7.0 QUNATITATIVE RISK ASSESSMENT

7.1 Preamble

The main objective of The Quantitative Risk Analysis (QRA) study is to identify the potential hazards, assess the effect/consequence of all probable accidental releases and risk mitigating measures to reduce hazards of the proposed facilities. The Quantitative Risk Analysis (QRA) study scheme is shown in **Figure 7.1**.

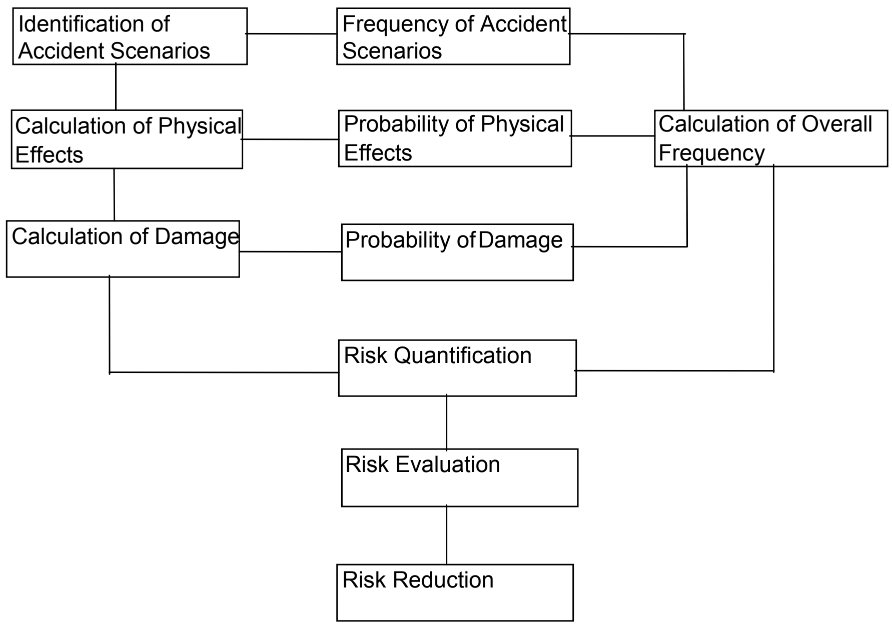


Figure 7.1: Risk Assessment Methodology

Detailed scope of work for QRA study is given below:

- Identification of Hazards and Selection of Failure Scenarios
- Effects & Consequence Estimation
- Frequency and Risk Analysis
- Risk Mitigation Measures

The criteria of acceptance of risk is **A**s **L**ow **A**s **R**easonably **P**racticable (the ALARP principle).

7.2 Hazard Identification and Selection of Failure Scenarios

Hazard is defined as a chemical or physical condition having the potential for causing damage to life, property or the environment. Hazards associated at the steel plant have been identified using HAZAN techniques. For each selected release source, several scenarios may be possible depending upon the failure mode causing loss of containment.

The hazard identification includes a selection of scenarios ranging from the more likely high probability-low consequence event to the low probability-higher consequence event. The criteria used for selection of scenarios for the consequences analysis is the Maximum Credible Accidental (MAC) scenarios.

- **Hazardous Substances to be stored and Handled at the Plant**

The storage and operation conditions of hazardous substances to be stored and handled during the operation of expanded plant are described in **Table 7.1.**

Table 7.1: Storage and Operation Conditions of Hazardous Substances

Sn	Hazardous Materials	Details
1.	**Blast Furnace (BF) Gas**	
i.	Quantity of BG Gas Generation	2,30,000 Nm^3/hr
ii.	Volume of BF gas Holder	50,000 m^3
iii.	Size of BF gas Piping (diameter)	1500 mm
iv.	Pressure in BF gas Piping	0.08 kg/cm^2 or 800 mm WC
v.	Temperature	40 ^oC
2.	**LD Gas**	
i.	Volume of LD gas Holder	2,00,000 m^3
ii.	Size of LD gas Piping	1500 mm
iii.	Pressure in LD gas Piping	0.08 kg/cm^2 or 800 mm WC
iv.	Temperature	40 ^oC
3.	**Cove Oven Gas**	No generation of coke oven gas. Only flue gases will be generated from Coke Oven batteries. Heat of flue gases will be recovered through Heat recovery boilers of power plant and waste gases will be vented in to the atmosphere though flare stack.
4.	**Propane**	
i.	Nos Bullets	2
ii.	Capacity of Each Bullet	16 T
iii.	Storage Pressure in Bullet	10 kg/cm^2
iv.	Temperature	Atmospheric
v.	Connecting Piping	50 mm NB
vi.	Size of Propane gas piping for Plant after Vaporizer	100 mm NB
vii.	Pressure in Propane gas piping for Plant after Vaporizer	1 to 2 kg/cm^2

Sn	Hazardous Materials	Details
5.	**Light Diesel Oil (LDO)**	
i.	Nos. LDO Tanks	2
ii.	Capacity of Each Tank	700 kl capacity each
iii.	Size	Dia 12 m, Height 8 m
iv.	Connecting Piping	100 mm NB
v.	Dyke	Full Containment
6.	**Furnace Oil**	
i.	Nos. Furnace Tanks	2
ii.	Capacity of Each Tank	760 kl
iii.	Size	Dia 12m, Height: 9 m
iv.	Connecting Piping	100 mm NB
v.	Dyke	Full Containment

❑ Hazards Associated with Steel Plant

Broadly, there will be mainly three major types of hazards during operation of expanded plant as described below:

- Fire in flammable materials;
- Explosion in flammable and explosive materials; and
- Toxic Release of hazardous gases.

Apart from these, there will also other hazardous conditions during lifting of hot coke and hot metal handling by cranes and hoists, furnace and coke oven operations, handling of industrial gases throughout the plant.

