QUANTITATIVE RISK ASSESSMENT (QRA) REPORT

Prepared For

VSCL
Sustaining purity • Enhancing value

M/s. VADIVARHE SPECIALITY CHEMICALS LTD.

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Conducted & Prepared By

MEMBER GREEN GROUP
THE GREEN PEOPLE

GREEN CIRCLE INC.

Integrated HSEQR Consulting Engineers, Scientists & Trainers

(MoEF Recognized Environmental Research Laboratory)

An ISO: 9001, NABL/ISO: 17025, ISO14001, OHSAS: 18001 Certified Organization & GPCB approved Environment Auditor – Schedule II

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ALSO AT

NEW DELHI	MUMBAI	PUNE	BANGALORE	HYDERABAD
AUSTRALIA	OMAN	QATAR	AFRICA	UAE

INDEX

List of Tables

List of Figures

ABBREVIATIONS

DNV	Det Norske Veritas
HSE	Health Safety and Environment
LFL	Lower Flammability Level
NH	No Hazard
NR	Not Reached
PHAST	Process Hazard Analysis Software tool
ppm	Parts Per Million
QRA	Quantitative Risk Assessment
UFL	Upper Flammability Level

1 Executive Summary

M/s., Vadivarhe Speciality Chemicals Ltd. has engaged the services of M/s. Green Circle, Inc., Vadodara, India for carrying out Quantitative Risk Assessment. The renowned PHAST software package of DNV has been used by M/s. Green Circle, Inc. Ltd. for carrying out this study.

QRA study for the said facility has been carried out based on the data provided by the client.

The Consequence results for different events such as dispersion, Jet fire; pool fire and overpressure are presented in the form of tables and graphs.

Following safety measures have been implemented in tank farm area:

1. Gas detectors are available
2. Alarms are in place
3. Fire hydrant system is available
4. Fire extinguishers are in place
5. Jumpers are in place at flange joints
6. Earthing & bonding are in place
7. Dyke wall is present

The following control measures shall be implemented in tank farm area:

1. Fencing and no smoking and prohibited area, warnings signage should be displayed in Hindi, English and local language at prominent locations.
2. LG TG, PG, gas detectors shall be inspected and calibrated periodically as per manufacturer's recommendation and record should be maintained.
3. Training should be conducted for all the personnel engaged in handling the solvents activity.

2 INTRODUCTION

Quantitative Risk Assessment (QRA) study for M/s. Vadivarhe Speciality Chemicals Ltd. has been carried out based on data provided by client.

2.1 Project Objective

The main objective for conducting this Quantitative Risk Assessment (QRA) study is to determine the potential risks and their consequences to the facility due to storage and transferring of hazardous chemicals at various locations and other equipment. This is achieved by the following:

- Identification of hazards that could be realized from hazardous material.
- Identify the potential failure scenarios that could occur within the facility.
- To asses, the potential risks associated with identified hazards to which the plant and its personnel and community outside may be subjected. Consequence analysis of various hazards is carried out to determine the vulnerable zones for each probable accident scenario.
- Evaluate the process hazards emanating from the identified potential accident scenarios.
- Analyze the damage effects to the surroundings due to such accidents.
- Conclusion and Recommendations in order to mitigate the hazard.

3 DETAILS OF STORAGE TANK

The details of the storage tanks are provided in following table:

SN	Raw Materials	Storage Condition	Storage capacity (KL)	Storage conditions	
				T (Deg C)	P (bar)
1.	Methanol	Tank	10	Room Temp	Atm.
			3		
			3		
2.	Isopropyl Alcohol	Tank	2.5		
			2.5		
3.	Butanol	Drum	0.2		

3.1 Properties of chemicals

The physical properties of the materials used in the facility are summarized in below table:

Table 3-1 Physical Properties of Material

SN	Chemical Name	Flash Point (°C)	LEL(%)	UEL (%)	Boiling point (°C)	Auto Ignition temp. (°C)	Physical state
1.	Methanol	12	6	36.5	64.5	464	Liquid
2.	Iso-Propyl Alcohol	11.66	2	12.7	82.5	399	Liquid
3.	Butanol	28.9	1.4	11.2	117.7	343	Liquid

4 METHODOLOGY

The consequences of released flammable material are largely dependent on the prevailing weather conditions. Consequences of loss of containment can lead to hazardous situation in any industry handling potentially hazardous materials. Following factors govern the severity of consequence of the loss of containment.

- Intrinsic properties: flammability, toxicity and reactivity.
- Dispersive energy: pressure, temperature and state of matter.
- Quantity present
- Environmental factors: weather (wind speed, wind direction, atmospheric temperature &pressure).

Consequence analysis and calculations are effectively performed by computer software using models validated over a number of applications. Consequence modeling is carried out by PHAST of DNV Software, UK.

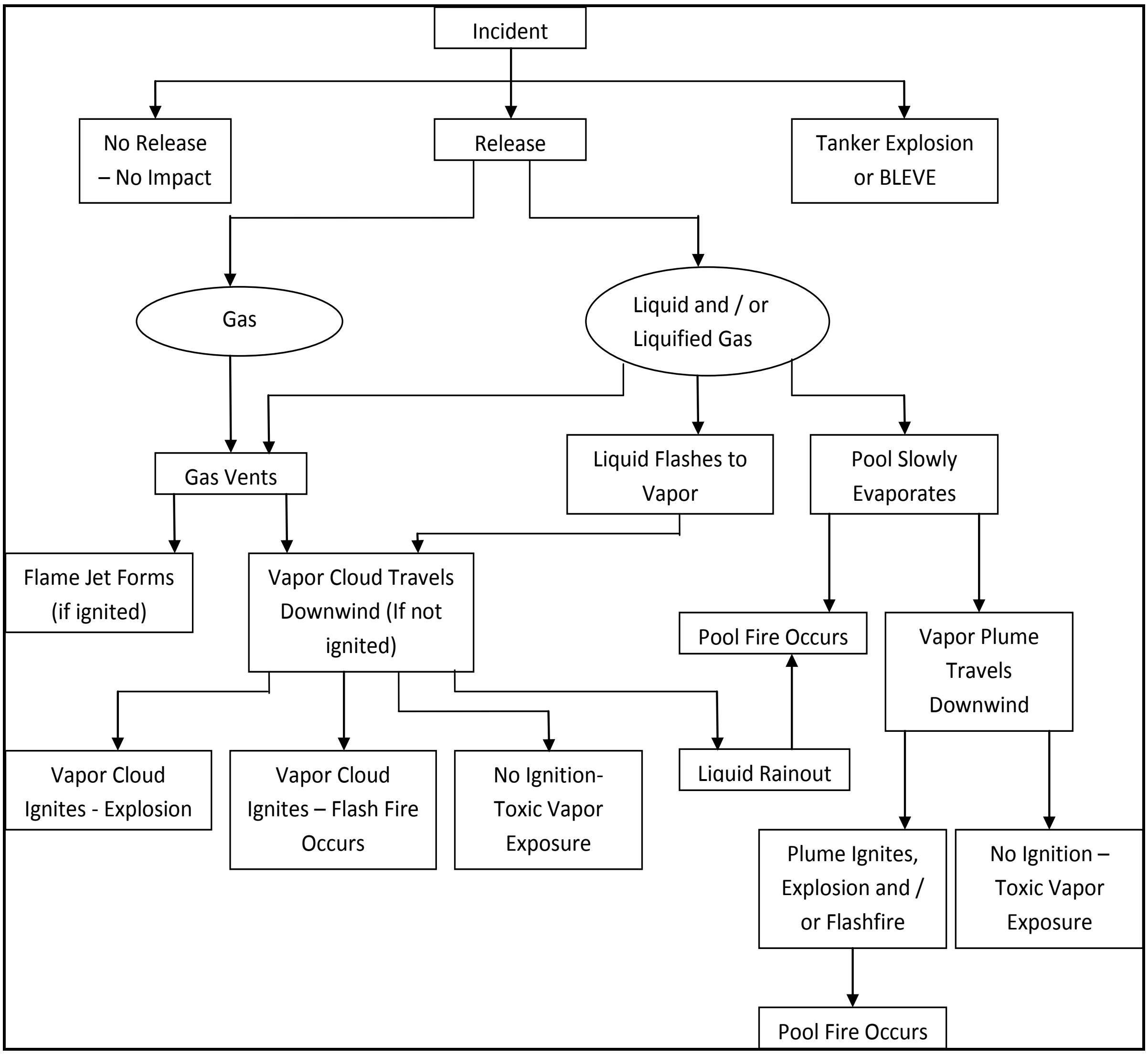
PHAST uses the Unified Dispersion Model (UDM) capable of describing a wide range of types of accidental releases. The Model uses a particularly flexible form, allowing for sharp-edged profiles, which become more diffuse downwind.

PHAST contains data for a large number of chemicals and allows definition of mixtures of any of these chemicals in the required proportion. The calculations by PHAST involve following steps for each modeled failure case:

- Run discharge calculations based on physical conditions and leak size.
- Model first stage of release (for each weather category).
- Determine vapor release rate by flashing of liquid and pool evaporation rate.
- Dispersion modeling taking into account weather conditions.
- In case of flammable release, calculate size of effect zone for fire and explosion.
- The hazardous materials considered in this study are mostly flammable liquids

Flow chart for consequence analysis is shown in the form of event tree for release of flammable liquid.

Figure 4-1: Methodology adopted for the study



4.1 Meteorological Condition

The consequences of released flammable material are largely dependent on the prevailing weather conditions. For the assessment of major scenarios involving release of flammable materials, the most important meteorological parameters are those that affect the atmospheric dispersion of the escaping material. The crucial variables are wind direction, wind speed, atmospheric stability and temperature. Rainfall does not have any direct bearing on the results of the risk analysis; however, it can have beneficial effects on absorption / washout of released materials. Actual behavior of any release would largely depend on prevailing weather condition at the time of release.

Wind Speed and Wind Direction

The wind speed and wind direction data which have been used for the study is summarized below:

Average Wind Speed	:	1 m/s, 3m/s, 5 m/s
Stability Class	:	F and D

Weather Category

One of the most important characteristics of atmosphere is its stability. Stability of atmosphere is its tendency to resist vertical motion or to suppress existing turbulence. This tendency directly influences the ability of atmosphere to disperse pollutants emitted into it from the facilities. In most dispersion scenarios, the relevant atmospheric layer is that nearest to the ground, varying in thickness from a few meters to a few thousand meters. Turbulence induced by buoyancy forces in the atmosphere is closely related to the vertical temperature gradient.

Temperature normally decreases with increasing height in the atmosphere. The rate at which the temperature of air decreases with height is called Environmental Lapse Rate (ELR). It will vary from time to time and from place to place. The atmosphere is said to be stable, neutral or unstable according to ELR is less than, equal to or greater than Dry Adiabatic Lapse Rate (DALR), which is a constant value of 0.98°C/100 meters.

Pasquill stability parameter, based on Pasquill – Gifford categorization, is such a meteorological parameter, which describes the stability of atmosphere, i.e., the degree of convective turbulence. Pasquill has defined six stability classes ranging from `A' (extremely unstable) to `F' (moderately stable). Wind speeds, intensity of solar radiation (daytime insulation) and nighttime sky cover have been identified as prime factors defining these stability categories.

Table 4-1: Pasquill stability classes

Stability class	Definition	Stability class	Definition
A	Very Unstable	D	Neutral
B	Unstable	E	Slightly Stable
C	Slightly Unstable	F	Stable

When the atmosphere is unstable and wind speeds are moderate or high or gusty, rapid dispersion of pollutants will occur. Under these conditions, pollutant concentrations in air will be moderate or low and the material will be dispersed rapidly. When the atmosphere is stable and wind speed is low, dispersion of material will be limited and pollutant concentration in air will be high. In general, worst dispersion conditions (i.e. contributing to greater hazard distances) occur during low wind speed and very stable weather conditions.

4.2 Software Used

PHAST has been used for consequence analysis include discharge and dispersion calculations.

5 HAZARDS & DAMAGE CRITERIA OF MATERIALS

The release of flammable liquid can lead to different types of fire or explosion scenarios. These depend on the material released, mechanism of release, temperature and pressure of the material and the point of ignition. Types of flammable effects are as follows.

5.1 Hazards associated with Flammable materials

A. Pool fire:

The released flammable material which is a liquid stored below its normal boiling point, will collect in a pool. The geometry of the pool will be dictated by the surroundings. If the liquid is stored under pressure above its normal boiling point, then a fraction of the liquid will flash into vapor and the remaining portion will form a pool in the vicinity of the release point. Once sustained combustion is achieved, liquid fires quickly reach steady state burning. The heat release rate is a function of the liquid surface area exposed to air. An unconfined spill will tend to have thin fuel depth (typically less than 5 mm) which will result in slower burning rates. A confined spill is limited by the boundaries (e.g. a dyke area) and the depth of the resulting pool is greater than that for an unconfined spill.

B. Flash fire:

It occurs when a vapor cloud of flammable material burns. The cloud is typically ignited on the edge and burns towards the release point. The duration of flash fire is very short (seconds), but it may continue as jet fire if the release continues. The overpressures generated by the combustion are not considered significant in terms of damage potential to persons, equipment or structures. The major hazard from flash fire is direct flame impingement. Typically, the burn zone is defined as the area the vapor cloud covers out to half of the LFL. This definition provides a conservative estimate, allowing for fluctuations in modeling. Even where the concentration may be above the UFL, turbulent induced combustion mixes the material with air and results in flash fire.

C. Jet Fire:

Jet flames are characterized as high-pressure release of gas from limited openings (e.g. due to small leak in a vessel or broken drain valve). Boiling liquid expanding vapor explosion (BLEVE) or fireball: A fireball is an intense spherical fire resulting from a sudden release of pressurized liquid or gas that is immediately ignited. The best known cause of a fireball is a boiling liquid expanding vapor explosion (BLEVE). Fireball duration is typically 5 – 20 seconds.

D. Vapor cloud explosion:

When a large quantity of flammable vapor or gas is released, mixes with air to produce sufficient mass in the flammable range and is ignited, the result is a vapor cloud explosion (VCE). Without sufficient air mixing, a diffusion-controlled fireball may result without significant overpressures developing. The speed of flame propagation must accelerate as the vapor cloud burns. Without this acceleration, only a flash fire will result.

Vapour cloud explosions (VCE) are one of the most serious hazards in chemical process industries. When a large quantity of flammable gas or vapor is accidentally released in to atmosphere it may form a vapour cloud and if its ignition is delayed (5-10 min) could produce a vapour cloud explosion. The damage effects of a vapour cloud explosion are mostly due to the overpressure that is created from the fast expansion of the combustion products. The overpressure is the most important causes of damage to people, equipment and facilities.

Unconfined Vapour Cloud Explosion

Definition: Type of explosion in a liquefied hydrocarbons or other flammable gas cloud in a non-confined space (within and/or beyond the premises)

Effect of Unconfined Vapour Cloud Explosion

When the vapor cloud is ignited, following may result:-.

1. Blast waves
2. Shock waves
3. Fire Ball
4. Multiple fires

Above may causes huge loss of life and property and may also damage the onsite disaster mitigation resources making it an offsite emergency.

Management of Vapour Cloud

Don't switch off or switch on any electrical or heat generating source like DG and Compressor

Any hot job inside or outside the station premises should be immediately stopped

Declare station emergency and evacuate the station as per evacuation

Stay upwind

Try to close the valve by remote operation if leakage is from the valve otherwise isolate the oil supply to leak tank/piping/valve

If not possible to isolate the valve by remote, wear BA set and close the valve locally. Don't try to approach site without BA set otherwise asphyxiation will lead to collapse and death

When the clouds gets ignited causing an explosion, follow the management procedure

Vapor Cloud Formation & Its Effect:

When a cloud of flammable vapor burns, the combustion may give rise to an overpressure or it may not. If there is no overpressure, the event is a vapor cloud fire, or flash fire: and if there is overpressure, it is vapor cloud explosion.

