures will be provided: a) DCP extinguisher; b) AFFF extinguisher; c) Water cum foam monitor; and d) Sand bucket.
Iso Propanol	Following fire fighting measures will be provided: a) DCP extinguisher b) Sand bucket c) Well laid fire hydrant system d) During unloading, tankers will be provided with extinguishers
Liquefied Petroleum Gas (LPG)	1. Hydrocarbon sensors will be provided for continuous monitoring of the flammable vapour in the atmosphere. 2. Medium pressure water sprinkler system will be provided with automatic detection and operation. 3. Water blanketing system will be installed to control outside fire 4. Following fire fighting facilities will be provided: • DCP extinguisher • Sand bucket • Water monitor 4. CO_2 extinguishers will be placed in LPG unloading area and in LPG tankers.
Copper Concentrate Ware house	• Well laid fire hydrant system • Dust suppression system • Mechanised operation • Air conditioned operator cabin • 5 kg DCP extinguisher
Rock phosphate	• Well laid fire hydrant system • Dust suppression /extraction system • Mechanized operation • Air conditioned operator cabin

1.6 Maximum Credible Accident Analysis (MCAA)

Hazardous substances may be released as a result of failures or catastrophes, causing possible damage to the surrounding area. This section deals with the question of how the consequences of the release of such substances and the damage to the surrounding area can be determined by means of models. Major hazards posed by flammable storage can be identified taking recourse to MCA analysis. MCA analysis encompasses certain techniques to identify the hazards and calculate the consequent effects in terms of damage distances of heat radiation, toxic releases, vapour cloud explosion, etc. A host of probable or potential accidents of the major units in the complex 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. The reason and purpose of consequence analysis are many folds like:

- Part of risk assessment;
- Plant layout/code requirements;
- Protection of other plants;
- Protection of the public;
- Emergency planning; and
- Design criteria.

The results of consequence analysis are useful for getting information about all known and unknown effects that are of importance when some failure scenario occurs in the plant and also to get information as how to deal with the possible catastrophic events. It also gives the workers in the plant and people living in the vicinity of the area, an understanding of their personal situation.

- **Selected Failure Cases**

The purpose of this listing is to examine consequences of such failure individually or in combination. It will be seen from the list that failure cases related to storage of Furnace Oil, LPG and HSD have been identified.

1.6.1 Damage Criteria

The fuel storage and unloading at the storage facility may lead to fire and explosion hazards. The damage criteria due to an accidental release of any hydrocarbon arise from fire and explosion. The vapors of these fuels are not toxic and hence no effects of toxicity are expected.

Tank fire would occur if the radiation intensity is high on the peripheral surface of the tank leading to increase in internal tank pressure. Pool fire would occur when fuels collected in the dyke due to leakage gets ignited.

- **Fire Damage**

A flammable liquid in a pool will burn with a large turbulent diffusion flame. This releases heat based on the heat of combustion and the burning rate of the liquid. A part of the heat is radiated while the rest is convected away by rising hot air and combustion products. The radiations can heat the contents of a nearby storage or process unit to above its ignition temperature and thus result in a spread of fire. The radiations can also cause severe burns or fatalities of workers or fire fighters located within a certain distance. Hence, it will be important to know beforehand the damage potential of a flammable liquid pool likely to be created due to leakage or catastrophic failure of a storage or process vessel. This will help to decide the location of other storage/process vessels, decide the type of protective clothing the workers/fire fighters need, the duration of time for which they can be in the zone, the fire extinguishing measures needed and the protection methods needed for the nearby storage/process vessels. **Table-7.** Tabulates the damage effect on equipment and people due to thermal radiation intensity.

TABLE-7
DAMAGE DUE TO INCIDENT RADIATION INTENSITIES

Sr. No.	Incident Radiation (kW/m^2)	Type of Damage Intensity	
		Damage to Equipment	**Damage to People**
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 at indefinitely long exposure without a flame	50% Lethality in 1 min. Significant injury in 10 sec.
3	19.0	Maximum thermal radiation intensity allowed on thermally unprotected adjoining equipment	-
4	12.5	Minimum energy to ignite with a flame; melts plastic tubing	1% lethality in 1 min.
5	4.5	-	Causes pain if duration is longer than 20 sec, however blistering is un-likely (First degree burns)
6	1.6	-	Causes no discomfort on long exposures

Source: Techniques for Assessing Industrial Hazards by World Bank.

1.6.2 Fuel Storage

The details of storages are given in **Table-1.** In case of fuel released in the area catching fire, a steady state fire will ensue. Failures in pipeline may occur due to corrosion and mechanical defect. Failure of pipeline due to external interference is not considered as this area is licensed area and all the work within this area is closely supervised with trained personnel.

1.6.3 Modeling Scenarios

There are two plots for storage of LPG and oil fuel, each covering 160 m x 80 m area, one for Phase-I and the other for Phase-II project. Each plot contains two above-ground LPG bullets, two Furnace oil tanks and one HSD tank. Based on the storage and consumption of various fuels and chemicals the following failure scenarios for the proposed Copper refinery project have been identified for MCA analysis and the scenarios are discussed in **Tables-8.**

TABLE-8
SCENARIOS CONSIDERED FOR MCA ANALYSIS

Sr. No.	Description	Capacity of Storage Tank		Remarks
		Phase-I	**Phase-II**	
1	LPG Bullets	2 x 100 T	2 x 100 T	Above-ground horizontal cylindrical pressure vessels
2	Furnace oil Tanks	2 x 1,000 T	2 x 1,000 T	Vertical cone roof tanks
3	HSD Tank	1 x 500 KL	1 x 500 KL	Vertical cone roof tank

1.6.4 Model Computations

Hazardous Properties of LPG & Oil Fuels

The flammable consequences of LPG release from equipment are mainly the following:

- Jet fire/pool fire/ flash fire
- Vapour cloud explosion

Properties of LPG relevant to this QRA study are as follows:

Composition	:	Mixture of Propane and Butane
Normal Boiling Point	:	(-)6 °C
Lower Flammable Limit (LFL)	:	1.8 % (vol)
Upper Flammable Limit (UFL)	:	9.5 % (vol)
Auto ignition temperature	:	410-580 °C (approx.)