The details of various possible hazards during operation of expanded plant are listed as per given below:

Sn.	Nature of Hazard	Sources
1.	Fire Hazard	Release/leakage of propane, Blast Furnace gas, LD gas, Oxygen, Hydrogen, Light Diesel Oil, Furnace Oil, Hot liquid metal, etc.
2.	Explosion Hazard	Release/leakage of Propane Hydrogen, BF gas, LD gas, etc.
3.	Toxic Hazard	Release of LD Gas and BF Gas
4.	Cold Burns	Exposure to liquid oxygen, liquid nitrogen and liquid argon
5.	Asphyxiation	Release of Nitrogen, Argon, Oxygen, BF gas and LD gas

Sn.	Nature of Hazard	Sources
6.	Fire/Explosions Due To Spillage of Liquid Hot Metal	Spillage/transfer of liquid hot metal and hot slag
7.	Heat Radiations Due To Hot Metal Handling	Spillage of liquid hot metal, liquid steel and hot slag
8.	Accidents Due To Material Handling Equipment	Concerned with all material handling equipments

- **Hazard Analysis (HAZAN)**

The various types of probable hazards present during the operation of proposed expanded plant have been analysed along with their possible cause, risk involved (likely hood of occurrence and degree of hazard) and effects/consequence on the occurrence and presented in **Table 7.2**.

Table 7.2 : Hazard Analysis (HAZAN)

Sn.	Nature of Hazard	Location	Possible Cause	Risk Involved		Effect/Consequence
				Probability	Severity	
1.	**Coke Ovens Batteries**					
i.	Spillage from Hot coke from batteries	Battery Coke discharging side	Misalignment between loco car and pusher car	$1x10^{-4}$/yr	Moderate	• Injuries due to direct thermal radiations
2.	**Sinter Plant**					
ii.	Fire	Furnace, Mixed Gas Piping	Piping rupture or leakage	--	Moderate	• Injuries due to thermal radiations as a result of jet fire.
iii.	Overflow /spill of hot sinter machine	Sinter Machine	Conveyer fails, Speed ratio not synchronised.	$9x10^{-5}$/yr	Moderate	Injuries due to direct thermal radiations in close vicinity.
3.	**Blast Furnace**					
iv.	Explosion in Stove	Blast Furnace Stoves	• Combustion air supply fails • Gas accumulation in stoves • Snort Control Valve Malfunction • High pressure build-up	$0.42x10^{-6}$/ yr	Severe	Loss of life and property due to fire and explosion,
v.	Explosion in Blast Furnace	Blast Furnace	• Gas accumulation • Cooling System fails • High pressure build-up	$8.55x10^{-6}$/ yr	Severe	Injuries due to thermal radiation and pressure wave

Sn.	Nature of Hazard	Location	Possible Cause	Risk Involved		Effect/Consequence
				Probability	Severity	
			• Instrumentation fails			
vi	Tap hole gets opened by it self	Blast Furnace proper	• Improper mudgun operation • Incorrect quality/quantity of tap hole mass • Interlock fails	$1x10^{-3}$/ yr	Severe	Loss of life and property due to fire and explosion,
4.	**Energy and Fuel Management**					
vii	Fire and Explosion Toxic Release	Coke Oven Gas Boosting Station	• High pressure, high temperature, air ingression at booster inlet. • Inter look and instrumentation fail.	$4.75x10^{-3}$/ yr	Severe	Fire & Explosion, Toxic Concentration
viii	Fire and Explosion hazards Toxic Gas Release	LD Gas Holder	• High O_2 % in LD Gas. • High pressure of gas leakage. • Inter look and instrumentation fail	$1.47x10^{-17}$/ yr	Severe	Fire & Explosion, Toxic Concentration
ix.	Fire and Explosion	Booster Fan	• Inter look fails • U seal fails • Instrumentation fails	$1.5x10^{-17}$/ yr	Moderate	Fire and Explosion
x.	Leakage of	Propane bullet	• Rupture, leakage, hole	$1.5x10^{-4}$/yr	Severe	Fire & Explosion

Sn.	Nature of Hazard	Location	Possible Cause	Risk Involved		Effect/Consequence
				Probability	Severity	
	Propane		in bullets and piping			
xi.	Leakage of LDO/Furnace oil	Tank farm area	• Rupture, leakage, hole in storage tanks and piping	1 x 10^{-6} /yr	Moderate	Pool fire
5.	**Utilities Department**					
xii.	Release or rupture in nitrogen tank	Liquid Nitrogen Tank	• Instrumentation failure • High pressure, • Corrosion • Overfilling	--	Moderate	Asphyxiation
xiii.	Release or rupture in Argon Tank	Liquid Argon Tank	• Instrumentation failure • High pressure, • Corrosion • Overfilling	--	Moderate	Asphyxiation
xiv.	Release or rupture in Oxygen Tank	Liquid Oxygen Tank	• Instrumentation failure • High pressure, • Leakage	--	Moderate	Asphyxiation

Characteristics of Hazardous Substances

The characteristics of hazardous chemicals to be handled and stored during the operation of proposed expanded plant are described below:

- **LD Gas**

LD gas is by-product gas generated from LD converter during steel manufacturing. It is colorless and almost odorless. LD gas is flammable but not self sustaining. It is toxic also and toxicity of the LD gas is due to the presence of carbon monoxide (CO). It shows immediate health hazard due to presence of high carbon monoxide. As it has marginally higher specific gravity than air, therefore, it remains within the released zone. Physical & chemical properties of LD gas are as given below:

Form	:	Gas
Color	:	Colorless
Odor	:	Almost Odorless
Density	:	1.303 kgs/Nm^3
Ignition Temperature	:	550 to 650°C
Lower Explosion Limit	:	15 % in air
Upper Explosion Limit	:	72 % in air
Solubility in water	:	almost insoluble

Chemical Composition of LD gas is given below:

Carbon Monoxide (CO)	:	55 to 70 %,
Carbon Dioxide (CO_2)	:	13 to 15 %,
Hydrogen (H_2)	:	2 to 3 %,
Oxygen (O_2)	:	1 to 2 %,
Nitrogen (N_2)	:	22 to 25 %

- **Blast Furnace Gas**

Blast furnace gas is by-product gases from blast furnaces. It is colorless and almost odorless. Blast furnace gas is flammable gas. Toxicity of the blast furnace gas is due to the presence of carbon monoxide (CO). As it has marginally higher specific gravity than air, therefore, it remains within the released zone. Physical & chemical properties of blast furnace gas are as given below:

Form	:	Gas
Color	:	Colorless

Odor	:	Almost Odorless
Density	:	1.322 kgs/Nm^3
Ignition Temperature	:	550 to 650°C
Lower Explosion Limit	:	35 % in air
Upper Explosion Limit	:	73.5 % in air
Solubility in water	:	almost insoluble
Calorific Value	:	850 - 950 Kcal/Nm^3.