A vapor cloud explosion is one of the most serious hazards in the process industries. Vapor cloud explosions do occasionally occur and they are generally very destructive.

A feature of vapor cloud is that it may drift some distance from the point where the leak has occurred and thus threaten a considerable area. Such types of vapor cloud find an ignition source and can create overpressure and blast effects which can cause severe damage at considerable distance from the source of leak.

5.2 Hazards Associated with Explosive Chemicals:

Damage Criteria:

Damage estimates due to thermal radiations and overpressure have been arrived at by taking in to consideration the published literature on the subject. The consequences can then be visualized by the superimposing the damage effects zones on the proposed plan site and identifying the elements within the project site as well as in the neighboring environment, which might be adversely affected, should one or more hazards materialize in real life.

5.2.1 Thermal Damage:

The effect of thermal radiation on people is mainly a function of intensity of radiation and exposure time. The effect is expressed in terms of the probability of death and different degrees of burn. The following tables give the effect of various levels of heat flux.

Table 5-1: Fatal Radiation Exposure Level

Radiation Level(KW/m^2)	Fatality		
	1%	50%	99%
	Exposure In Seconds		
4.0	150	370	930
12.5	30	80	200
37.5	8	20	50

The following table gives damage to equipment and people due to different radiation levels.

Table 9.2: Fatal Radiation Exposure Level (Details)

Radiation (KW/m2)	Damage to Equipment	Damage to People
1.2	No damage	Solar heat at noon
1.6	PVC insulated cables damaged	Minimum level of pain threshold
2.0	No damage	No damage
4.0	No damage	Causes pain if duration is longer than 20 secs. But blistering is unlikely
6.4	No damage	Pain threshold reached after 8 secs. Second degree burns after 20 secs.
12.5	Minimum energy to ignite wood with a flame; Melts plastic tubing.	1% lethality in one minute. First degree burns in 10 secs
16.0	No damage	Severe burns after 5 secs.
25.0	Minimum energy to ignite wood at identifying long exposure without a flame.	100% lethality in 1 minute. Significant injury in 10 secs.

Radiation (KW/m2)	Damage to Equipment	Damage to People
37.5	Severe damage to plant	100% lethality in 1 minute. 50% lethality in 20 secs. 1% lethality in 10 secs.

5.2.2 *Overpressure Damage:*

The following tables give effect due to different overpressure on equipment and people.

Table 5-2: Over Pressure Damage Criteria with Damage to People

Over Pressure (mbar)	Mechanical Damage to Equipments	Damage To People
300	Heavy damage to plant & structure	1% death from lung damage >50% eardrum damage >50% serious wounds from flying objects
100	Repairable damage	>1% eardrum damage >1% serious wounds from flying objects
30	Major glass damage	Slight injury from flying glass
10	10% glass damage	No damage

Table 5-3: Over Pressure Damage Criteria with Mechanical Damage to Equipments

Over Pressure		*Mechanical damage to Equipment*
Bar	K Pa	
0.0021	0.21	Occasional breaking of large glass windows already under strain
0.0028	0.28	Loud noise (143 dB), sonic boom, glass failure
0.0069	0.69	Breakage of small windows under strain
0.0103	1.03	Typical pressure for glass breakage
0.0207	2.07	Safe distance" (probability 0.95 of no serious damage below this value);projectile limit; some damage to house ceilings; 10% window glass broken
0.0276	2.76	Limited minor structural damage
0.03-0.069	3.4-6.9	Large and small windows usually shattered; occasional damage to window frames
0.138	13.8	Corrugated asbestos shattered; corrugated steel or aluminum panels, fastenings fail, followed by buckling; wood panels (standard housing)fastenings fail, panels blown in

Over Pressure		*Mechanical damage to Equipment*
Bar	**K Pa**	
0.09	9.0	Steel frame of clad building slightly distorted
0.138	13.8	Partial collapse of walls and roofs of houses
0.207	20.7	Concrete or cinder block walls, not reinforced, shattered
0.158	15.8	Lower limit of serious structural damage
0.172	17.2	50% destruction of brickwork of houses
0.207-0.276	20.7-27.6	Frameless, self-framing steel panel building demolished; rupture of oil tanks
0.276	27.6	Cladding of light industrial buildings ruptured
0.345	34.5	Wooden utility poles snapped; tall hydraulic press (40,000 lb) in building slightly damaged
0.345-0.482	34.5-48.2	Nearly complete destruction of houses
0.482	48.2	Loaded, lighter weight (British) train wagons overturned
0.482-0.551	48.2-55.1	Brick panels, 8 –12 in. thick, not reinforced, fail by shearing or flexure
0.689	68.9	Probable total destruction of buildings; heavy machine tools (7,000 lb) moved and badly damaged, very heavy machine tools (12,000 lb) survive

6 CONSEQUENCE ANALYSIS

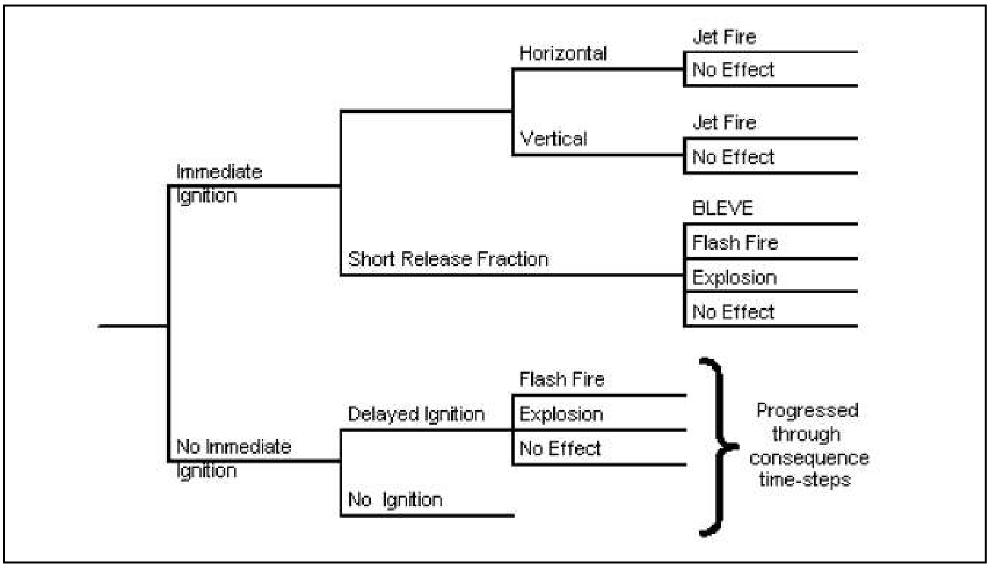
The consequence analysis is carried out to determine the extent of spread (dispersion) by accidental release which may lead to jet fire, pool fire, catastrophic ruptures resulting in generation of heat radiation, overpressures, explosions etc.

In order to form an opinion on potentially serious hazardous situations and their consequences, consequence analysis of potential failure scenarios are conducted. It is qualitative analysis of hazards due to various failure scenarios. In consequence analysis, each failure case is considered in isolation and damage effects predicted, without taking into account the secondary events or failures it may cause, leading to a major disastrous situation. The results of consequence analysis are useful in developing Disaster Management Plan and in developing a sense of awareness among operating and maintenance personnel. It also gives the operating personnel and population living in its vicinity, an understanding of the hazard they are posed to.

6.1 Event Outcomes

Upon release of flammable / toxic gas & liquids, the hazards could lead to various events which are governed by the type of release, release phase, ignition etc. PHAST has an inbuilt event tree for determining the outcomes which are based on two types of releases namely continuous and instantaneous. Leaks are considered to be continuous releases whereas, ruptures are considered to be instantaneous releases. These types of releases are further classified into those which have a potential for rain-out and those which do not. Whether the release would leak to a rain-out or not depends upon droplet modeling which is the main cause of formation of pools. Following figure present the event tree utilized by PHAST to generate the event outcomes.

Figure 6-1: Event Tree for continuous release without rain-out (from PHAST)



6.2 Effects of Release

When hazardous material is released to atmosphere due to any reason, a vapor cloud is formed. Direct cloud formation occurs when a gaseous or flashing liquid escapes to the atmosphere. Release of hydrocarbons and toxic compounds to atmosphere may usually lead to the following:

1. Dispersion of hydrocarbon vapor with wind till it reaches its lower flammability limit (LFL) or finds a source of ignition before reaching LFL, which will result in a flash fire or explosion.
2. Spillage of liquid hydrocarbons will result in a pool of liquid, which will evaporate taking heat from the surface, forming a flammable atmosphere above it. Ignition of this pool will result in pool fire causing thermal radiation hazards.
3. A fireball or BLEVE (Boiling Liquid expanding Vapor Explosion) occurs when a vessel containing a highly volatile liquid (e.g. LPG, Propylene etc) fails and the released large mass of vapor cloud gets ignited immediately. It has damage potential due to high intensity of radiation and generation of the overpressure waves, causing large scale damage to nearby equipment and structures.
4. Catastrophic failure of tanks/ pressurized vessels, rotary equipment and valves etc. can result in equipment fragments flying and hitting other equipment of the plant.
5. Release of toxic compounds results in the toxic vapour cloud traveling over long distances, affecting a large area, before it gets sufficiently diluted to harmless concentration in the atmosphere.
6. The material is in two phases inside the containment - liquid & vapor. Depending on the location of the leak liquid or vapor will be released from the containment. If vapor is released a vapor cloud will form by the mixing of the vapor and air. The size of the vapor cloud will depend on the rate of release, wind speed; wind direction & atmospheric stability will determine the dispersion and movement of the vapor cloud.
7. If liquid is released there will be some flashing as the boiling point of liquid is below the ambient temperature. The vapor formed by immediate flashing will behave as vapors release. The liquid will fall on the ground forming a pool. There will be vaporization from the pool due to the heat gained from the atmosphere & ground.
8. There will be dispersion and movement of vapor cloud formed by evaporation of liquid.

The behavior of material released by loss of containment depends on the following factors:

1. Physical properties of the material
2. Conditions of material in containment (pressure and temperature)
3. Phase of material released (liquid or gas)
4. Inventory of material released
5. Weather parameters (temperature, humidity, wind speed, atmospheric stability)
6. Material with boiling point below ambient condition.

7 CONSEQUENCE ANALYSIS RESULTS

The Consequence result tables along with their graphs and contours are shown in the report ahead.

1. Methanol Tank (10Kl)

Table 7-1 Damage Distances for Methanol tank

Scenario details		5 mm leak			25 mm leak			100 mm leak			Catastrophic Rupture		
Weather Category		1F	3D	5D	1F	3D	5D	1F	3D	5D	1F	3D	5D
Dispersion Distances (m)													
Conc. (ppm)	UFL	1	1	1	2	2	2	13	3	3	26	26	27
	LFL	2	2	2	13	5	2	52	12	9	1012	121	102
	0.5 LFL	2	2	2	22	11	5	71	21	16	1885	234	167
Thermal Damage Distances by Jet Fire (m)													
Radiation Intensity (KW/m²)	4	NR	NR	NR	8	7	5	23	21	19	NH	NH	NH
	12.5	NR	NR	NR	NR	NR	NR	NR	18	16	NH	NH	NH
	37.5	NR	NR	NR	NR	NR	NR	NR	NR	NR	NH	NH	NH
Thermal Damage Distances by Pool Fire (m)													
Radiation Intensity (KW/m²)	4	8	8	9	36	35	35	128	126	126	1311	1307	1305
	12.5	5	5	5	21	24	25	81	86	88	942	956	972
	37.5	NR	NR	NR	NR	NR	NR	55	52	51	708	695	697
Maximum Distance at Overpressure Level (m)													
Overpressure (bar)	0.02068	NH	NH	NH	63	19	19	260	80	47	2793	481	423
	0.1379	NH	NH	NH	31	12	12	119	35	19	1957	250	213
	0.2068	NH	NH	NH	29	12	12	108	32	17	1907	234	199

Notes:
NH: No Hazard
NR: Not Reached

The results for 25 mm leak size and catastrophic are superimposed on plot plan and presented in below figures.

Dispersion distances in case of 25mm leak of methanol tank

Figure 7-1: Dispersion distances in case of 25mm leak of methanol tank

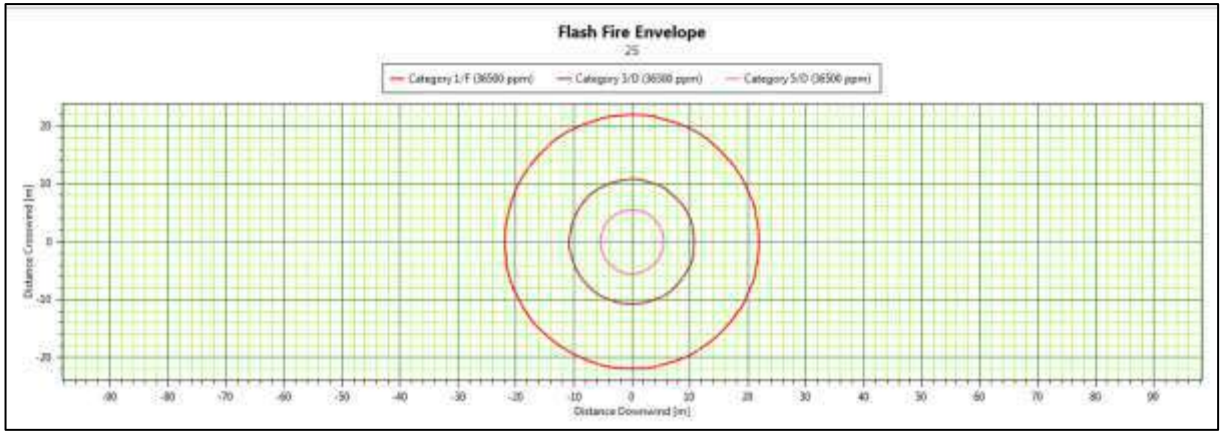
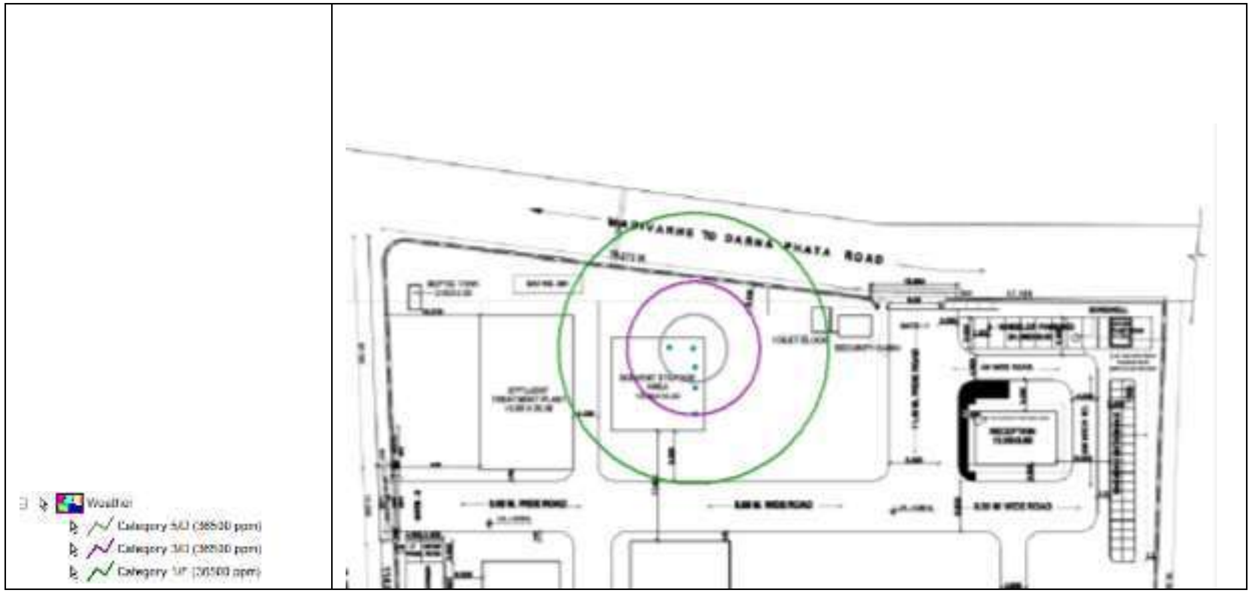