LPG is stored as liquid under pressure. LPG vapours are heavier than air and disperse close to ground level. LPG odorized with ethyl mercaptan is received in the plant so as to provide warning in case of leakage.

High speed diesel (HSD) is Class 'B' petroleum product with minimum flash point of 35 °C. Furnace oil is Class 'C' petroleum product with minimum flash point of 66 °C.

1.6.5 Consequence Analysis

Jet/ Pool Fire Radiation

The effect from jet fire and pool fire is thermal radiation intensity on the receptor surface as shown in **Table-9**.

TABLE7.9
DAMAGE EFFECTS DUE TO JET/ POOL FIRE RADIATION

Heat Radiation Intensity (kW/m^2)	Observed Effect
4.5	Sufficient to cause pain to personnel if unable to reach cover within 20 seconds; 0% lethality.
12.5	Minimum energy required for piloted ignition of wood, melting of plastic tubing.
37.5	Sufficient to cause damage to process equipment.

- Thermal radiation intensity exceeding 37.5 kW/m^2 may cause escalation due to damage of other equipment.
- Thermal radiation intensity exceeding 12.5 kW/m^2 may cause ignition of combustibles on buildings and impairment of escape route.
- Thermal radiation intensity exceeding 4 kW/m^2 may cause burn injury on personnel injury.

Vapour Cloud Explosion (VCE)

When a large quantity of flammable vapour or gas is released, mixes with air to produce sufficient mass in the flammable range and is then ignited, the result is a vapour cloud explosion (VCE). In the LPG installation large release of LPG from equipment or piping has potential for vapour cloud explosion. The damage effect of vapour cloud explosion is due to overpressure as shown in **Table-10**.

TABLE-10
VCE OVER PRESSURE LIMIT AND OBSERVED EFFECT

Over-pressure Effect		Observed Damage
bar(g)	psig	
0.021	0.3	"Safe distance" (probability 0.95 of no serious damage below this value); projectile limit; some damage to house ceilings; 10% of window glass broken.
0.069	1	Repairable damage; partial demolition of houses; steel frame of clad building slightly distorted.
0.138	2	Partial collapse of walls of houses.
0.207	3	Heavy machines in industrial buildings suffered little damage; steel frame building distorted and pulled away from foundations.

Consequence Analysis Results

The failure scenario of leak of liquid LPG through 25 mm diameter hole which represents a maximum credible scenario. Results of consequence analysis carried out using Phast software are summarized in **Table-11**.

TABLE-11
CONSEQUENCE ANALYSIS RESULTS

Sr. No.	Description	Parameter	Downwind Distance (metres) Weather (Wind speed & Stability)		
			2 m/s; D	3 m/s; D	5 m/s; D
1	**LPG Bullet Liquid Leak (25 mm dia)**				
	Pool Fire Radiation Intensity	4 kW/m^2	45	45	44
		12.5 kW/m^2	28	28	29
		37.5 kW/m^2	13	14	15
	Jet Fire Radiation Intensity	4 kW/m^2	24	23	23
		12.5 kW/m^2	15	14	13
		37.5 kW/m^2	12	11	10
	Flash Fire Envelope	LFL (1.7%)	50	43	38
	VCE Overpressure	0.02 bar	81	80	58
		0.07 bar	53	52	39
		0.2 bar	Not reached	Not reached	Not reached
2	**Furnace oil Tank – Dyke Spill**				
	Dyke Fire Radiation Intensity	4 kW/m^2	40	42	43
		12.5 kW/m^2	17	18	19
		37.5 kW/m^2	Not reached	Not reached	Not reached
3	**HSD Tank – Dyke Spill**				
	Dyke Fire Radiation Intensity	4 kW/m^2	39	41	43
		12.5 kW/m^2	17	18	19
		37.5 kW/m^2	Not reached	Not reached	Not reached

Graphical results of consequence analysis plotted on plot plan diagram are shown in the following **Figure-1** to **Figure-12**.