Chemical Composition of Blast Furnace gas is given below:

Carbon Monoxide (CO)	:	21 to 24 %
Carbon Dioxide (CO_2)	:	18 to 21 %
Hydrogen (H_2)	:	4 to 6 %
Oxygen (O_2)	:	0.4 to 0.6 %
Nitrogen (N_2)	:	50 to 55 %

- **Propane**

Propane is colorless and odourless gas. It is a flammable gas at normal temperature and pressure. On release, propane may give rise to both fire and explosion hazards.

- **Oxygen**

Oxygen gas is colorless, odorless, non-toxic cryogenic liquid or oxidizing gas. It is oxidizer and flammable when contact with flammable materials. It vigorously accelerates combustion, when come in contact with oxygen liquid. Its cold vapors or cold piping can cause frostbite and cryogenic burns to exposed tissue. Liquid oxygen releases will quickly vaporize to gas.

Liquid oxygen is extremely cold and is stored under pressure. A complete hose failure can result in a large release of oxygen and violent movement of the hose and associated equipment, which may cause severe injury or death. Special care must be taken when depressurizing and disconnecting hoses. Physical & chemical properties of oxygen gas are as given below:

Physical state	:	Liquid
Appearance & odour	:	Light blue, odorless liquid
Odor threshold (PPM)	:	Odourless
Vapour pressure	:	Gas@ 21°C
Vapour sp. gravity (air=1)	:	0.967 @ 21°C
Volatiles (% by volume)	:	100%

Boiling point	:	-183°C (760 mmHg)
Freezing point	:	-218.8°C
Solubility in water (%)	:	Slight

It is incompatible with combustible materials, oils or grease and flammable materials.

- **Argon**

Argon gas is colorless, odorless and non flammable gas. Argon is an asphyxiant and in the absence of oxygen, it may be dangerous to life. Physical & chemical properties of Argon gas are as given below:

Color	:	Colorless
Odor	:	Odorless
Molecular weight	:	39.95
Vapor pressure	:	Not applicable
Vapor density	:	1.654 kg/m³ @ 21.1 °C
Specific gravity	:	1.38 @ 21.1 °C (air = 1)
Boiling point	:	-185.87 °C
Melting point	:	-189.35 °C
Water solubility	:	0.056 vol/vol @ 0 °C

- **Nitrogen Gas**

Nitrogen gas is colorless, odorless and non-flammable. It is non-toxic but is asphyxiation by displacement of oxygen. Closed containers of nitrogen may rupture or explode due to pressure build-up when exposed to extreme heat.

Appearance	:	Colourless & odourless liquid at temperatures up to the boiling point
Melting point	:	-209.95 °C
Boiling point	:	-195.86 °C
Density	:	0.808 g cm^{-3}

Liquid nitrogen poses special risks due to its low temperature and the large volume of gas produced when it vaporizes. Care should be taken when using liquid nitrogen, not to spill the liquid on clothing, since this can easily become saturated with the liquid and then hold it next to the skin for a significant period of time, leading to serious burns.

- **LDO**

LDO is clear liquid with slight petroleum odor. It is flammable liquid and highly flammable in presence of open flames and sparks. The flammability of Naphtha is ranked as 3 by National Fire Protection Association (NFPA). It is insoluble in water.

- **Probable Hazardous Conditions**

- **Dispersion of Toxic Gas**

An accidental release of LD gas and BF gas would result in spreading of toxic cloud, if not ignited immediately. On ignition jet/flash fire will take place. Delayed ignition may result in explosion or flash fire, if quantities of explosive mass (between LEL and UEL) are sufficient for it.

In the event of release of LD gas and BF gas, cloud of toxic gas will be formed and moved towards wind direction. The IDLH (immediately dangerous to life and health) concentration value has been taken as the criteria for the 'wounded' category and concentration for fatality have also been taken into consideration.

- **BLEVE (Boiling Liquid Expanding Vapour Explosion)**

BLEVE can occur when a vessel containing a pressurized liquid is ruptured. Such explosions can be extremely hazardous. A BLEVE results from the rupture of a vessel containing a liquid substantially above its atmospheric boiling point. The substance is stored partly in liquid form, with a gaseous vapour above the liquid filling the remainder of the container. If vessel is ruptured, vapour portion will rapidly leak, lowering the pressure inside the container. This sudden drop in pressure inside the container causes violent boiling of the liquid, which rapidly liberates large amount of vapour in the process. The pressure of this vapour can be extremely high, causing a significant wave of overpressure (an explosion) which may completely destroy the storage vessel and project fragments over the surrounding area. BLEVEs can also be caused by an external fire near the storage vessel causing heating of the contents and pressure build-up. BLEVE is possible in above ground storage of propane.

- **Jet Fire**

Jet fire is a turbulent flame resulting from the combustion of continuous release of flammable gas with a significant momentum (release velocity) in a particular direction. A jet fire can be expected upon release of gas from hole or ruptured pipe followed by fire.

There is likelihood of jet flame colliding with neighboring equipment. An instantaneous release of significant quantity of flammable gas and immediate ignition can result in a fireball of flammable gas.

- **Explosion/Flash fire**

If a released flammable gas is not ignited directly, the gas cloud will spread in the surrounding area toward wind direction. The drifting gas cloud will mix with air. As long as the gas concentration is between the lower and upper explosion limits, the gas cloud may be set on fire by an ignition source. In case of delayed ignition of a gas cloud, two physical effects may occur: a flash fire over the whole length of the flammable gas cloud; a gas cloud explosion which results in blast wave, with typical peak overpressures circular around the ignition source. For generation of overpressure effects, some degree of confinement of the flammable gas cloud is required. The extent of injury to people & damage to property or environment depends on the gas cloud size, explosive mass in the gas cloud and the degree of confinement at the time of ignition.

- **Delayed Ignition & Explosion**

In case of delayed ignition of a flammable gas cloud, two physical effects may occur:

  - Flash fire over the whole length of the explosive gas cloud;
  - Cloud explosion that results in blast wave, with typical peak overpressures circular around the ignition source. For generation of overpressure effects, some degree of confinement of the flammable cloud is required;
  - **Table 7.3** below gives an illustrative listing of damage effects caused by peak overpressure.