Figure 7-2: Dispersion distances in case of 25mm leak of methanol tank



Dispersion distances in case of catastrophic rupture of methanol tank

Figure 7-3: Dispersion distances in case of catastrophic rupture of methanol tank

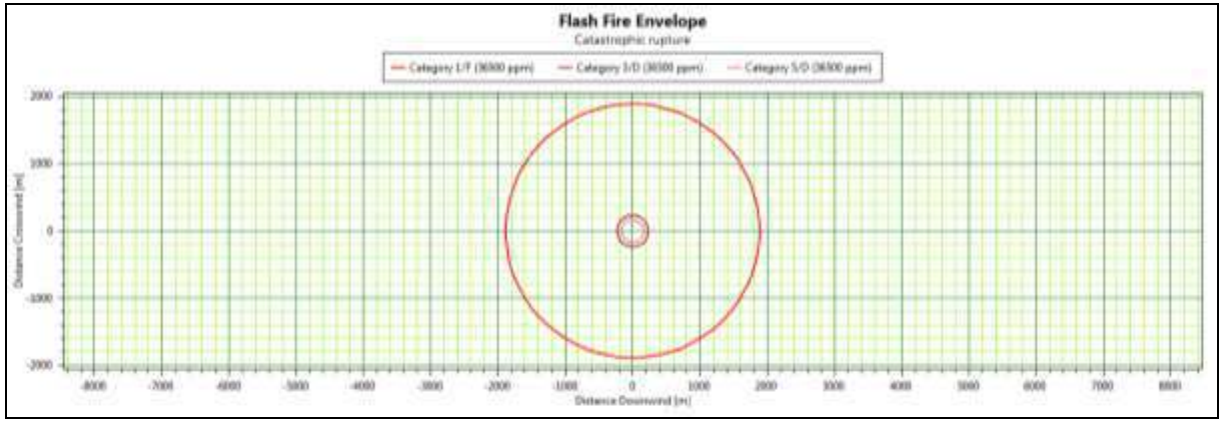
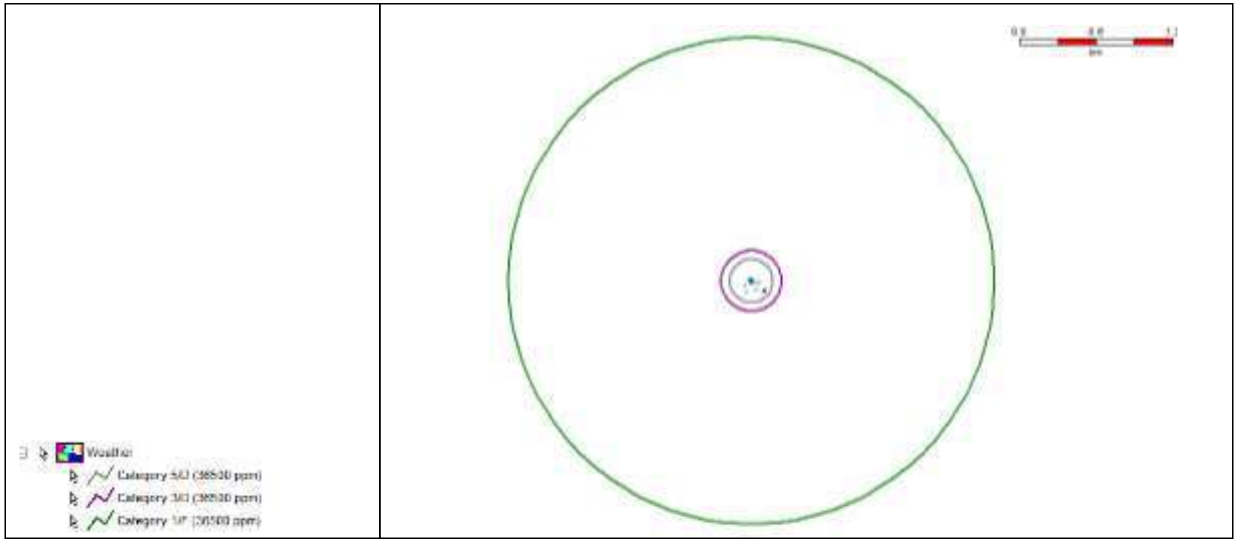


Figure 7-4: Dispersion distances in case of catastrophic rupture of methanol tank



Jet Fire results for 25mm leak of methanol tank

Figure 7-5: Jet fire intensity radii in case of 25mm leak of methanol tank

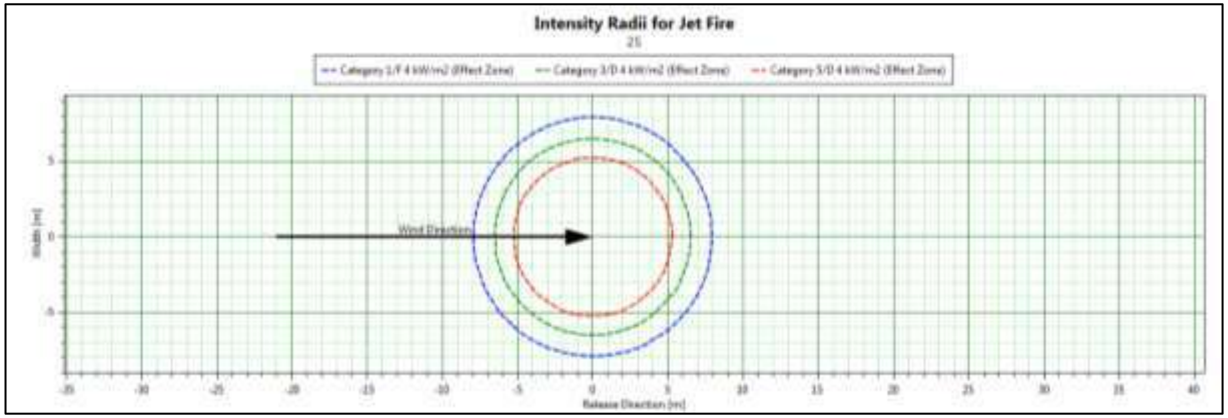
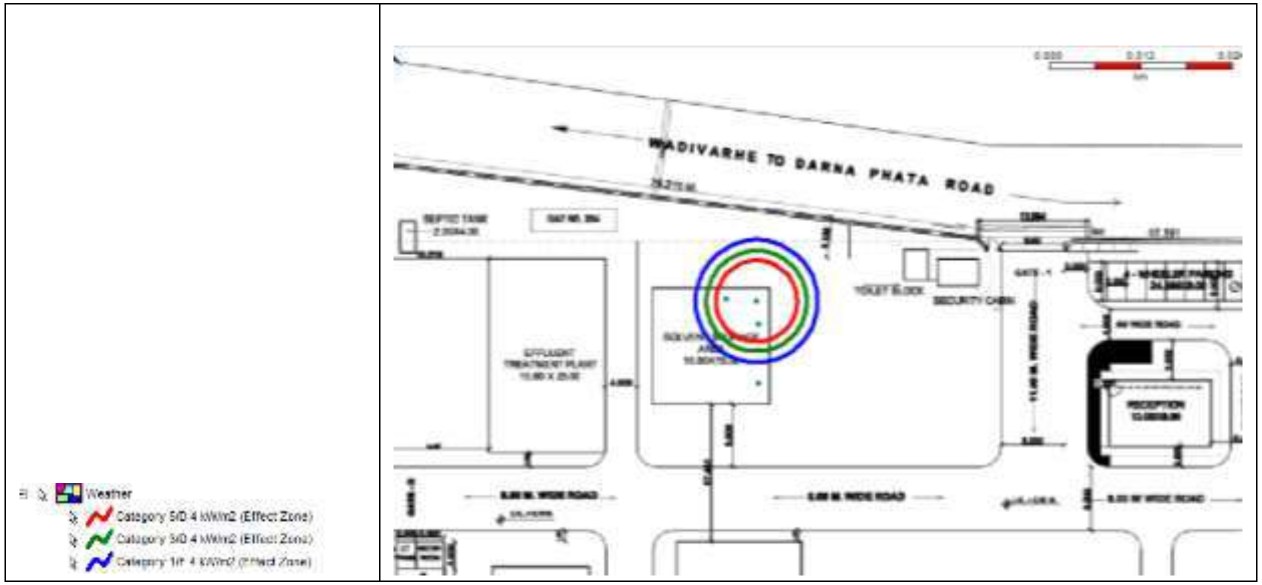


Figure 7-6: Jet fire intensity radii in case of 25mm leak of methanol tank



Pool fire results in case of 25 mm leak of methanol tank

Figure 7-7: Pool fire results in case of 25mm leak of methanol tank

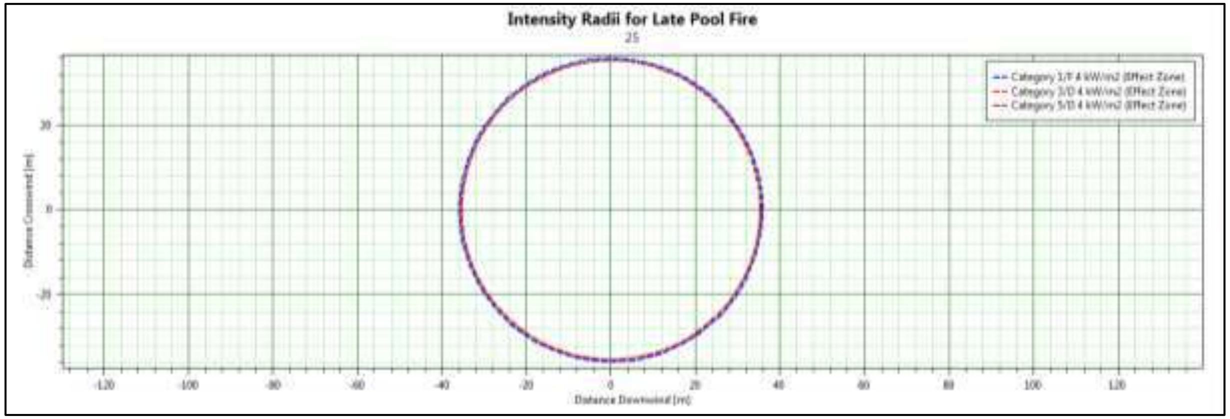
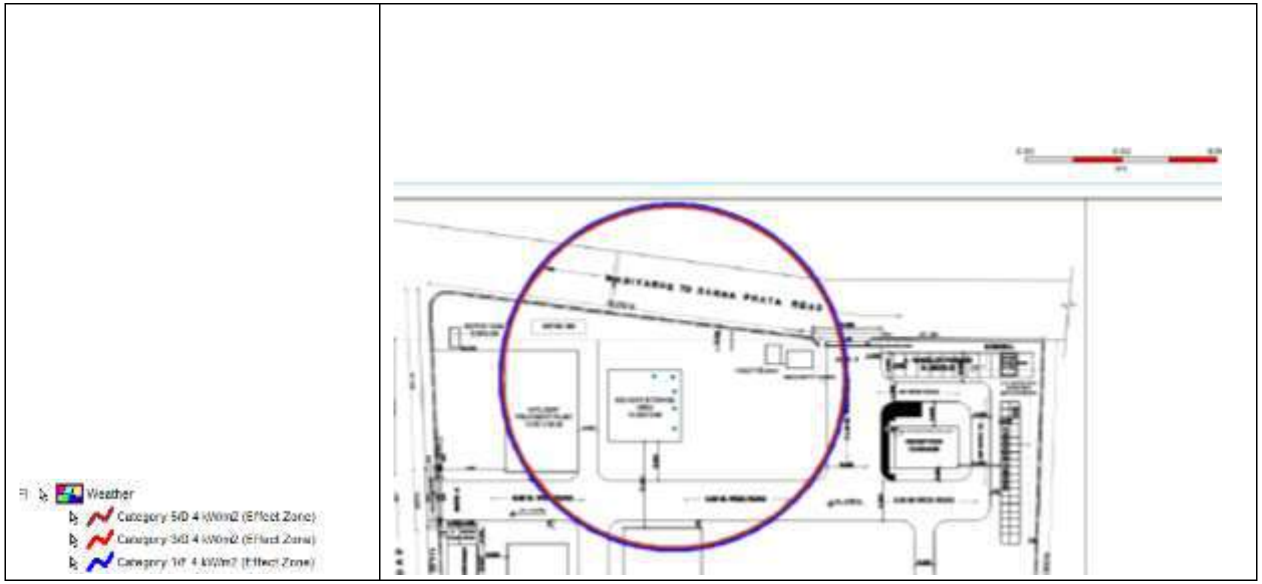


Figure 7-8: Pool fire results in case of 25mm leak of methanol tank



Pool fire results in case of catastrophic rupture of methanol tank

Figure 7-9: Pool fire results in case of catastrophic rupture of methanol tank

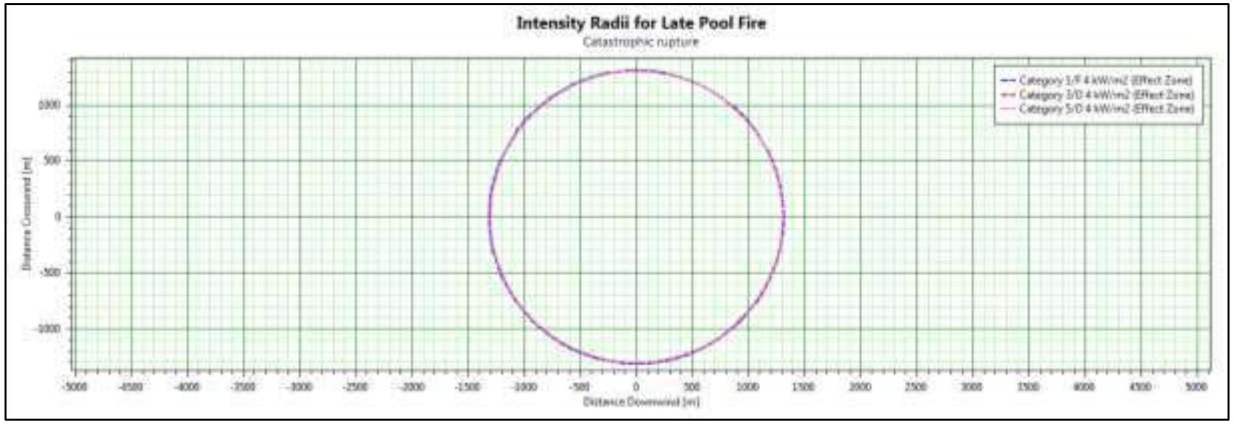
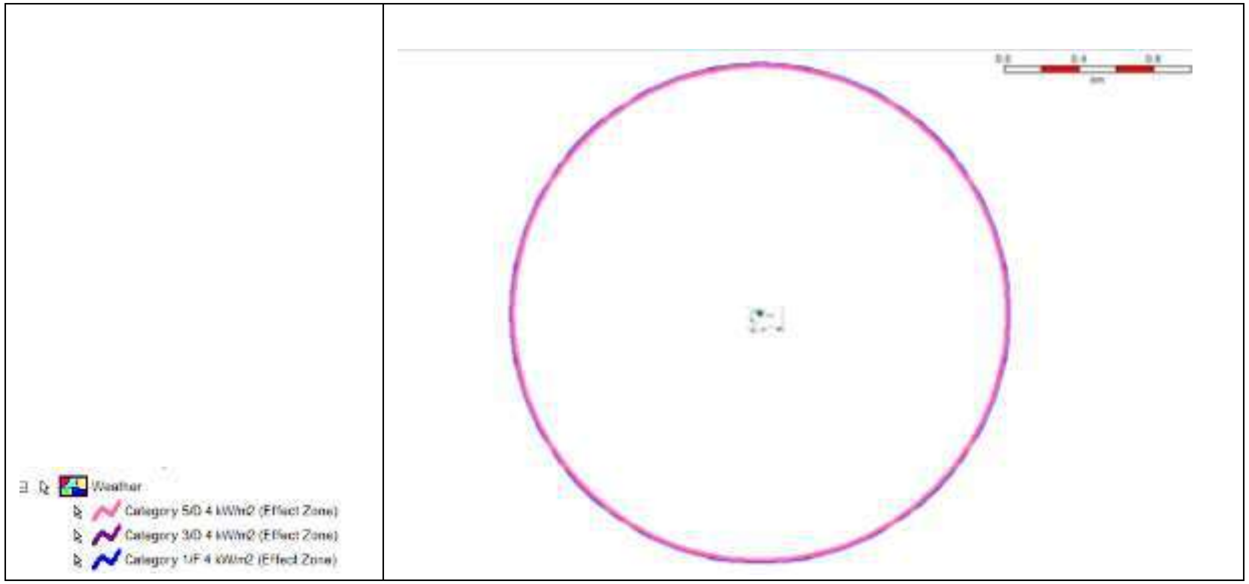