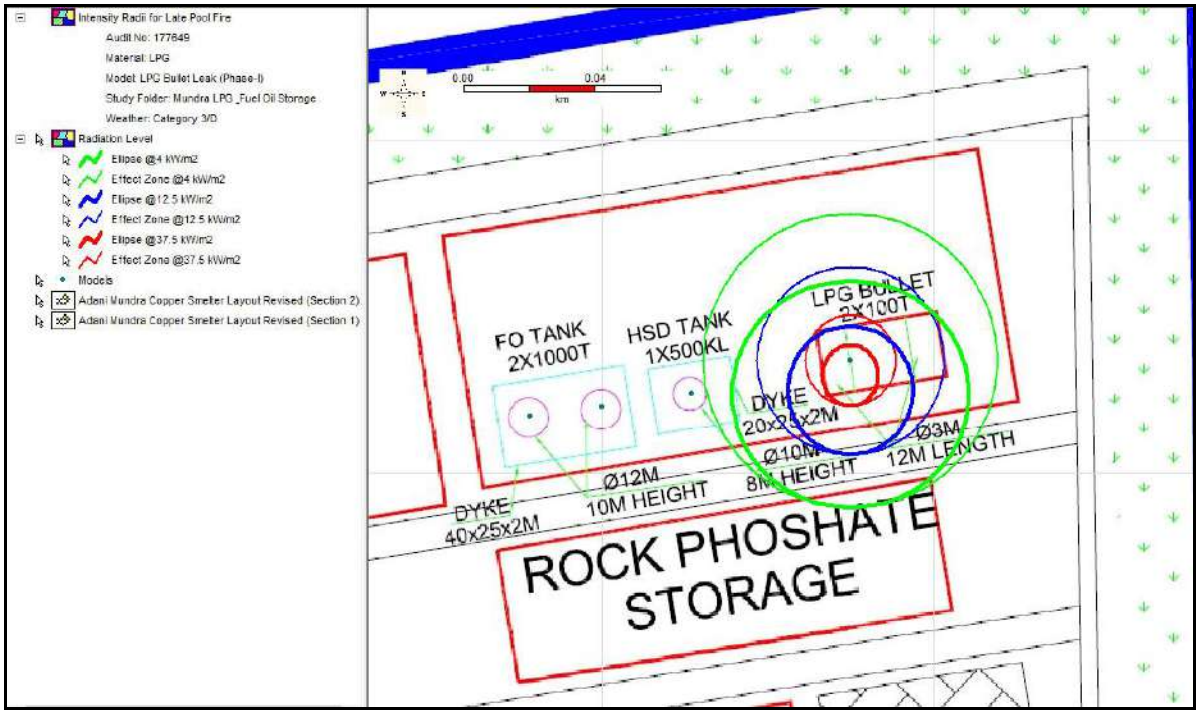

FIGURE-1
PHASE–I: LPG BULLET LIQUID LEAK - POOL FIRE RADIATION INTENSITY

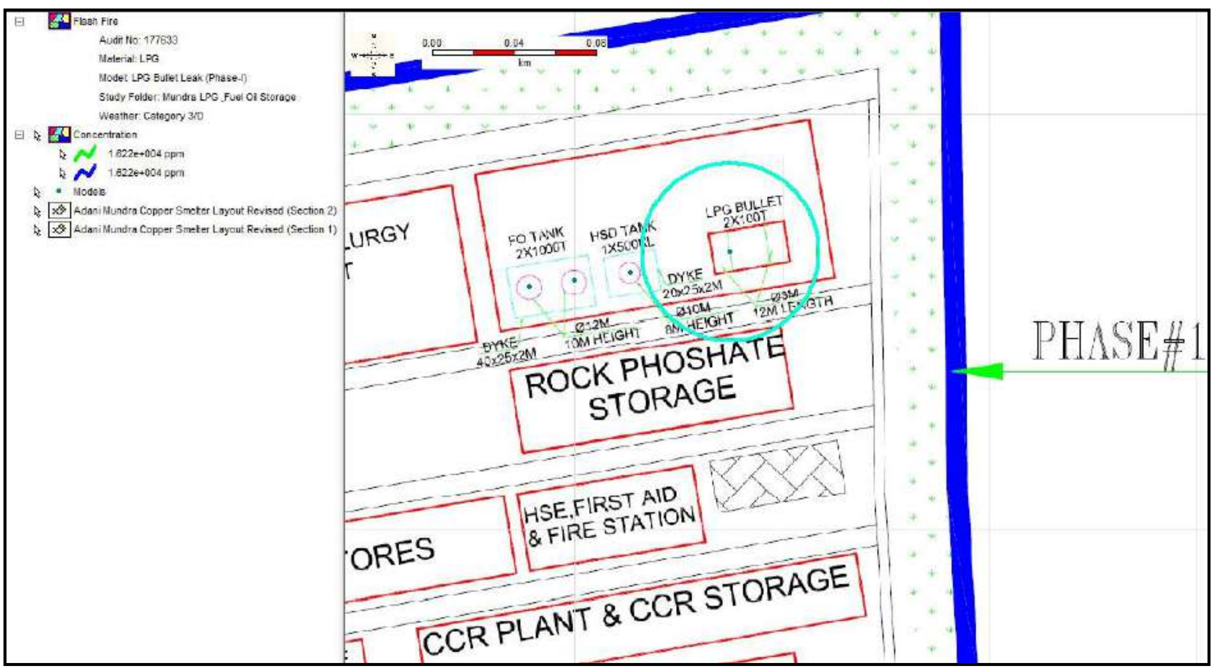

FIGURE-2
PHASE–I: LPG BULLET LIQUID LEAK - FLASH FIRE ENVELOPE

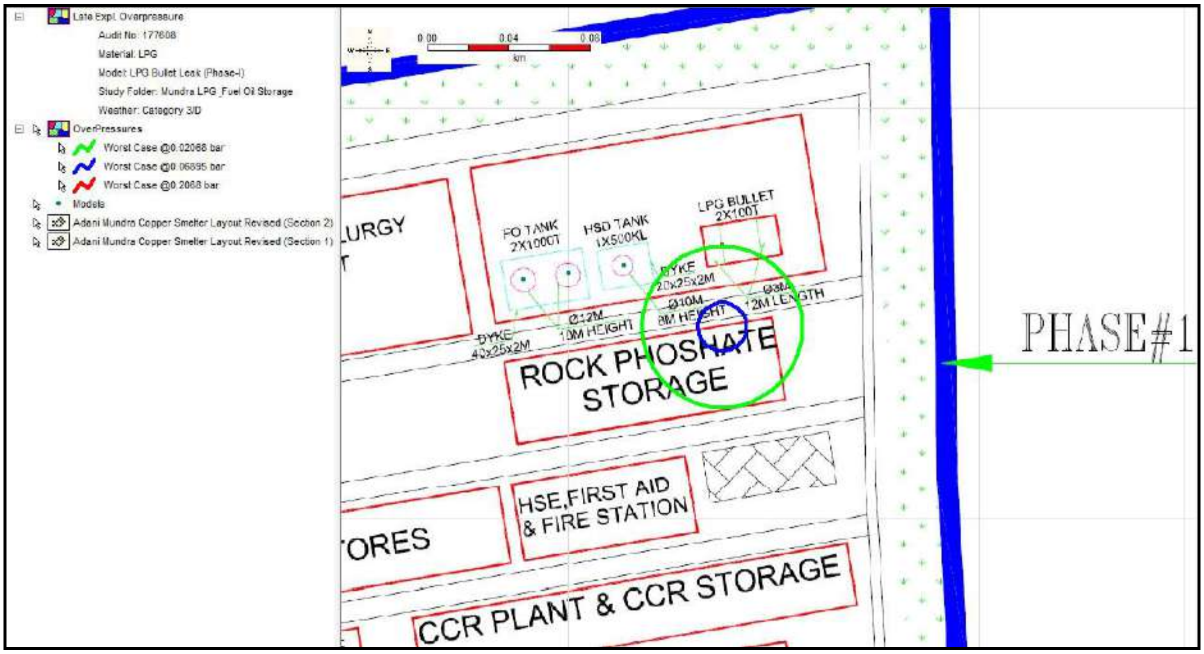

FIGURE-3
PHASE-I: LPG BULLET LIQUID LEAK - VAPOUR CLOUD EXPLOSION OVERPRESSURE

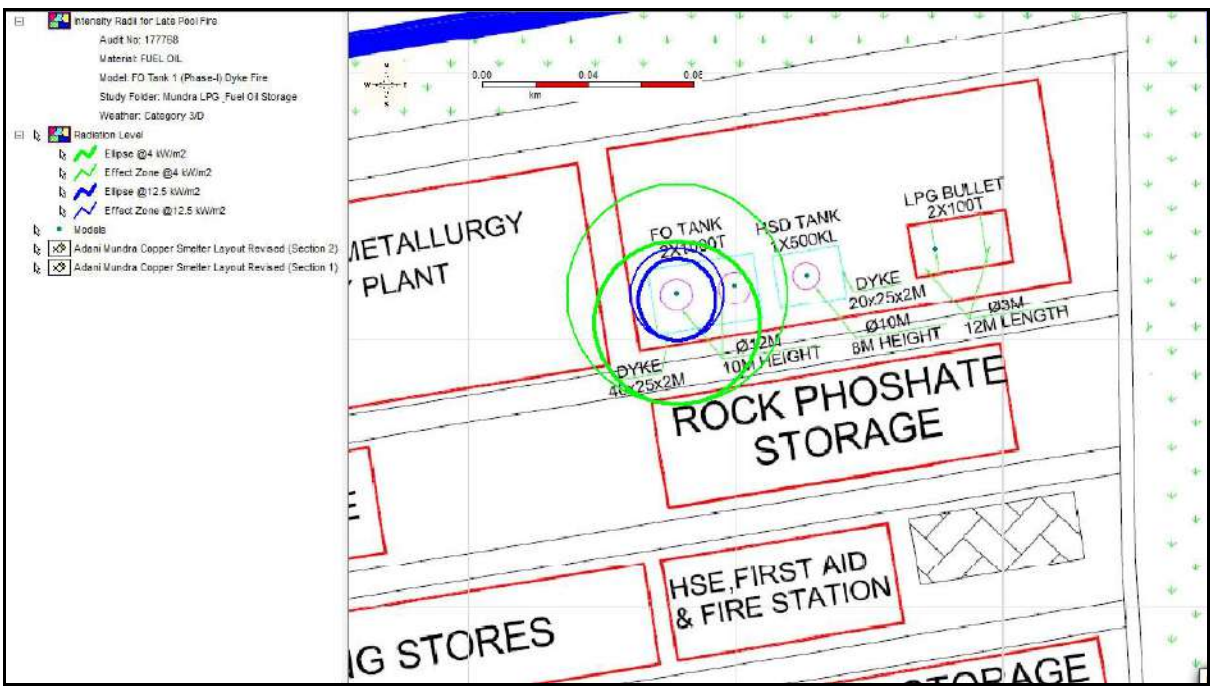

FIGURE-4
PHASE–I: FURNACE OIL TANK NO.1 DYKE FIRE - POOL FIRE RADIATION INTENSITY