Table 7.3: Illustrative Damage Effects due to Overpressures (Source TNO)

Peak Overpressure (Bar)	Failure
0.005	5 % Window Shattering
0.02	50 % Window Shattering
0.07	Collapse of a roof of a tank
0.07-0.14	Connection failure of panelling
0.08-0.1	Minor Damage to Steel Framework
0.15-0.2	Concrete block wall shattered
0.2	Collapse of Steel Framework
0.2-0.3	Collapse of self framing Steel panel building

Peak Overpressure (Bar)	Failure
0.2-0.3	Ripping of empty oil tanks
0.2-0.3	Deformation of a pipe bridge
0.2-0.4	Big trees topple over
0.3	Panelling torn off
0.35-0.4	Piping failure
0.35-0.8	Damage to Distillation Column
0.4-0.85	Collapse of pipe bridge
0.5	Loaded Train Wagon overturned
0.5	Brick walls shattered
0.5-1.0	Movement of round tank, failure of connecting piping

- **Pool Fire**

A leak or spill of sufficient size of LDO will result in an accumulation of LDO on the ground or in bund. If ignited, the resulting fire is known as spreading or fixed pool fire.

- **Thermal Effects**

In case of fire, thermal effect is likely to injure or damage to people and objects from incident outcomes. A substantial body of experimental data exists and forms the basis for thermal effect estimation. The consequences caused by exposure to heat radiation is a function of:

- Radiation energy onto the human body [kW/m^2];
- Exposure duration [sec]; and
- Protection of the skin tissue (clothed or naked body).

The following damage distances for thermal radiation have been used:

37.5 kW/m^2	-	Damage to process equipment. 100% lethality in 1min. 1% lethality in 10sec.
12.5 kW/m^2	-	First degree burn for 10 sec exposure
4 kW/m^2	-	First degree burn for 30 sec exposure

- **Maximum Accident Credible Scenarios for Consequence Analysis**

The methodology considered for selection of scenarios comprises following steps:

- From Piping/pipelines used for gas handling, rupture has been considered for consequence analysis;
- From the gas holders, releases of gases have been considered from rupture of connected pipeline; and
- For propane bullets failure, rupture has been considered.

The release scenarios selected for effect and consequence calculations are based on HAZAN methodology used as a technique for hazard identification. The MAC scenarios considered for further consequence analysis are as per given in **Table 7.4.**

Table 7.4: Scenarios for Consequence Analysis

Scenario No.	Activity	Hazards\
1.	Leak of LD gas from LD gas piping connected with gas holder	Dispersion of Toxic Cloud
		Jet Fire/Vapour Cloud Explosion / flash fire
2.	Leak of BF gas from BF gas piping connected with gas holder	Dispersion of Toxic Cloud
		Jet Fire/Vapour Cloud Explosion / flash fire
3.	Catastrophic Rupture of Propane Bullet	BLEVE on Immediate Ignition and Thermal radiation, Overpressure
4.	Hole (*eq.* size 50 mm) in Propane Line, followed by delayed ignition	Jet Fire/ Vapour Cloud Explosion / Flash fire, Overpressure
5.	Release of LDO in Dyke	Pool Fire and Thermal Radiation

7.3 Consequence Analysis

Subsequent to the accidental release of hazardous chemicals, the consequence depends on various factors *e.g.* type and quantity of released hazardous materials, presence and location of an ignition source, meteorological conditions, *etc*. Consequence analysis for the selected accident scenarios has been carried to estimate the vulnerable zones.

It is important to mention that for vapour cloud explosion, pressure wave effect calculations have been carried out based on LEL and UEL of LPG as per well established standard practices.

PHAST' (Version 6.53.1) software of DNV has been used to perform the consequence calculations. PHAST is a consequence and risk assessment software for calculation of physical effects (fire, explosion, atmospheric dispersion) of the escape of hazardous materials. PHAST software allows detailed modelling and quantitative assessment of release of pure chemicals and mixtures.

7.3.1 Consequence Analysis of Release Scenarios

- **Scenario 1: Rupture of Piping (1500 mm size) Connected to LD Gas holder**

Release Rate of LD Gas : 270 kg/s

- **Outcome I : Dispersion of Toxic Cloud of LD Gas**

Concentration Distances (m) for dispersion of toxic cloud of BF gas will be as given below:

Concentration	Concentration Distances (m)			
	1 m/s – F	2 m/s - F	3 m/s -D	3 m/s - B or C
Fatality (7000 ppm)	145.5	143.6	189.9	202.4
IDLH (1500 ppm)	186.2	183.9	240.9	328.7

Foot print for maximum concentration of toxic cloud are shown in **Figure 7.2**.

- **Outcome II : Immediate Ignition - Jet Fire**

Thermal radiation levels at various distances (m) are given below:

Radiation Level	Thermal Radiation Level Distances (m)			
	1 m/s - F	2 m/s -F	3 m/s -D	3 m/s - B or C
37.5 kW/m^2	98.8	105.4	112.7	112.7
12.5 kW/m^2	148.8	151.6	153.8	153.8
4 kW/m^2	204.1	208.0	210.9	210.9

Thermal intensity radii (m) for jet fire are shown in **Figure 7.3.**

- **Outcome III : Delayed (Late) Ignition/ Explosion Effect**

For this scenario, flammable mass (kg), over pressure radius (m) and maximum distance (m) for overpressure level 0.1 bar have been calculated under various wind speed and atmospheric stability classes and presented below:

	1 m/s - F	2 m/s - F	3 m/s - D	3 m/s - B or C
Flammable Mass (kg)	2144.9	1892.3	1553.8	1371.8
Overpressure Radius (m)	112.1	107.5	100.7	96.6
Maximum Distance (m) at Overpressure Level 0.1 bar	532.1	367.5	360.6	326.5

Delayed explosion worst case radii (m) are shown in **Figure 7.4.**

- **Scenario - 2: Rupture of Piping (1500 mm size) Connected to BF Gas Holder**

Release Rate of BF Gas : 111.62 kg/s

- **Outcome I : Dispersion of Toxic Cloud of BF Gas**

Concentration distances (m) for dispersion of toxic cloud of BF gas will be as given below:

Concentration	Concentration Distances (m)			
	1 m/s – F	2 m/s - F	3 m/s -D	3 m/s - B or C
Fatality (7000 ppm)	69.9	78.0	111.9	129.1
IDLH (1500 ppm)	89.8	98.7	191.3	246.3

Foot print for maximum concentration of toxic cloud are shown in **Figure 7.5**.