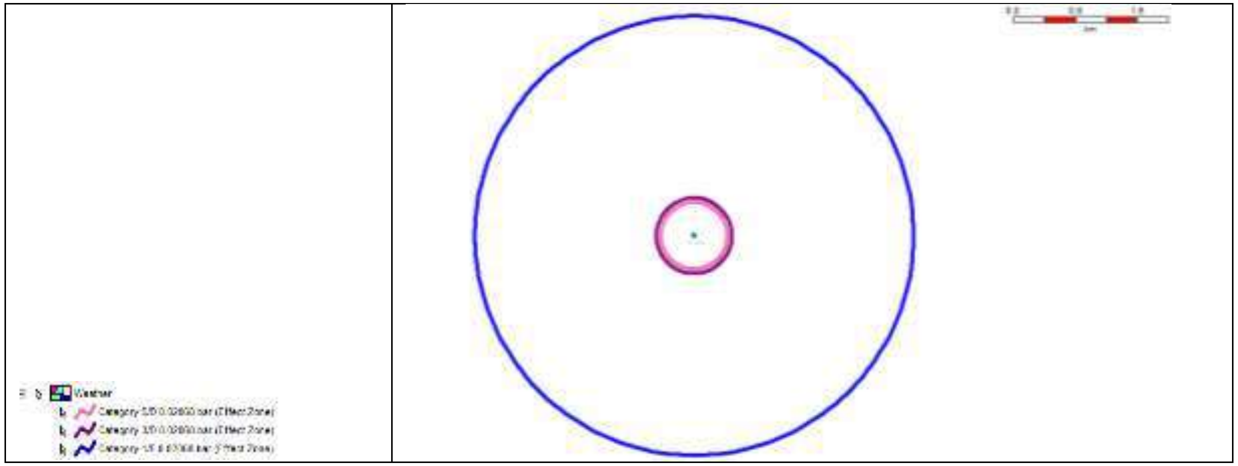
Figure 7-10: Pool fire results in case of catastrophic rupture of methanol tank



Overpressure results in case of catastrophic rupture of methanol tank

Figure 7-11: Overpressure results in case of catastrophic rupture of methanol tank

Figure 7-12: Overpressure results in case of catastrophic rupture of methanol tank



2. Methanol Tank (3 Kl)

Table 7-2 Damage Distances for Methanol tank

Scenario details		5 mm leak			25 mm leak			100 mm leak			Catastrophic Rupture		
Weather Category		1F	3D	5D	1F	3D	5D	1F	3D	5D	1F	3D	5D
Dispersion Distances (m)													
Conc. (ppm)	UFL	1	1	1	2	2	2	13	3	3	19	19	19
	LFL	2	2	2	13	5	2	52	12	9	449	80	67
	0.5 LFL	2	2	2	22	11	5	71	21	16	952	171	123
Thermal Damage Distances by Jet Fire (m)													
Radiation Intensity (KW/m^2)	4	NR	NR	NR	8	7	5	23	21	19	NH	NH	NH
	12.5	NR	NR	NR	NR	NR	NR	NR	18	16	NH	NH	NH
	37.5	NR	NR	NR	NR	NR	NR	NR	NR	NR	NH	NH	NH
Thermal Damage Distances by Pool Fire (m)													
Radiation Intensity (KW/m^2)	4	8	8	9	36	35	35	128	126	126	796	799	799
	12.5	5	5	5	21	24	25	81	86	88	556	572	585
	37.5	NR	NR	NR	NR	NR	NR	55	52	51	404	397	399
Maximum Distance at Overpressure Level (m)													
Overpressure (bar)	0.02068	NH	NH	NH	63	19	19	260	80	47	1327	332	291
	0.1379	NH	NH	NH	31	12	12	119	35	19	924	171	146
	0.2068	NH	NH	NH	29	12	12	108	32	17	906	159	136

Notes:
NH: No Hazard
NR: Not Reached

The results for 25 mm leak size and catastrophic are superimposed on plot plan and presented in below figures.

Dispersion distances in case of 25mm leak of methanol tank

Figure 7-13: Dispersion distances in case of 25mm leak of methanol tank

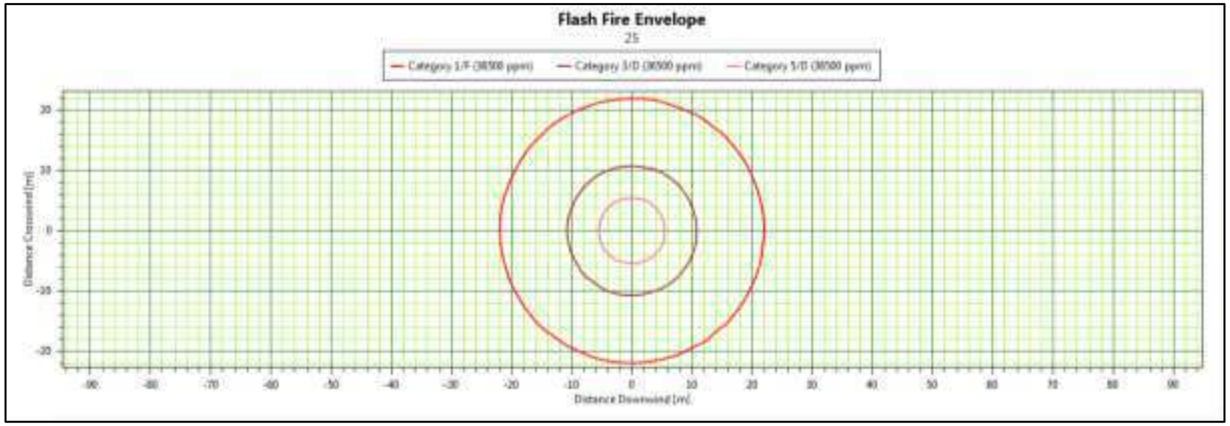
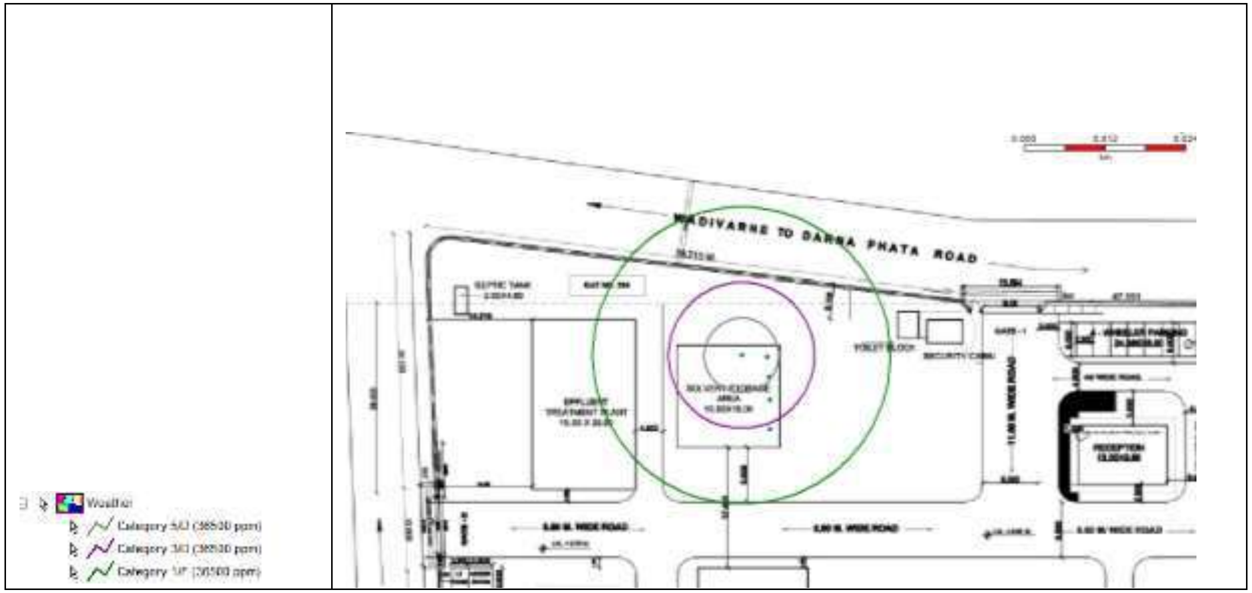


Figure 7-14: Dispersion distances in case of 25mm leak of methanol tank



Dispersion distances in case of catastrophic rupture of methanol tank

Figure 7-15: Dispersion distances in case of catastrophic rupture of methanol tank

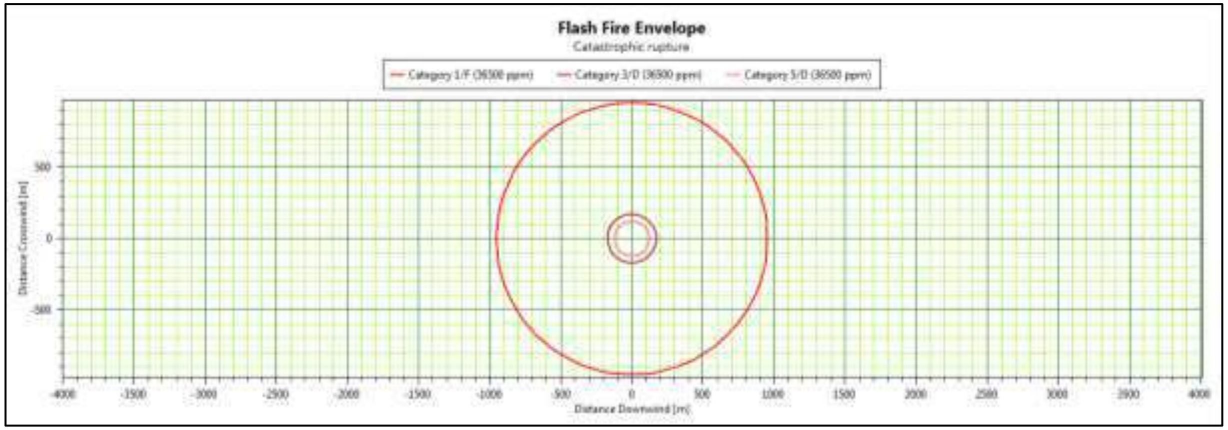
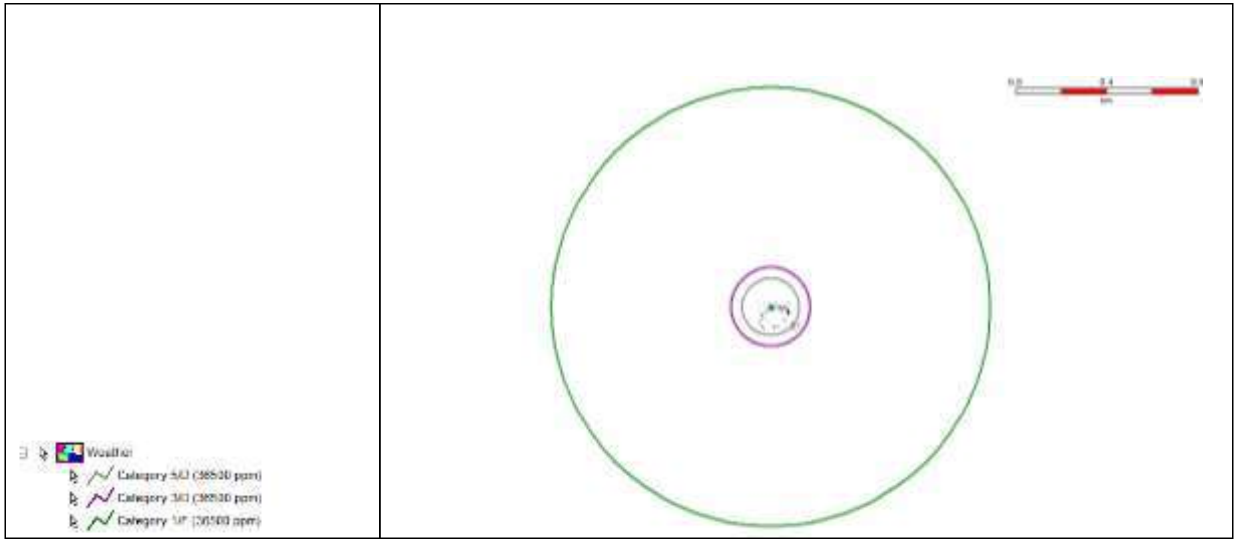


Figure 7-16: Dispersion distances in case of catastrophic rupture of methanol tank