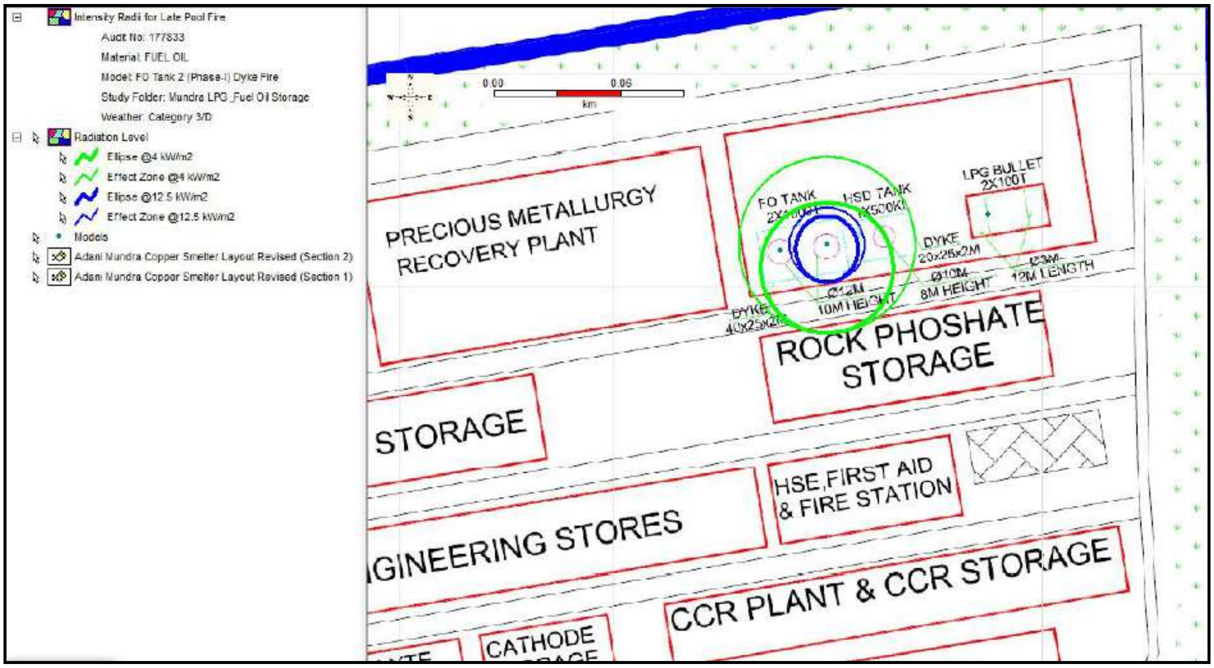

FIGURE-5
PHASE–I: FURNACE OIL TANK NO.2 DYKE FIRE - POOL FIRE RADIATION INTENSITY

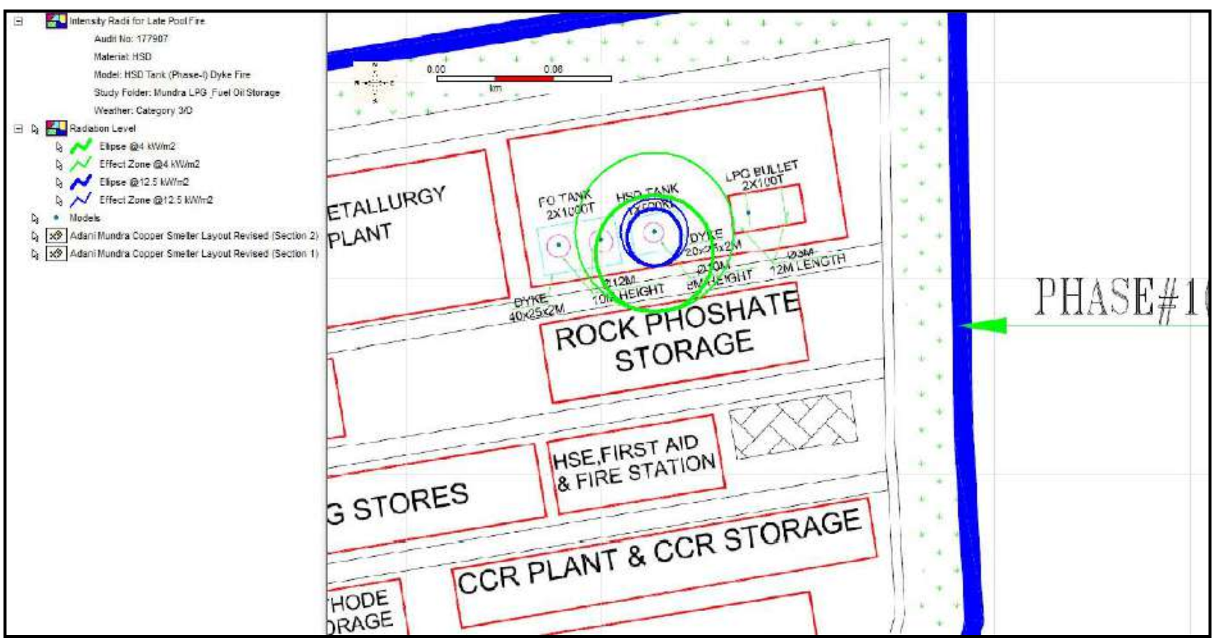

FIGURE-6
PHASE–I: HSD TANK DYKE FIRE - POOL FIRE RADIATION INTENSITY

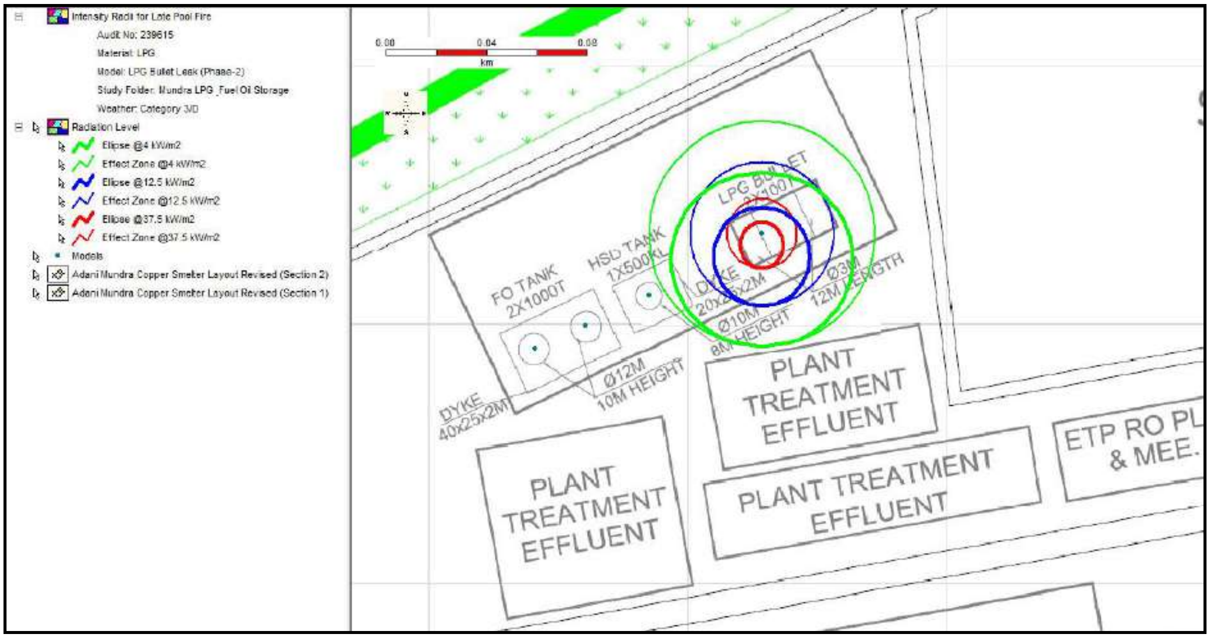

FIGURE-7
PHASE–II: LPG BULLET LIQUID LEAK - POOL FIRE RADIATION INTENSITY

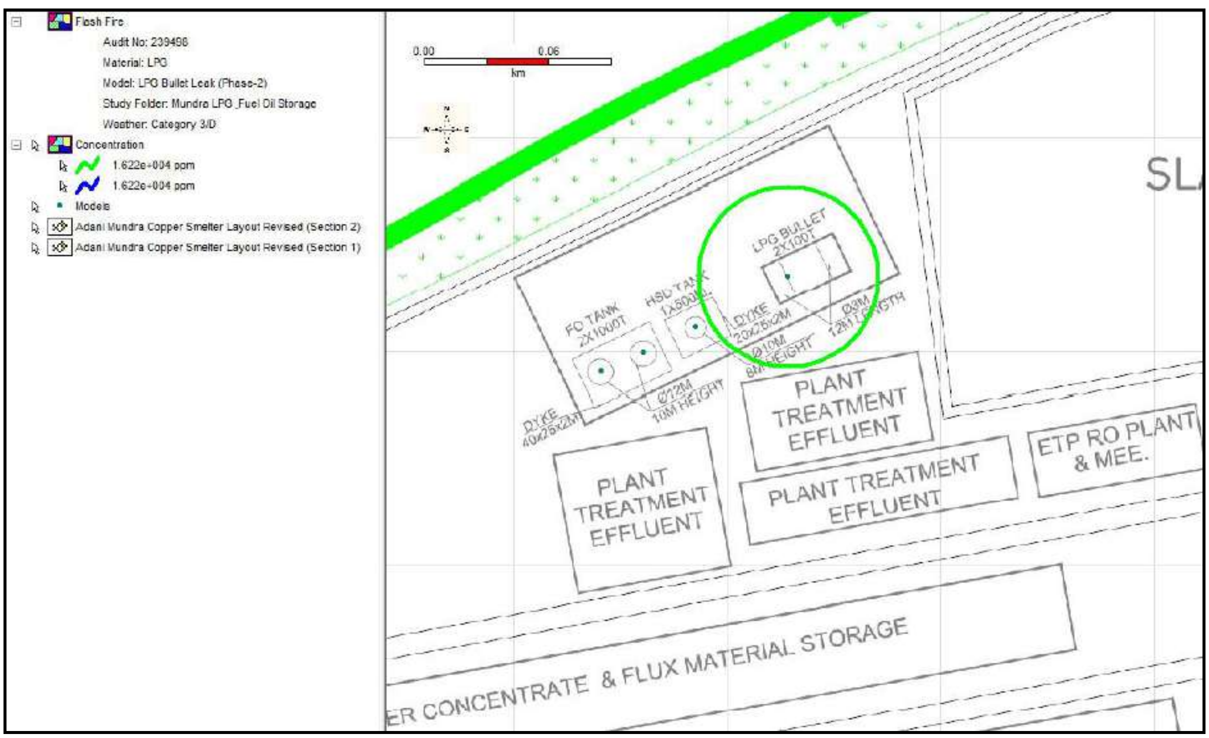

FIGURE-8
PHASE–II: LPG BULLET LIQUID LEAK - FLASH FIRE ENVELOPE

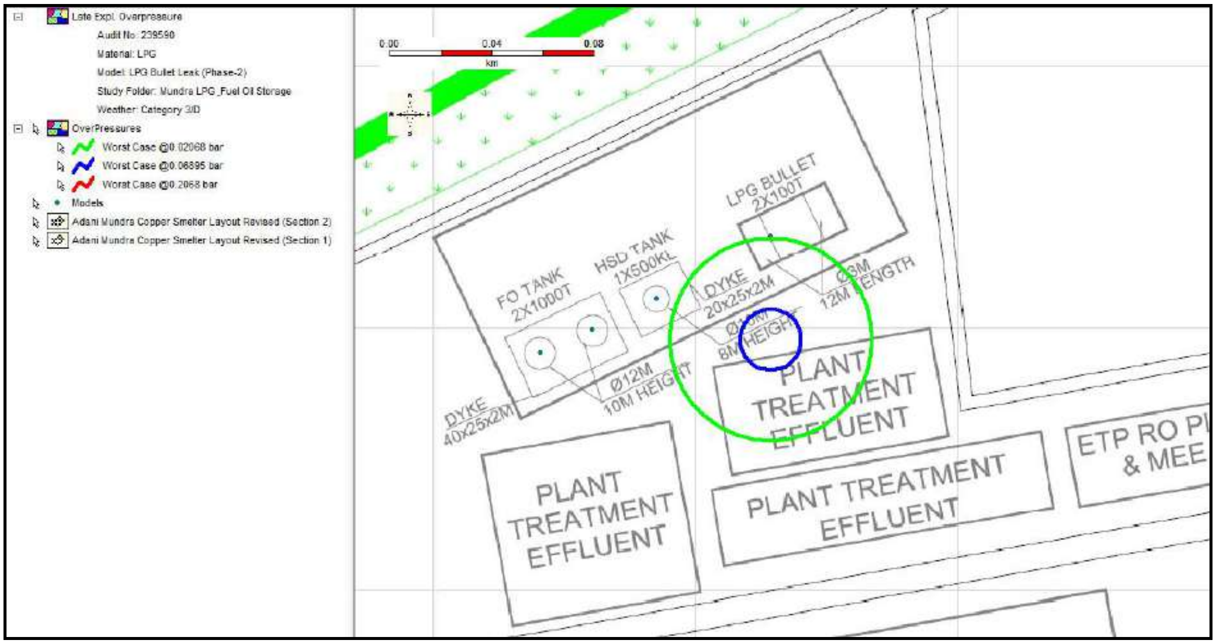