- **Outcome II : Immediate Ignition - Jet Fire**

Thermal radiation levels at various distances (m) are given below:

Radiation Level	Thermal Radiation Level Distances (m)			
	1 m/s - F	2 m/s -F	3 m/s -D	3 m/s - B or C
37.5 kW/m^2	31.9	66.5	116.4	116.4
12.5 kW/m^2	59.9	104.2	124.2	124.2
4 kW/m^2	106.9	125.01	135.1	135.1

Thermal intensity radii (m) for jet fire are shown in **Figure 7.6.**

- **Outcome III : Delayed (Late) Ignition/ Explosion Effect**

For scenarios of delayed ignition, flammable mass (kg), over pressure radius (m) and maximum distance (m) at overpressure level 0.1 bar have been calculated under various wind speed and atmospheric stability classes and presented below:

	1 m/s - F	2 m/s - F	3 m/s - D	3 m/s - B or C
Flammable Mass (kg)	507.4	448.9	355.9	312.9
Overpressure Radius (m)	47.7	45.8	42. 4	40.6
Maximum Distance (m) at Overpressure Level 0.1 bar	157.7	145.6	142.3	130.6

Delayed explosion worst case radii (m) are shown in **Figure 7.7.**

- **Scenario - 3 :Catastrophic Rupture of Propane Bullet**

- **Outcome I : Immediate Ignition/ BLEVE**

Normal storage capacity : 16 MT

Action : Catastrophic Rupture followed by BLEVE

Duration of Fire Ball, (s)	10.31
Radius of Fire Ball, (m)	73.16
Thermal Radiation Intensity	**Distance (m)**
37.5 kW/m^2	15.4
12.5 kW/m^2	190.6
4 kW/m^2	372.6

Thermal Radiations vs distance are shown in **Figure 7.8.**

- **Outcome II : Explosion Effects: Early Explosion**

Flammable Mass (kg) at Overpressure Levels	14630
0.1 bar Overpressure Distance (m)	258.2

Early explosion overpressure vs distance are shown in **Figure 7.9.**

- **Outcome III : Explosion Effects: Delayed Late Ignition**

	1 m/s - F	**2 m/s - F**	**3 m/s - D**	**3 m/s - B or C**
Flammable Mass generated (kg)	9073.6	8789.3	9644.5	8937.6

Maximum concentration footprints are as given in **Figure 7.10**.

- **Overpressure Radius and Maximum Distance (m) at Overpressure (0.1 bar) Level:**

	1 m/s - F	**2 m/s - F**	**3 m/s - D**	**3 m/s - B or C**
Overpressure Radius (m)	220.2	217.9	224.8	219.1
Maximum Distance (m) at Overpressure Level 0.1 bar	270.2	277.8	284.7	279.1

- **Scenario - 4 : Hole (*eq.* size 50 mm) in Propane Line**

- **Outcome I : Immediate Ignition/ Jet Fire**

Release rate 3.32 kg/s

Radiation Level	Thermal Radiation Level Distances (m)			
	1 m/s - F	2 m/s -F	3 m/s -D	3 m/s - B or C
37.5 kW/m^2	19.4	20.2	21.0	21.0
12.5 kW/m^2	25.1	25.7	26.3	26.3
4 kW/m^2	32.5	32.7	32.9	32.9

Thermal Intensity Radii for Jet Fire are as given in **Figure 7.11;**

- **Outcome II : Explosion Effects: Delayed Late Ignition**

	1 m/s - F	2 m/s - F	3 m/s - D	3 m/s - B or C
Flammable Mass generated (kg)	0.96	0.89	0.69	0.64

- **Overpressure Radius and Maximum Distance (m) at Overpressure (0.1 bar) Level:**

	1 m/s - F	2 m/s - F	3 m/s - D	3 m/s - B or C
Overpressure Radius (m)	10.4	10.1	9.3	9.1
Maximum Distance (m) at Overpressure Level 0.1 bar	50.4	50.1	39.3	39.1

Late explosion worst case radii are as given in **Figure 7.12.**

❑ **Scenario - 5 : Catastrophic Rupture of LDO Tank**

- **Outcome** : **Fixed Pool followed by Immediate Ignition, Outcome Pool Fire**

Consequence calculations for leakage of LDO in dyke area have been carried out as per the details given below:

a. Pool Fire Heat Radiation

Pool fire is possible due to delayed Ignition. The damage distances are as per given below in case of exposure duration with protected human body -20 seconds:

Radiation Level	Thermal Radiation Level Distances (m)			
	1 m/s - F	2 m/s -F	3 m/s -D	3 m/s - B or C
37.5 kW/m^2	Not Reached	Not Reached	Not Reached	Not Reached
12.5 kW/m^2	16.2	19.3	20.1	19.4
4 kW/m^2	40.6	49.1	53.9	53.2

Thermal Intensity for pool fire are shown in **Figure 7.13.**

b. Vapour Cloud Explosion:

No explosive mass will be formed from the pool.

7.4 Frequency

For frequency analysis, the failure rate is estimated by counting the different items. The failure rate for a certain item is broken down into the correct proportions for required release rate bands. The overall frequency for a particular set of equipment is calculated as:

$Fr = \Sigma F N$ where:

Fr	=	total failure frequency/per year/per unit
F	=	individual item frequency/per year
N	=	number of items

Failure modes of all components giving rise to similar release rates have been clustered and all corresponding failure frequencies have been added up to calculate the occurrence probability, since release could occur due to the failure of any of the components.

- **Failure Frequencies & Data Sources**
- **Probability Determination for Gas Holders**

For gas holders, accident frequencies are determined by the fault tree analysis and the event trees analysis. Input data of the frequency of loss of containment (LOCs) events were taken from the literature (Purple, 1999). For example major accident scenario i.e. a rupture of the inlet piping before the first fitting of water sealed gas holder and subsequent toxic gas release from the gas holder is taken and event tree is given in **Figure 7.14.** The frequency of gas holder ruptures is $f = 5x10^{-6}$ events/year (purple book) from the presented consequence determined by means of the event tree. Primarily the dispersion of combustion gases as a toxic substance is assessed in detail, because in this case the largest affected area is expected outside the plant establishment.

Further the scenario of less serious accident i.e. LD gas release is considered and fault trees for LD gas release from gas holder is given in **Figure 7.15**.

- **Probability Determination for Propane Facilities**

The E & P Forum database ('Hydrocarbon leak and ignition data base', Report, The Oil Industry International Exploration & Production Forum (E&P Forum)) for leaks and ignition probabilities gives the cumulative frequencies for all holes sizes up to full bore for piping and other equipment. The data are taken from this database and used for this QRA are listed below:

a. Pressure Vessels

This category includes the pressure vessel itself but excludes all valves, piping, fittings beyond the first flange and the flange.