Jet Fire results for 25mm leak of methanol tank

Figure 7-17: Jet fire intensity radii in case of 25mm leak of methanol tank

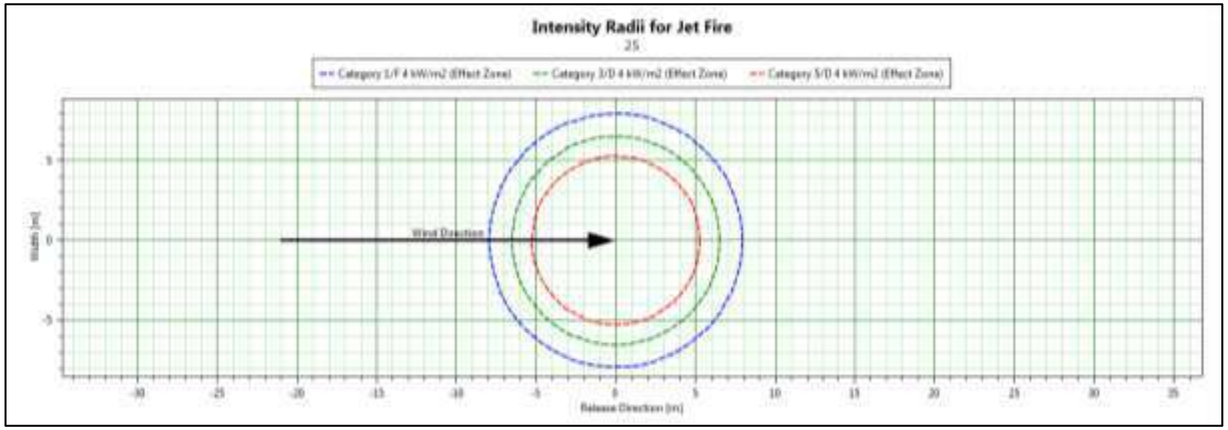
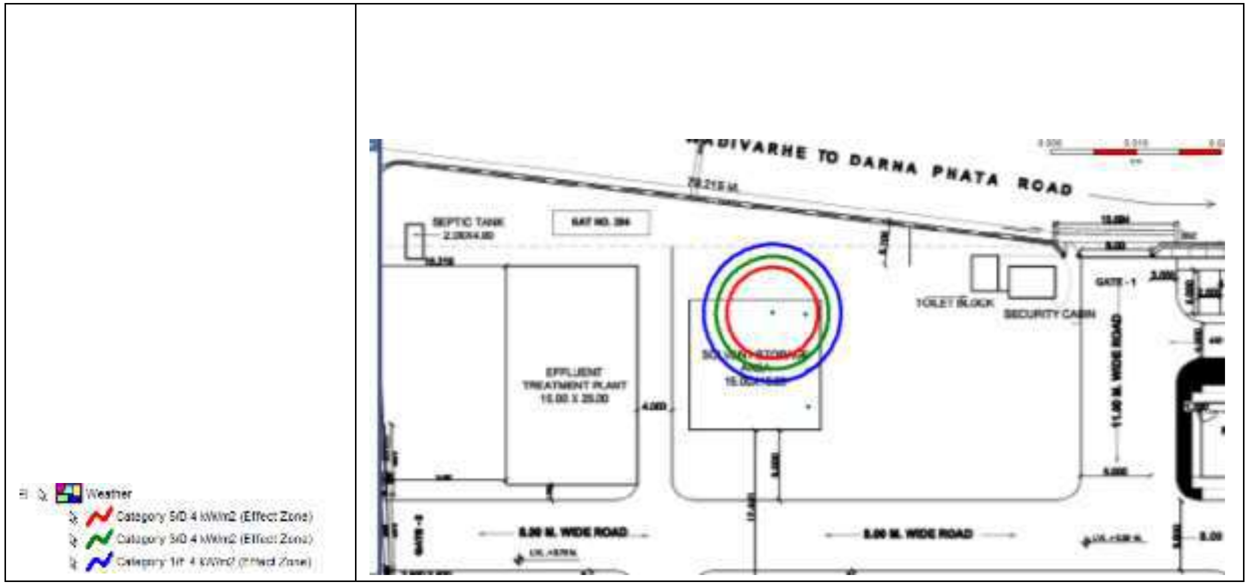


Figure 7-18: Jet fire intensity radii in case of 25mm leak of methanol tank



Pool fire results in case of 25 mm leak of methanol tank

Figure 7-19: Pool fire results in case of 25mm leak of methanol tank

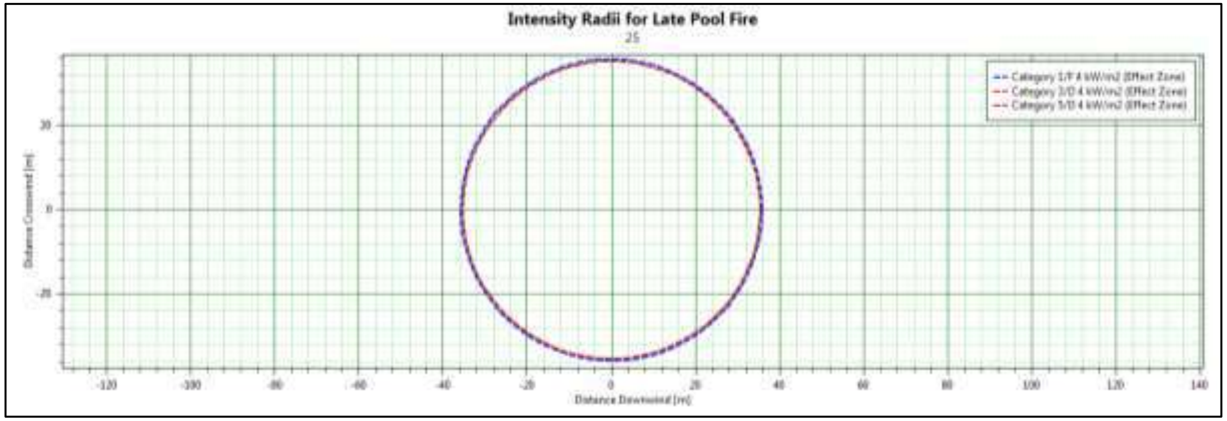
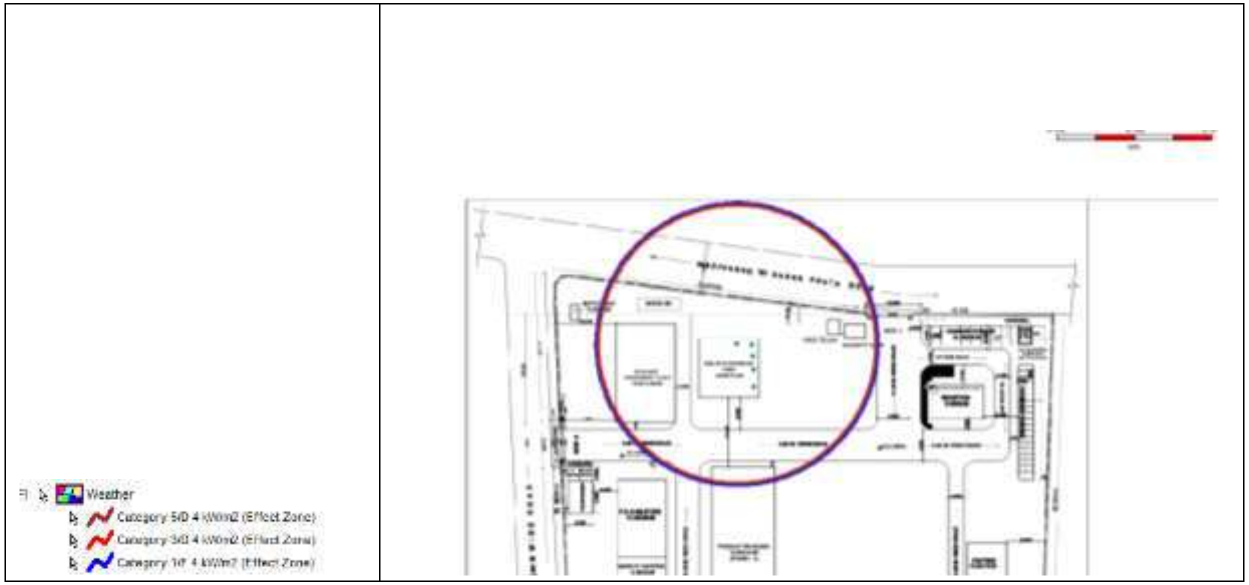


Figure 7-20: Pool fire results in case of 25mm leak of methanol tank



Pool fire results in case of catastrophic rupture of methanol tank

Figure 7-21: Pool fire results in case of catastrophic rupture of methanol tank

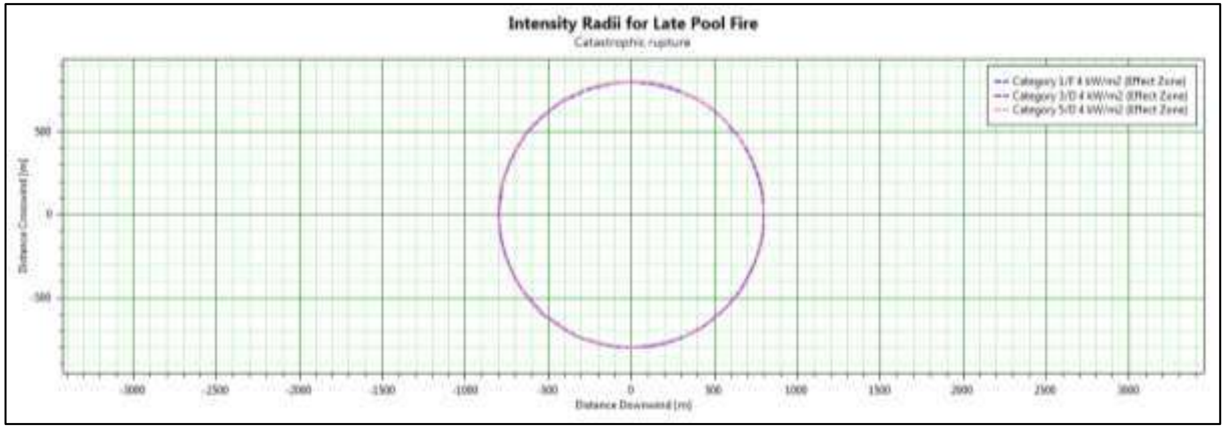
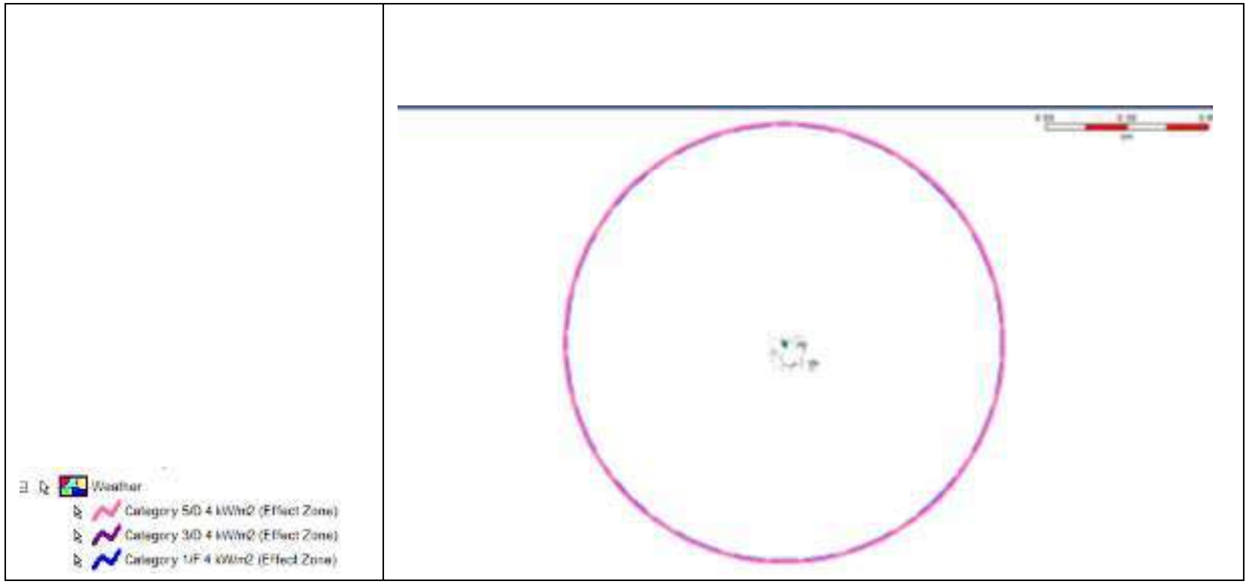


Figure 7-22: Pool fire results in case of catastrophic rupture of methanol tank



Overpressure results in case of catastrophic rupture of methanol tank

Figure 7-23: Overpressure results in case of catastrophic rupture of methanol tank

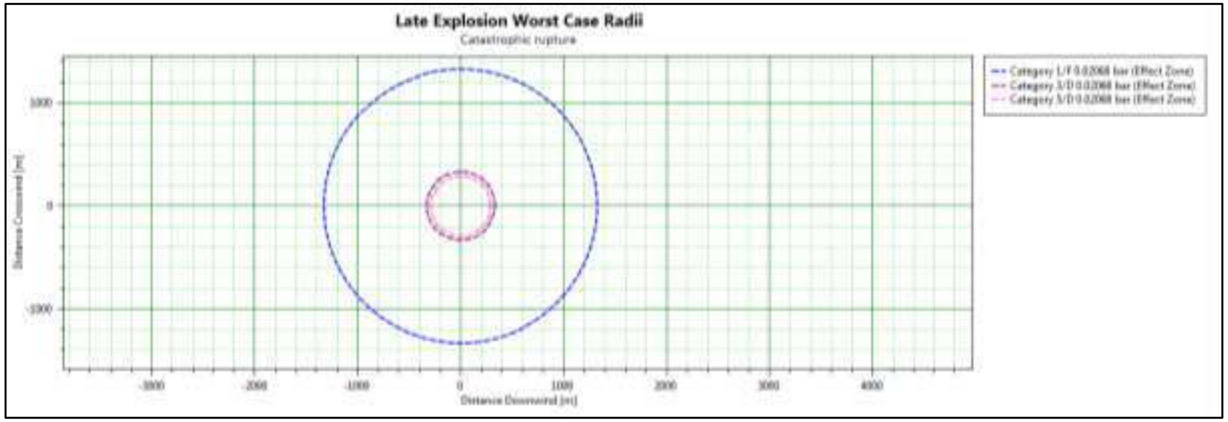
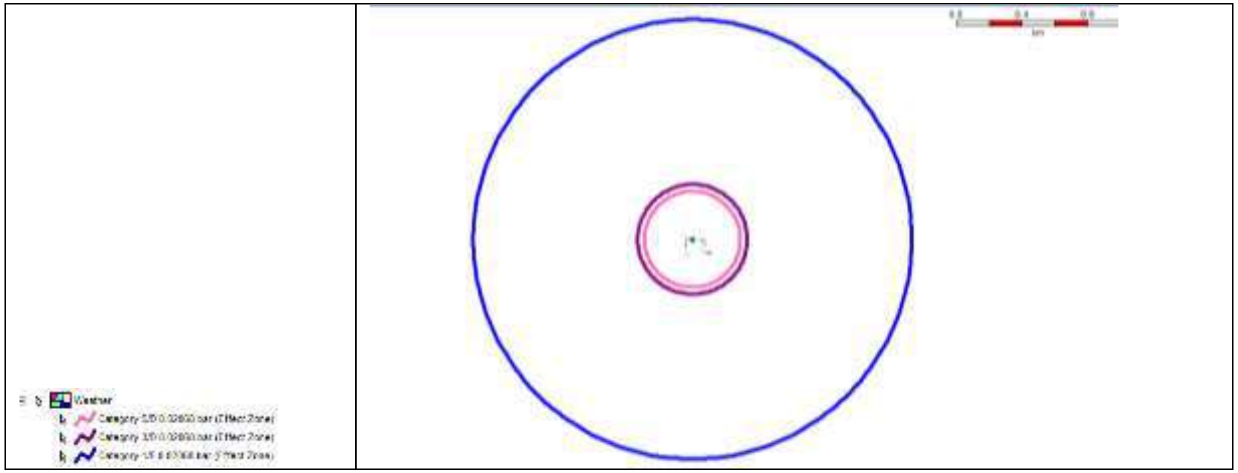


Figure 7-24: Overpressure results in case of catastrophic rupture of methanol tank



3. Isopropyl Alcohol (2.5 Kl)

Table 7-3 Damage Distances for Isopropyl Alcohol tank

Scenario details		5 mm leak			25 mm leak			100 mm leak			Catastrophic Rupture		
Weather Category		1F	3D	5D	1F	3D	5D	1F	3D	5D	1F	3D	5D
Dispersion Distances (m)													
Conc. (ppm)	UFL	1	1	1	3	2	2	22	4	4	156	18	19
	LFL	2	2	2	14	9	5	84	18	15	918	208	128
	0.5 LFL	2	2	2	23	15	11	137	30	26	1493	441	371
Thermal Damage Distances by Jet Fire (m)													
Radiation Intensity (KW/m²)	4	NR	NR	NR	5	4	4	17	16	14	NH	NH	NH
	12.5	NR	NR	NR	NR	NR	3	14	13	12	NH	NH	NH
	37.5	NR	NR	NR	NR	NR	NR	NR	11	10	NH	NH	NH
Thermal Damage Distances by Pool Fire (m)													
Radiation Intensity (KW/m²)	4	15	14	14	61	60	59	214	208	206	1237	1234	1236
	12.5	9	10	10	37	39	40	133	136	136	810	827	836
	37.5	5	5	5	18	20	21	75	84	90	528	561	586
Maximum Distance at Overpressure Level (m)													
Overpressure (bar)	0.02068	NH	NH	NH	45	26	20	405	91	69	2381	593	386
	0.1379	NH	NH	NH	19	14	13	201	46	33	1640	380	242
	0.2068	NH	NH	NH	17	13	12	185	42	30	1591	375	241

Notes:
NH: No Hazard
NR: Not Reached

The results for 25 mm leak size and catastrophic are superimposed on plot plan and presented in below figures.