FIGURE-9
PHASE–II: LPG BULLET LIQUID LEAK - VAPOUR CLOUD EXPLOSION OVERPRESSURE

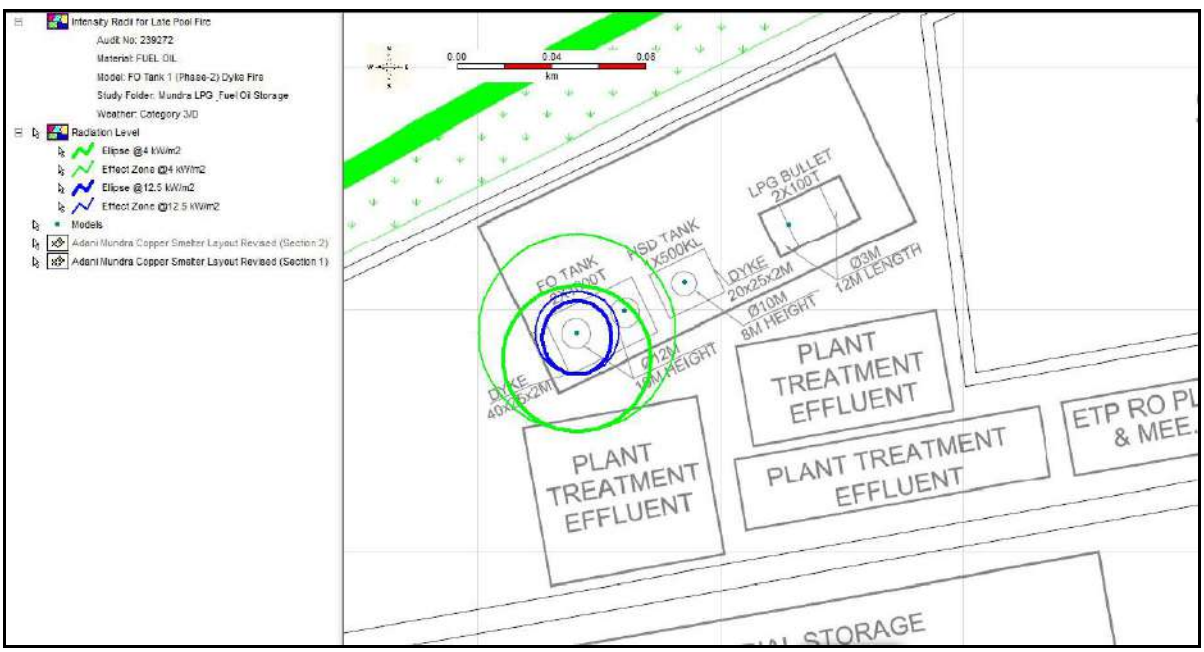

FIGURE-10
PHASE–II: FURNACE OIL TANK NO. 1 DYKE FIRE - POOL FIRE RADIATION INTENSITY

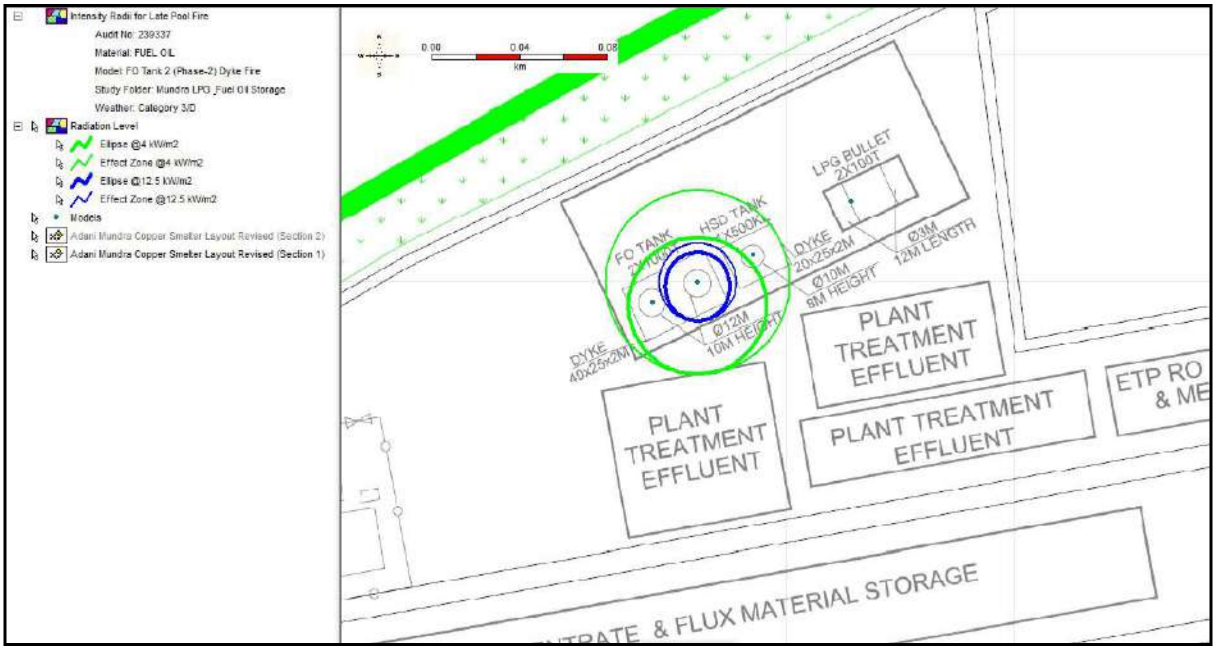

FIGURE-11

PHASE–II: FURNACE OIL TANK NO. 2 DYKE FIRE - POOL FIRE RADIATION INTENSITY

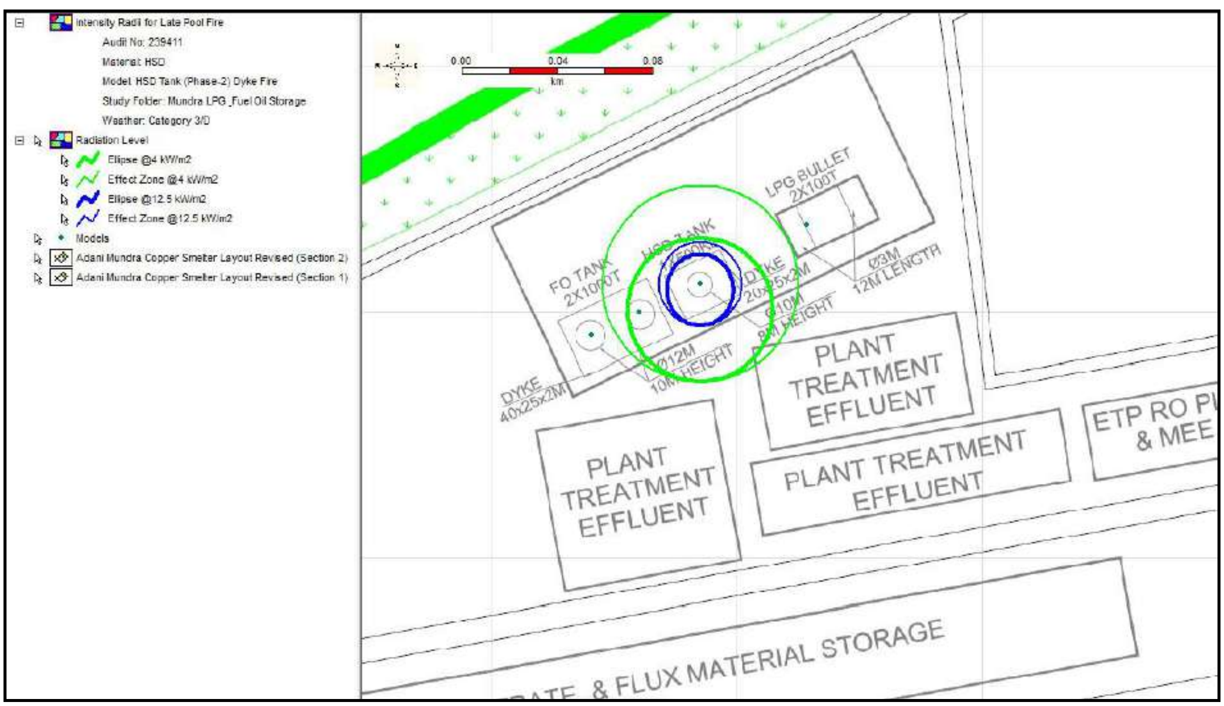

FIGURE-12

PHASE–II: HSD TANK DYKE FIRE - POOL FIRE RADIATION INTENSITY

1.7 Recommendations