- ***Failure Frequency :*** 1.5×10^{-4} per vessel year
- Hole size distribution

Hole size, (dhole)	P(deqv < dhole)
25 mm	0.54
50 mm	0.89
150 mm	0.96
full bore	1.00

(Full bore is usually taken as the inner diameter of the largest connecting pipe)

b. Piping

- ***Large Hole Size*** *(For piping dia d < 6" and 6"<d<12")*

  Full bore rupture ruptures for d< 6" is considered and the failure frequency taken is 1.8×10^{-6} /m. yr.

  - ***Small Hole Size***

    The failure frequency taken is 1.26×10^{-5} /m. yr.

c. Flanges

For flange leak failure frequency taken is 3.5×10^{-6} / flange.

d. Base flexible hose failure frequency

For flexible hose, failure frequency is taken as 4.0E-6/hr

e. Catastrophic rupture of storage tanks

Catastrophic failure frequency of tanks is taken as 1E^{-6} tank -1 yr. –1.

Frequency Analysis Results

Frequency Analysis results are presented below for base case operations and proposed operations:

- **Propane Bullet Failure (Largest Connection)**

Catastrophic failure	$1.0E^{-5}$/yr
No. of Bullets	2
Delayed Ignition probability	0.2
Accident likelihood	$4.0E^{-6}$/yr

- ***Propane Bullet Bottom Line Failure (Largest Connection)***

Catastrophic Failure	$1.0\ E^{-5}$/yr
Bottom Line Failure	1.8E-6/yr m x 10 m
Valve Failure	$9.2E^{-6}$/yr x 3
No. of Bullets	2
Delayed Ignition Probability	0.2
Accident Likelihood	2.23E-5/yr

Equipment Failure Frequency

The data sources referred for failure frequency is E & P Forum (Oil Industry International Exploration & Production Forum), Frequency database from TNO and Failure frequency data from the Rijmond Report (COVO Study). The failure frequencies have been distributed for three different failure sizes, Rupture, Hole (50mm equivalent hole size) and Leak (13 mm equivalent hole size).

Equipment	Rupture	Hole	Leak
Process piping	4.0×10^{-6} /m yr	6.0×10^{-6} /m yr	1.6×10^{-5} /m yr
Storage Tank	1×10^{-6} /yr	1×10^{-5} /yr.	1×10^{-4} /yr.
Pumps	1×10^{-4} /yr	1×10^{-3} /yr.	1×10^{-2} /yr.
Valves	9.2×10^{-6} /yr	1.8×10^{-5} /yr.	5.3×10^{-5} /yr.
Flanges	-	3.52×10^{-6} / flange yr.	8.5×10^{-5} / flange yr.
Tapping	-	-	1×10^{-4} /yr.

7.5 Risk Analysis

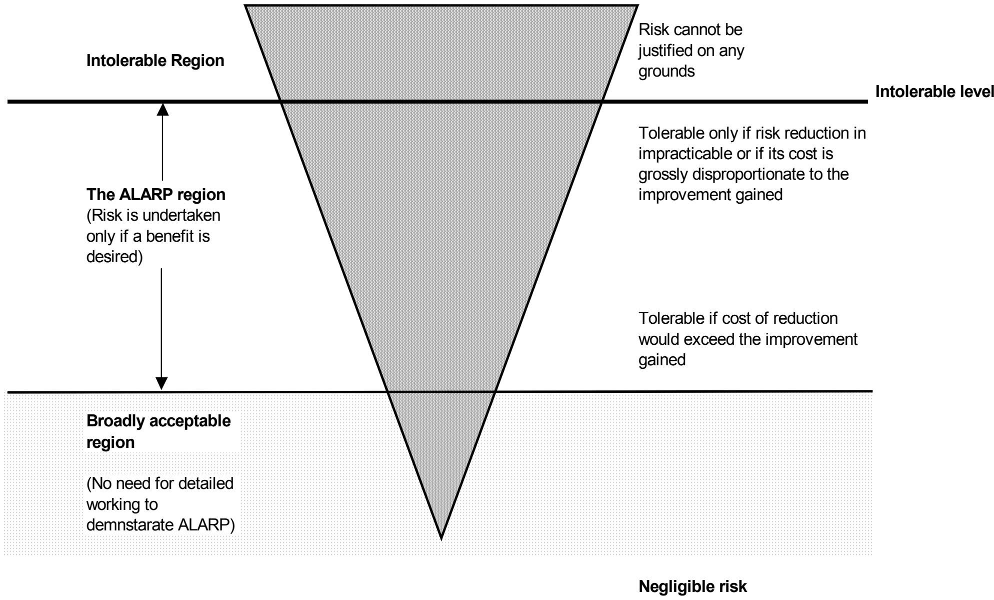
Risk is defined as the unwanted consequence of a particular activity in relation to the likelihood that this may occur. Risk thus comprises of two variables: magnitude of consequences & the probability of occurrence. It thus finds application as a decision making tool in situations where judgment has to be made about the tolerability of the risk posed by an existing/proposed activity. The normal approach adopted is to relate the risk measures obtained to risk acceptance criteria. The risk criteria simply attempt to establish whether Risk is "tolerable". Below is a list of words generally in use in risk analysis.

1. **ACCEPTABLE RISKS**: No risk should be called "acceptable". It might be better to say that the activity may be acceptable generally, but the risks can only ever be tolerable;
2. **TOLERABLE RISKS**: are the risks which are expected to bear without undue concern ; and
3. **NEGLIGIBLE RISKS**: are risks so small that there is no cause for concern.

Risk criteria, if they are to be workable, recognize the following:

- Level of risk that is so high that it is considered unacceptable or intolerable regardless of the benefits derived from an activity;
- Level of risk that is low enough as to be considered negligible; and
- Level of risk in between the two as mentioned above is to be considered tolerable subject to being reduced to a level i.e. "As Low As is Reasonably Practicable (ALARP)".

The ALARP (As Low As is Reasonably Practicable) principle seeks to answer the question "What is an acceptable risk?" The definition may be found in the basis for judgment used in British law that one should be as safe as is reasonably practicable. Reasonably practicable is defined as implying "that a computation must be made in which the quantum of risk is placed on scale and the sacrifice involved in the measures necessary for averting the risk (whether in money, time, or trouble) is placed on the other, and that, if it be shown that there is a gross disproportion between them – risk being insignificant in relation to the sacrifice – the defendants discharge the onus upon them".