Dispersion distances in case of 25mm leak of Isopropyl Alcohol tank

Figure 7-25: Dispersion distances in case of 25mm leak of Isopropyl Alcohol tank

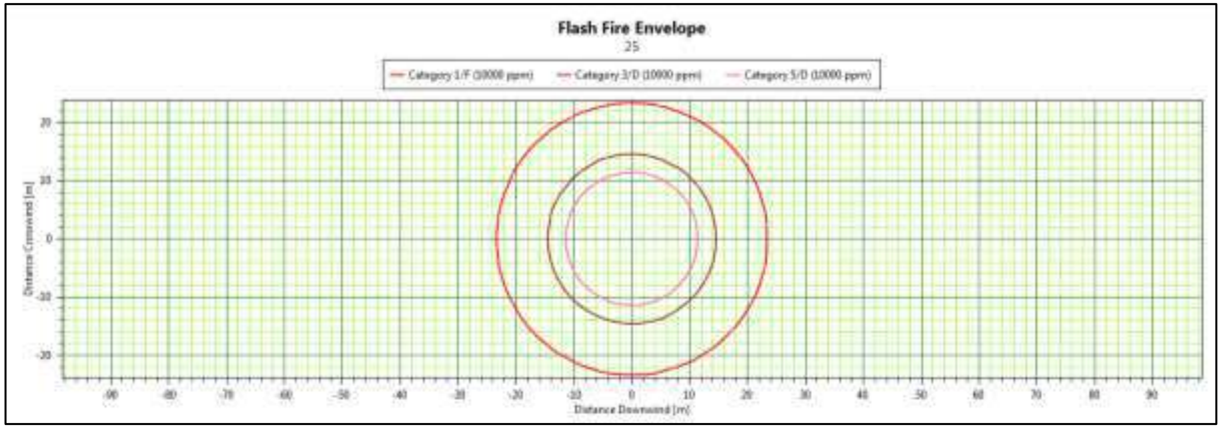
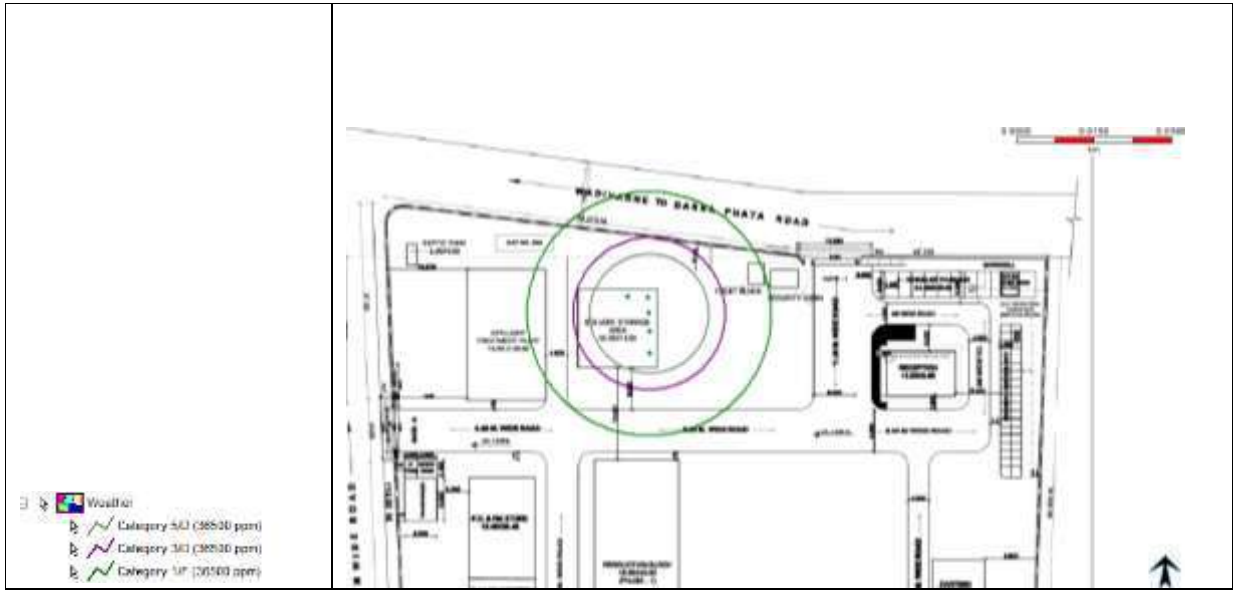


Figure 7-26: Dispersion distances in case of 25mm leak of Isopropyl Alcohol tank



Dispersion distances in case of catastrophic rupture of Isopropyl Alcohol tank

Figure 7-27: Dispersion distances in case of catastrophic rupture of Isopropyl Alcohol tank

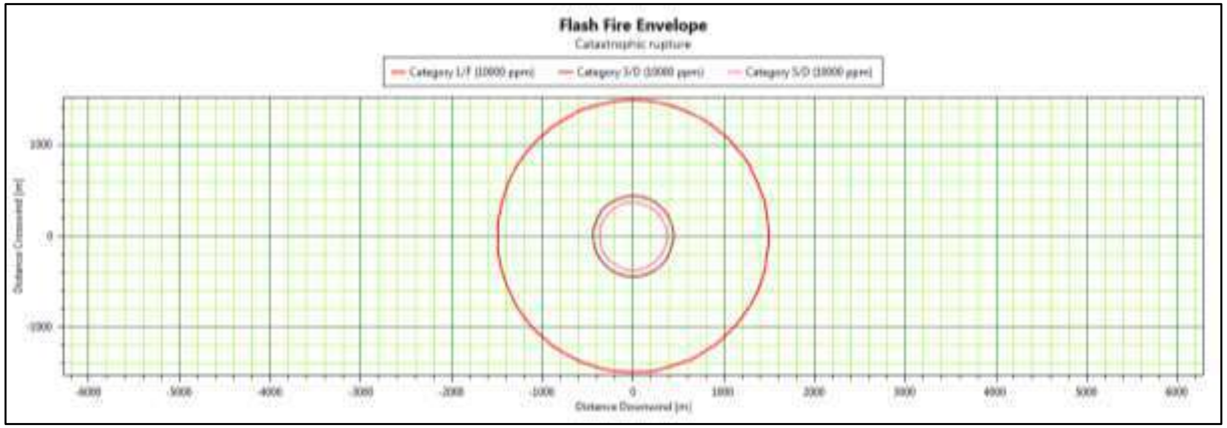
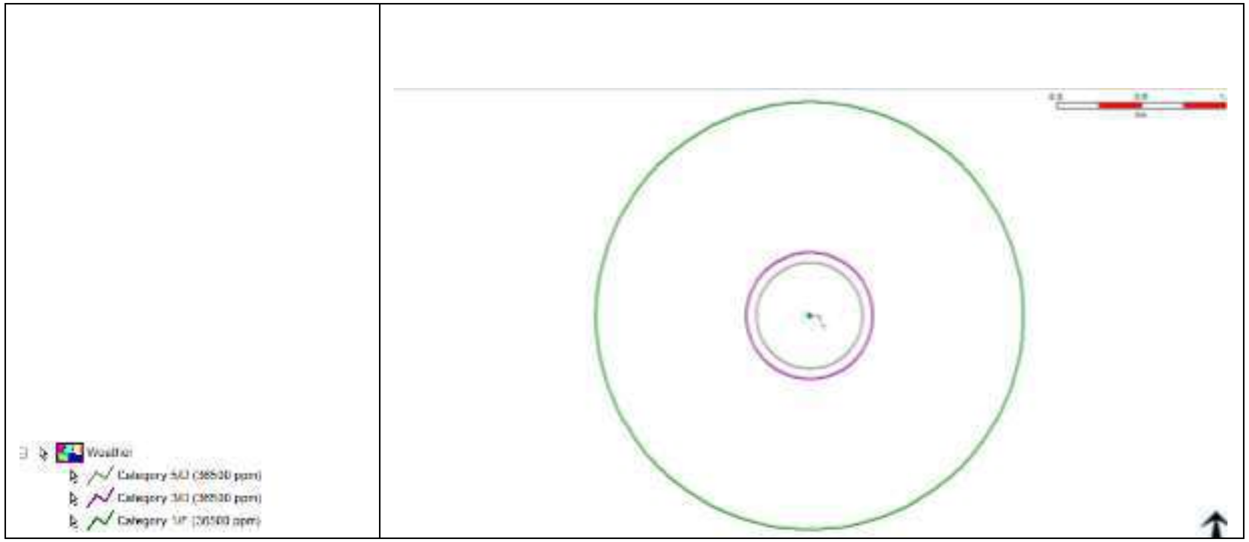


Figure 7-28: Dispersion distances in case of catastrophic rupture of Isopropyl Alcohol tank



Jet Fire results for 25mm leak of Isopropyl Alcohol tank

Figure 7-29: Jet fire intensity radii in case of 25mm leak of Isopropyl Alcohol tank

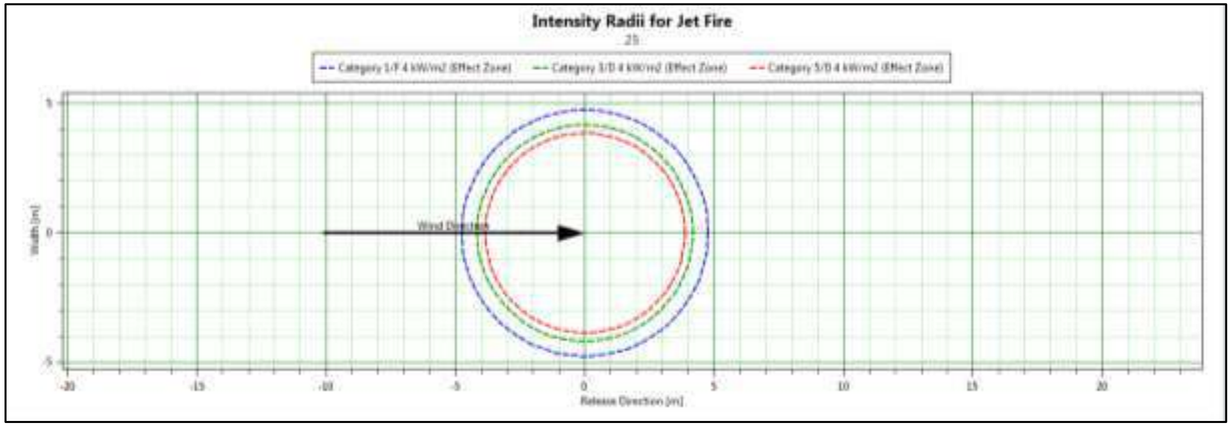
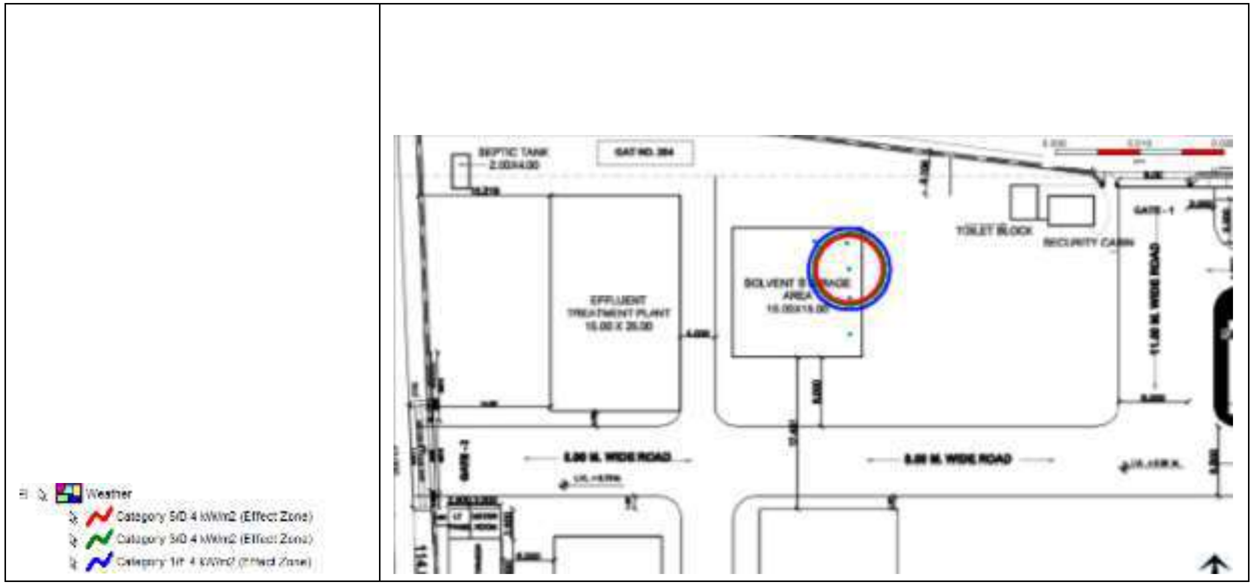


Figure 7-30: Jet fire intensity radii in case of 25mm leak of Isopropyl Alcohol tank