(1) LPG Storage System

LPG Storage system shall conform to the requirements of OISD Standard 144 and 158.

Above-ground LPG bullets are susceptible to BLEVE/ fire ball hazard if engulfed in external fire. Therefore, all measures are to be taken to prevent leakage and fire. Large leak of LPG has potential to cause vapour cloud explosion.

Fire protection system shall be provided conforming to the requirement of OISD standards. This includes the following:

- Fire/ gas detectors with alarms
- Fire water storage and distribution system with hydrants, monitors and sprinklers

Each LPG bullet shall have a single nozzle at the bottom for liquid inlet as well as outlet. A remote operated shut off valve (ROSOV) shall be provided on this bottom nozzle at a distance of at least 3 meters from the shadow of the bullet. The ROSOV shall be fire-safe and fail-safe type.

Each LPG bullet shall be provided with at least two independent level indicators and one independent level switch. The ROSOV shall automatically close on actuation of alarm from high level switch.

(2) Furnace Oil & HSD Storage System

The storage tanks are to be provided with fixed foam system. Mobile medium expansion foam generators (2 Nos.) should be available to fight dyke fires.

(3) General

In Phase-1 plot plan, it is recommended to consider shifting the block HSE, first aid and fire station to other area to avoid overpressure damage byvapour cloud explosion in case of large LPG leak.