ALARP Criteria

The effects-consequence and frequency analyses for the selected releases have been summarized in previous sections. In this section results of Risk summation are presented as following:

Individual Risk is the probability of death occurring as a result of accidents at a installation or a transport route expressed as a function of the distance from such activity. Such a risk actually exists only when a person is present at that spot. The unit of Individual Risk is fatality likelihood of an individual per year. Individual risk for a single accident scenario is calculated as:

Individual Risk = Accident frequency x Response fraction x Weather class probability x Wind direction probability

Response fraction is the percentage of the exposed population who would be lethally injured when exposed to the calculated thermal radiations over the exposure duration. In case of a vapour cloud explosion, other probabilities such as ignition probability, probability of flash fire versus explosion also are taken into account.

The calculation of individual risk at a geographical location near a site assumes that the contributions of all incident outcome cases are to be added. Thus, the total individual risk at each point is equal to the sum of the individual risks resulting from all incident outcome cases associated with the plant.

There is no specified risk acceptance criterion in India for Individual Risk levels. A review of risk acceptance criteria in use in other countries indicates the following:

For industrial plants, Individual Risk Criteria have been developed by various countries and the review indicates that Individual Risk of fatality to the members of the public outside the installation boundaries may be adopted between 10^{-5} per year (in populated areas) for intolerable risk and lower than 10^{-6} per year for negligible risk. The region in between is the so-called ALARP region where risk is acceptable subjected to its being **A**s **L**ow **A**s **R**easonably **P**racticable (the ALARP principle).

- **Findings of Risk Summation**

The individual risk (10^{-5} /yr) for gas holders is within ALARP region and tolerable. The activities at steel plant also lies in ALARP region and tolerable.

7.6 Risk Reduction Measures

Risk Assessment study provides a quantitative technique for assessing the significance of the impact of any facility on its external environment, a means for highlighting key areas for greater attention and a tool for comparing alternative options. Though, it can not substitute for close attention to the fundamentals of safety throughout the design process or for design reviews.

For risk reduction, attempts should be made to either reduce inventories that could get released in the event of loss of containment or failure likelihood's or both as feasible. Risk Assessment identifies the dominant risk contributors, which enables prioritisation of plants/section that deserve special attention in terms of inspection and maintenance in particular and over all safety management as a whole.

a) Gas Holders

- Gas holders should be provided to maintain a positive line pressure in gas network;
- The gas line pressure should be maintained by a floating piston;
- The level of holder should be monitored and recorded on hourly basis in the logbook;
- The leakage of gas inside the gasholder should be prevented by maintaining a certain level (160mm) of oil (Servo Seal) in the sealing arrangement. The oil should be

maintained by re-circulating the oil through pumps;

- Fresh oil should be added to make up the losses due to contamination of oil;
- The seals of the gasholder (sealing oil level) should be checked on alternate day to ensure safety and recorded in the logbook;
- At least two numbers of portable CO gas detectors should be provided with concerned operating staff to monitor CO concentration while working Gas Holders premises. The safe limit for 8 hours of working is below 50 ppm of CO concentration in the vicinity. There should be also provision of continuous CO detection and monitoring system. This system should give alarm if CO concentration exceeds 50 ppm; and
- The safety device, such as limit switches, shut off bell along with other mechanical and electrical system should be inspected on weekly basis jointly with gas safety and electrical and recorded.

b) Propane Handling

- Safety Relief Valve should be tested in once every year by a third party as a statutory requirement as per Static & Mobile Pressure Vessel Rule (SMPV) – 18;
- Hydraulically pressure testing of the storage tank should be carried once in every 5 years by a third party as a statutory requirement as per SMPV Rule – 19;
- It should be ensured that the gas shut off valves to be installed on gas lines are always in working order and operable on auto mode with reference to fluctuations in gas pressure for the safety;
- Ultrasonic thickness measurement of critical locations on gas lines should be carried out once in 2 years. If thickness reduction is found to be more than 30%, it must be replaced;
- Illumination measurement at different plant locations should be carried out especially in control rooms and monitoring should be done once in two years;
- Tank Trucks should has suitable spark arrestor, approved by CCOE, Nagpur, properly fixed to exhaust;
- It carries DCP type Fire Extinguisher" in easy accessible and removable position; written with Truck No, date of checking and charging; and
- No loose electrical wiring / terminal should be allowed; all electrical wiring should be properly insulated.

c) Sinter Plant

- Water sprinkling system should be provided for fire prone belts *viz* sinter conveyors;

- Fire Fighting System should be provided for yard conveyors; and
- Infrared temperature scanner should be installed on the straight line cooler output with temperature indication and a tripping circuit (when sinter temperature exceeds 100°C).