Pool fire results in case of 25 mm leak of Isopropyl Alcohol tank

Figure 7-31: Pool fire results in case of 25mm leak of Isopropyl Alcohol tank

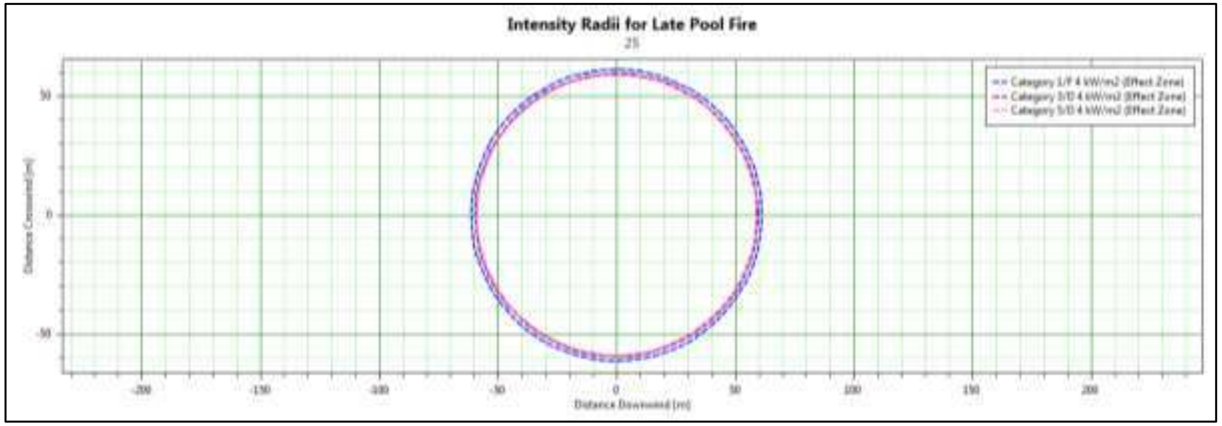
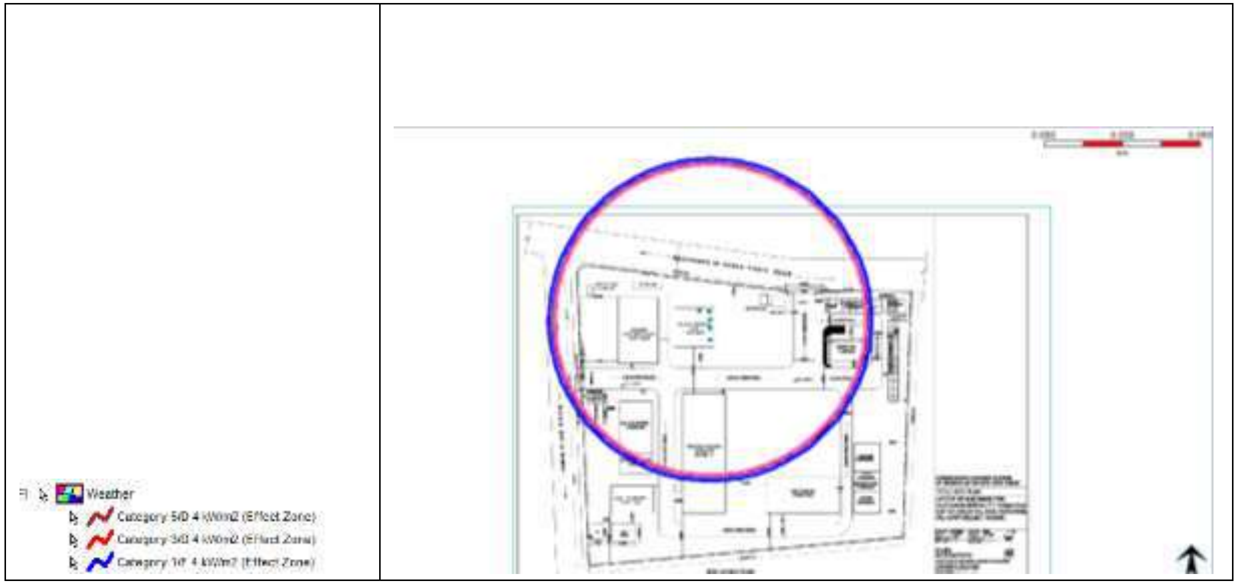


Figure 7-32: Pool fire results in case of 25mm leak of Isopropyl Alcohol tank



Pool fire results in case of catastrophic rupture of Isopropyl Alcohol tank

Figure 7-33: Pool fire results in case of catastrophic rupture of Isopropyl Alcohol tank

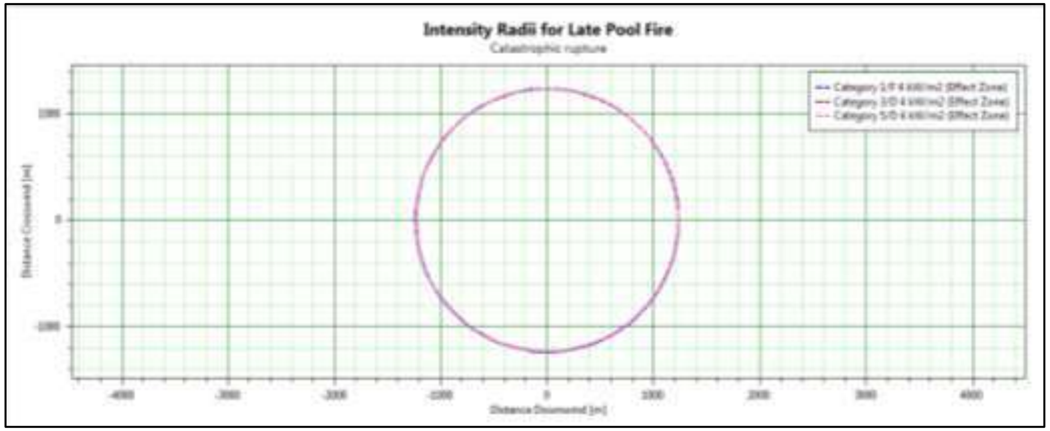
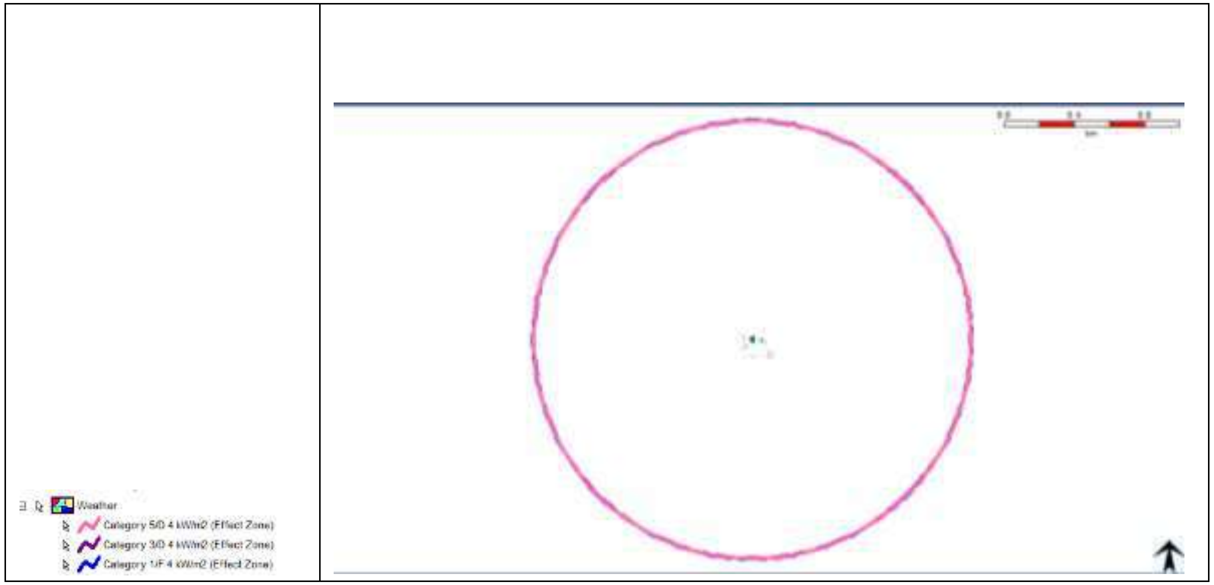


Figure 7-34: Pool fire results in case of catastrophic rupture of Isopropyl Alcohol tank



Overpressure results in case of catastrophic rupture of Isopropyl Alcohol tank

Figure 7-35: Overpressure results in case of catastrophic rupture of Isopropyl Alcohol tank

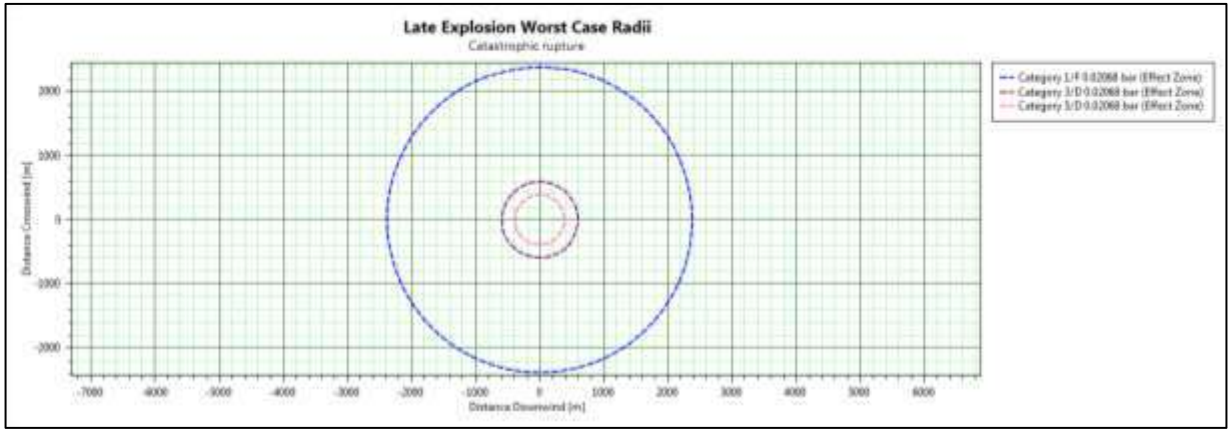
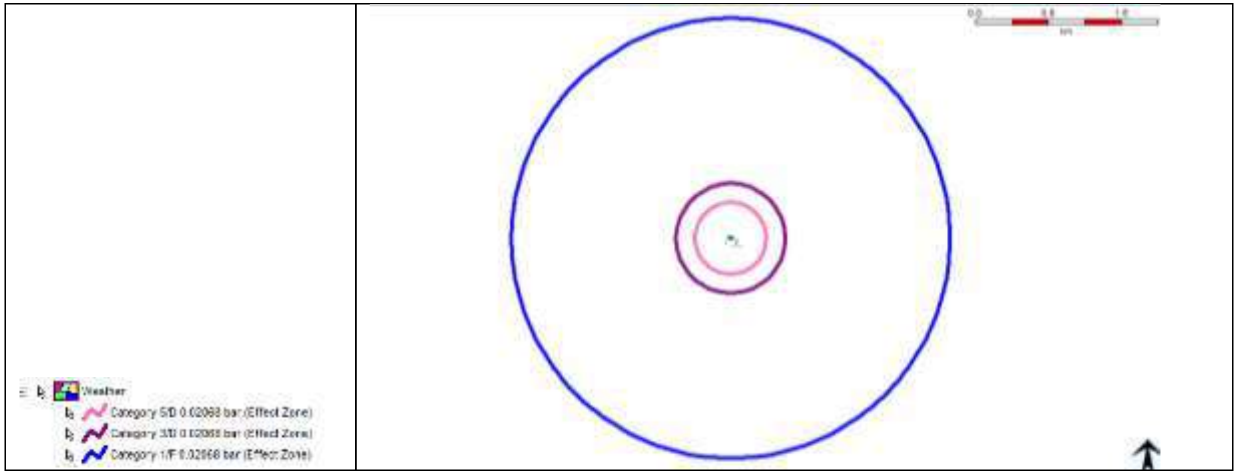


Figure 7-36: Overpressure results in case of catastrophic rupture of Isopropyl Alcohol tank



4. Butanol

Table 7-4 Damage Distances for Butanol drum

Scenario details		5 mm leak			25 mm leak			100 mm leak			Catastrophic Rupture		
Weather Category		1F	3D	5D	1F	3D	5D	1F	3D	5D	1F	3D	5D
Dispersion Distances (m)													
Conc. (ppm)	UFL	1	1	1	2	2	2	2	2	2	2	2	2
	LFL	2	2	2	2	2	2	2	2	2	2	2	2
	0.5 LFL	2	2	2	2	2	2	3	2	2	3	4	3
Thermal Damage Distances by Jet Fire (m)													
Radiation Intensity (KW/m²)	4	NR	NR	NR	NR	NR	NR	8	7	6	NH	NH	NH
	12.5	NR	NR	NR	NR	NR	NR	7	5	5	NH	NH	NH
	37.5	NR	NR	NR	NR	NR	NR	NR	5	NR	NH	NH	NH
Thermal Damage Distances by Pool Fire (m)													
Radiation Intensity (KW/m²)	4	19	20	20	22	23	23	22	23	24	21	22	22
	12.5	11	13	14	13	16	16	13	16	16	12	14	15
	37.5	5	6	6	6	7	8	7	7	8	5	6	6
Maximum Distance at Overpressure Level (m)													
Overpressure (bar)	0.02068	NH	NH	NH	NH	NH	NH	NH	NH	NH	NH	NH	NH
	0.1379	NH	NH	NH	NH	NH	NH	NH	NH	NH	NH	NH	NH
	0.2068	NH	NH	NH	NH	NH	NH	NH	NH	NH	NH	NH	NH

Notes:
NH: No Hazard
NR: Not Reached

The results for 25 mm leak size and catastrophic are superimposed on plot plan and presented in below figures.

Dispersion distances in case of 25mm leak of Butanol drum

Figure 7-37: Dispersion distances in case of 25mm leak of Butanol drum

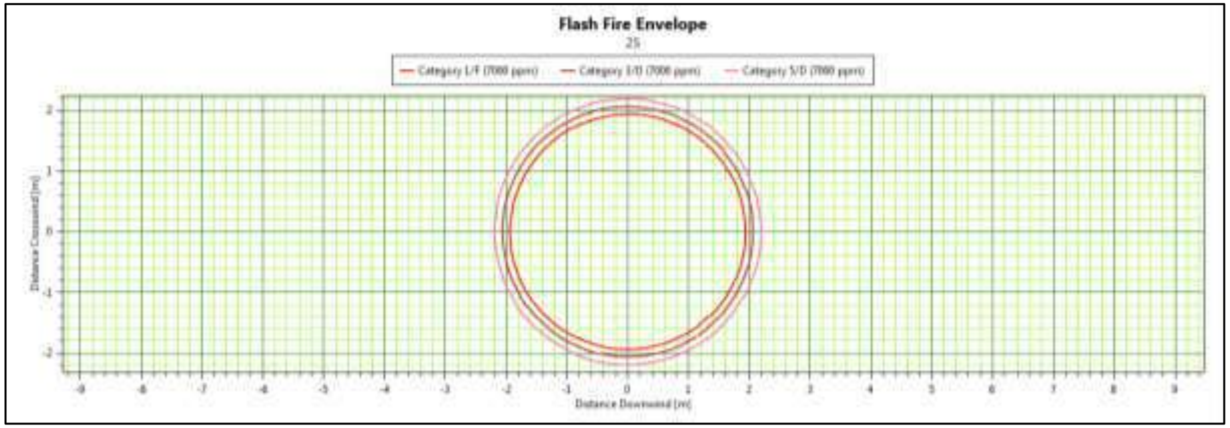
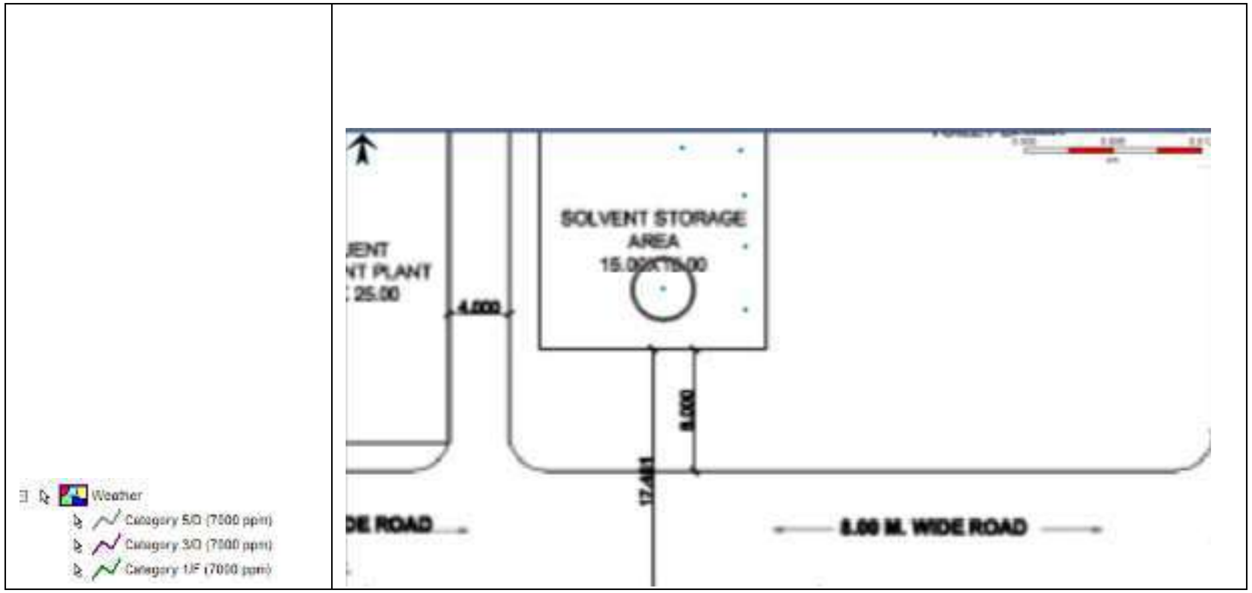


Figure 7-38: Dispersion distances in case of 25mm leak of Butanol drum



Dispersion distances in case of catastrophic rupture of Butanol drum

Figure 7-39: Dispersion distances in case of catastrophic rupture of Butanol drum

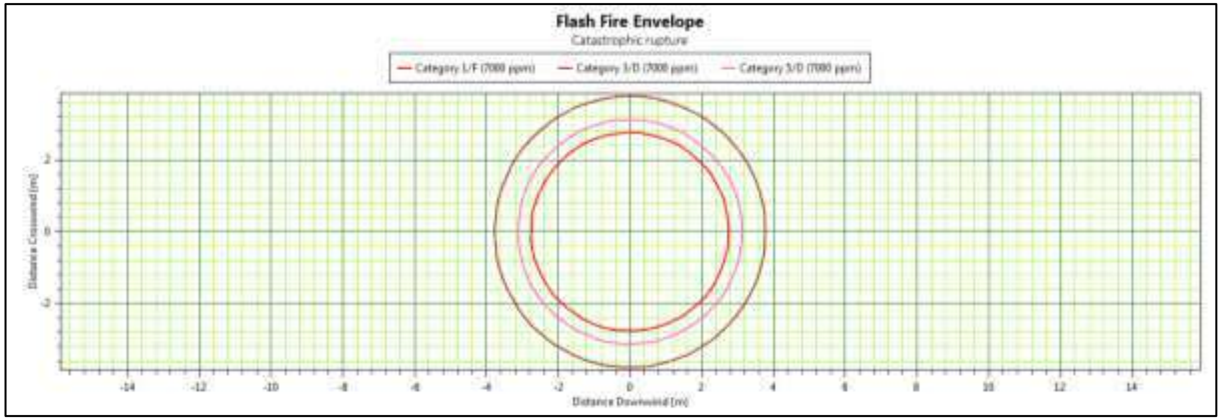
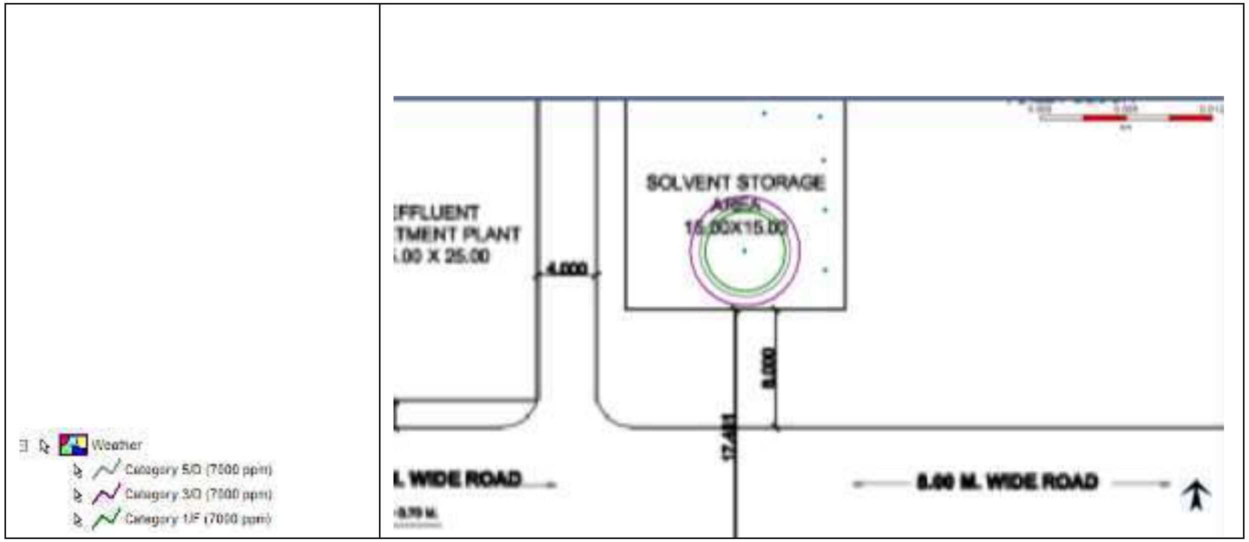


Figure 7-40: Dispersion distances in case of catastrophic rupture of Butanol drum



Pool fire results in case of 25 mm leak of Butanol drum

Figure 7-41: Pool fire results in case of 25mm leak of Butanol drum

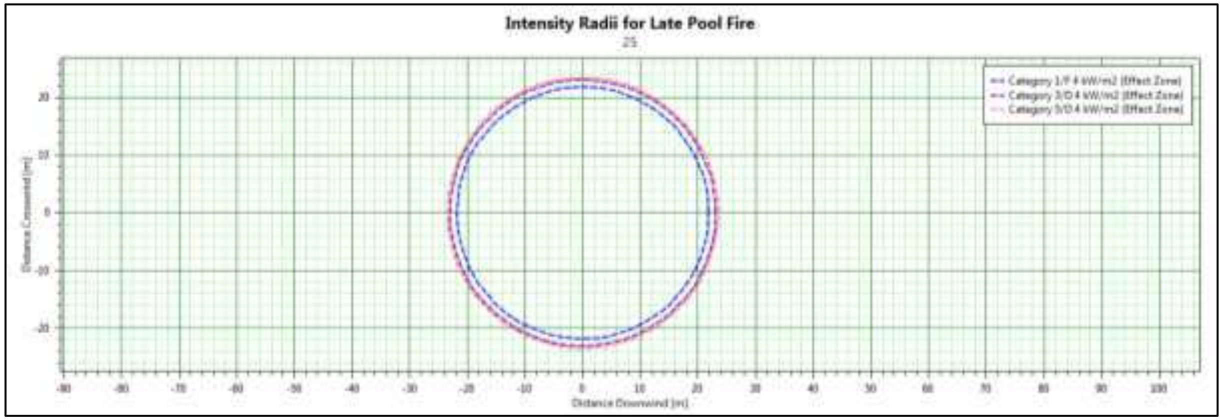
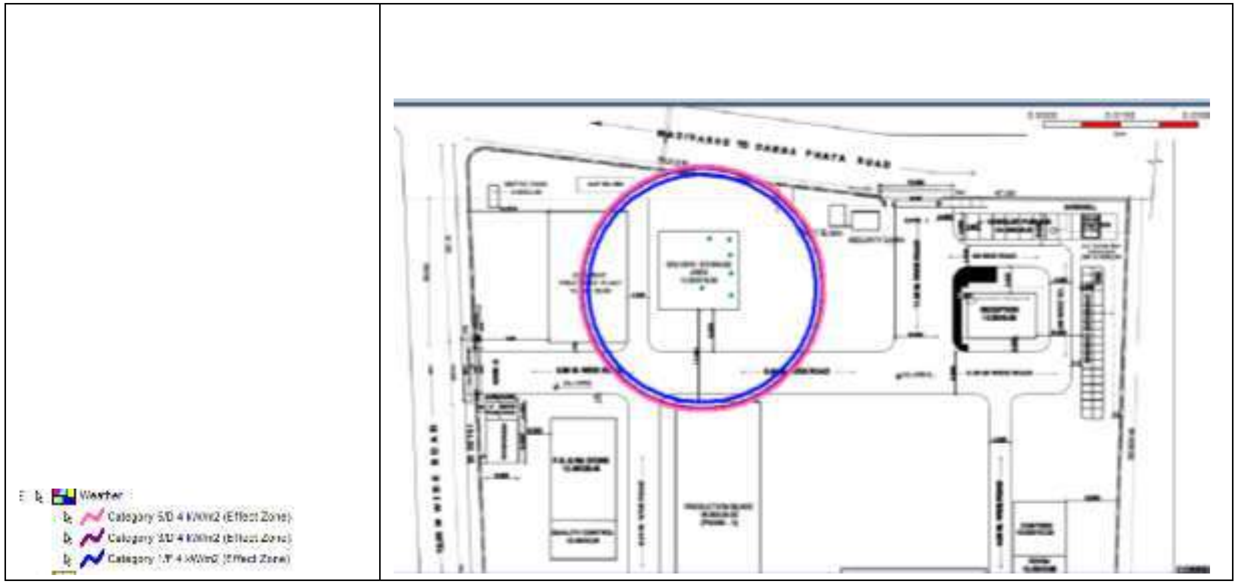


Figure 7-42: Pool fire results in case of 25mm leak of Butanol drum



Pool fire results in case of catastrophic rupture of Butanol drum

Figure 7-43: Pool fire results in case of catastrophic rupture of Butanol drum

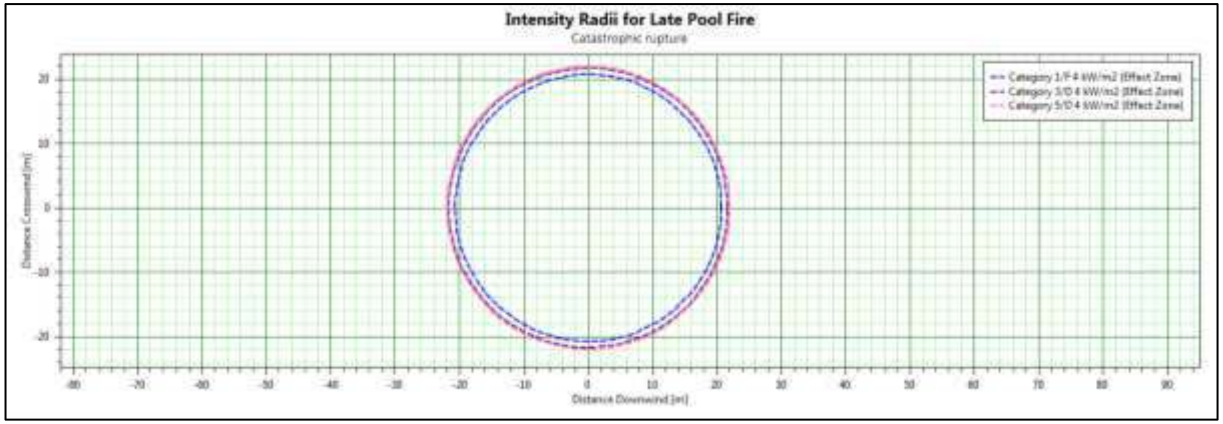
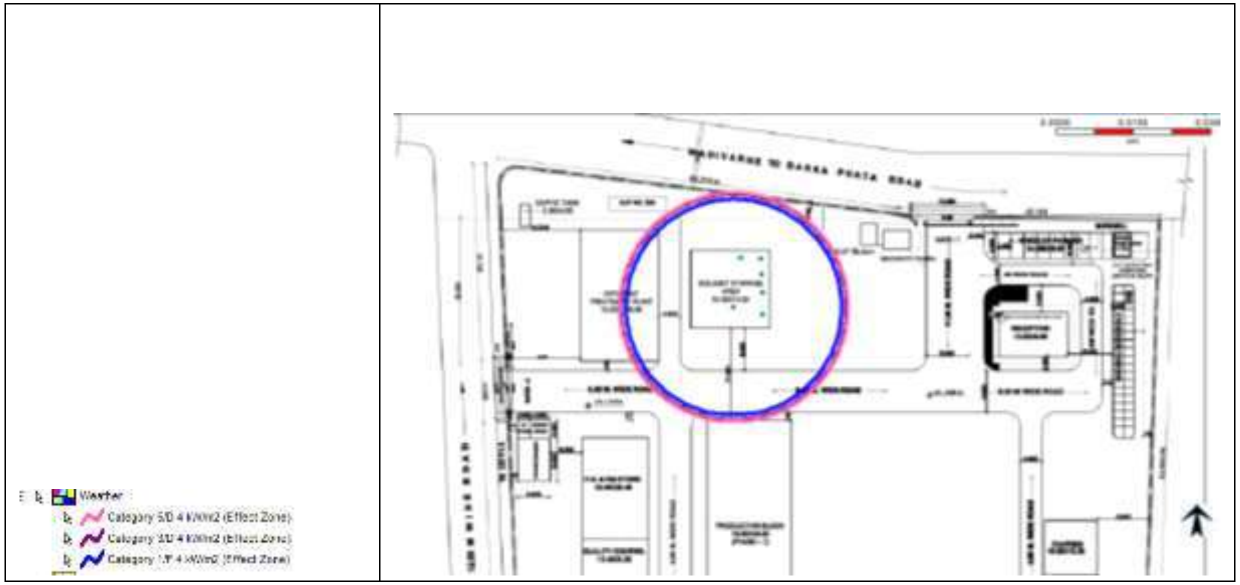


Figure 7-44: Pool fire results in case of catastrophic rupture of Butanol drum



8 CONCLUSION

Different hazards leading consequence events are identified for the facility. Consequence assessment has been carried out for different identified fire and explosion scenarios. All possible event outcomes studied in the study using PHAST software. The impact criteria for different radiation levels and overpressure levels are presented in the report.

The Consequence results for different events such as dispersion, Jet fire; pool fire and overpressure are presented in the form of tables and graphs.

Fire is the major risk at M/s. Vadivarhe Speciality Chemicals Ltd. because of storage handling and use of flammable substances within the premises as raw material and products. Adequate control measures are provided to detect and fight fires.

The major firefighting arrangement provided includes:

1. **Fire Detection and Alarm system:** in Production block, Good Store/Raw Material Store, Q.C. Building and Solvent Store areas 33 Nos. of Optical smoke detector, 24 Nos. Multi Criteria Detector and 3 Nos. Optical Heat detectors are installed along with 12 Nos. manual call points and 12 Nos. of Hooters.
2. **Firefighting Arrangement:** fire hydrant system consisting of 18 Nos. of fire hydrants have been installed and 54 Nos. of Fire Extinguishers, consisting CO2 Type, Dry Chemical Powder Type and Foam Type, are installed at various locations in the premises.

Safety measures:

Following safety measures have been implemented in tank farm area:

1. Gas detectors are available
2. Alarms are in place
3. Fire hydrant system is available
4. Fire extinguishers are in place
5. Jumpers are in place at flange joints
6. Earthing & bonding are in place
7. Dyke wall is present

9 RECOMMENDATIONS & MITIGATION MEASURES

The following control measures shall be implemented in tank farm area:

1. Fencing and no smoking and prohibited area, warnings signage should be displayed in Hindi, English and local language at prominent locations.
2. LG, TG, PG, gas detectors shall be inspected and calibrated periodically as per manufacturer's recommendation and record should be maintained.
3. Training should be conducted for all the personnel engaged in handling the solvents activity.

10 REFERENCES

1. Guideline for QRA from the- "PURPLE BOOK"
2. PHAST Software-By DNV
3. MSDS of material
4. Layout
5. EIA report