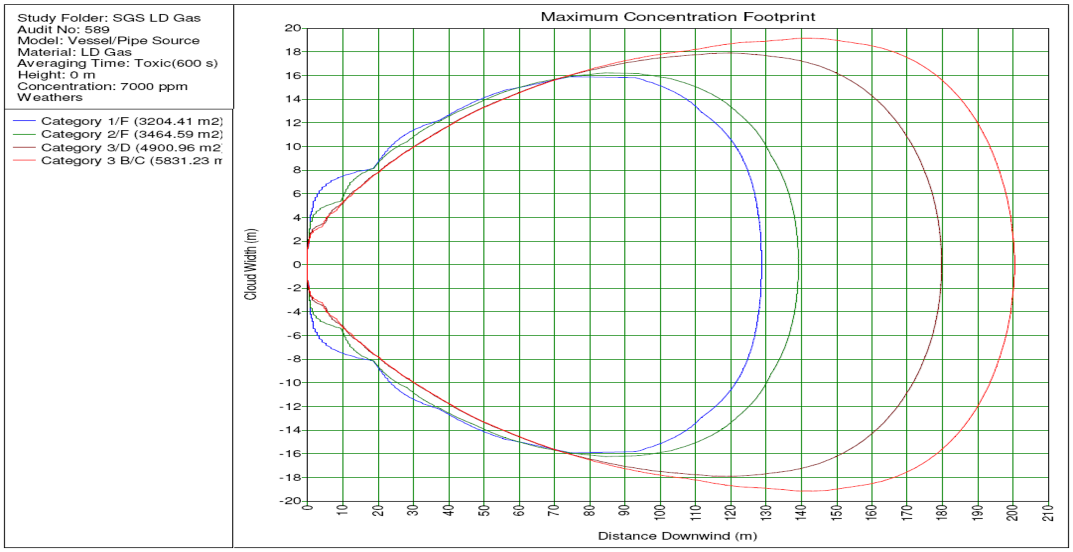


Figure 7.2: Maximum Concentration Footprint

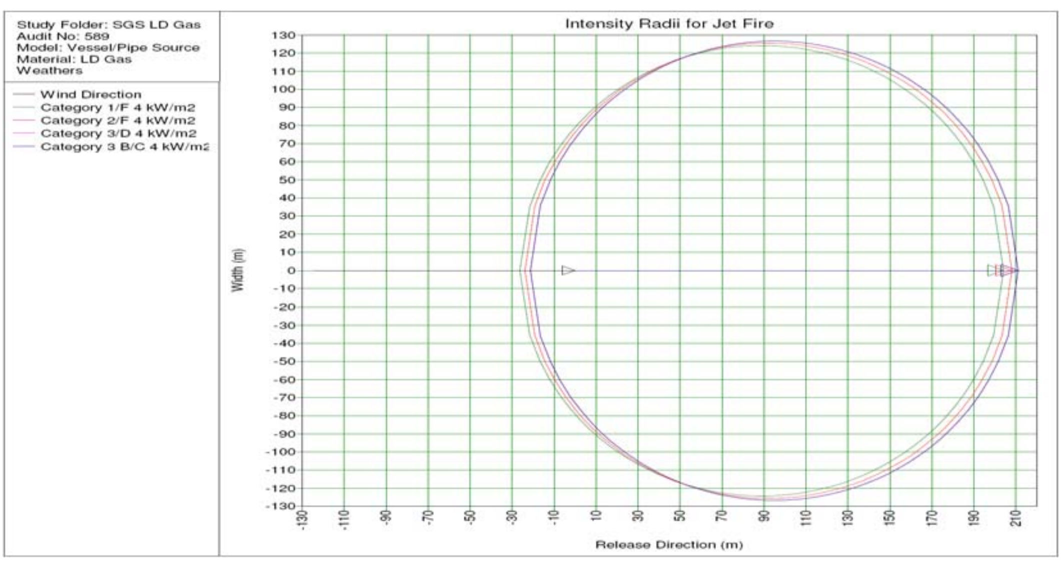


Figure 7.3: Thermal Intensity for Jet Fire

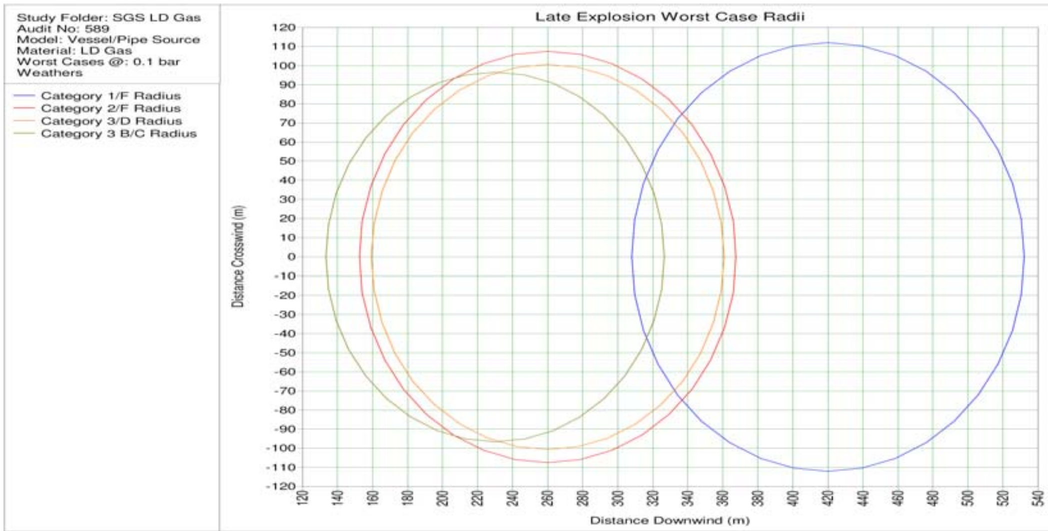


Figure 7.4: Delayed Explosion Worst Case Radii

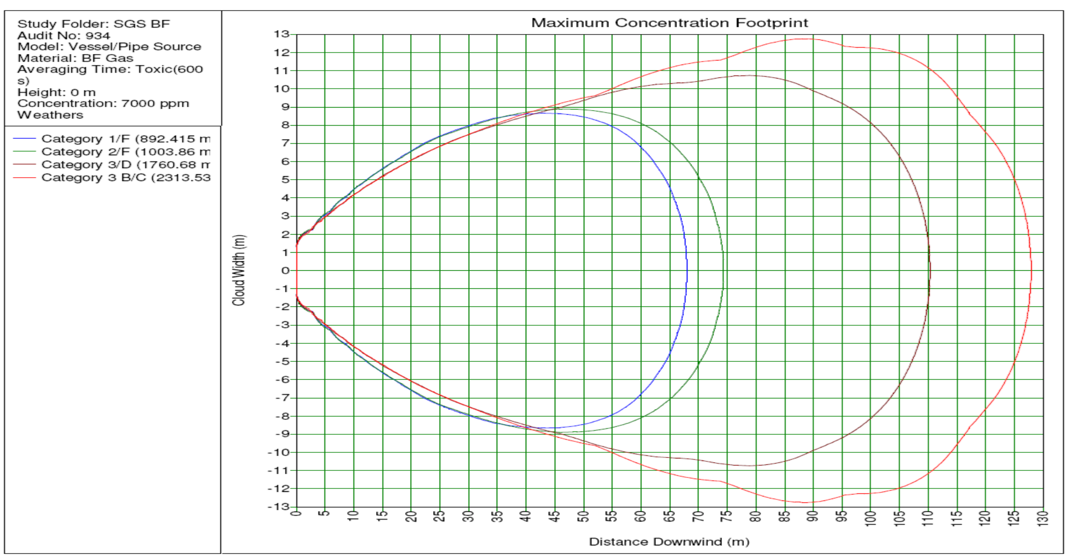


Figure 7.5 : Delayed Explosion Worst Case Radii

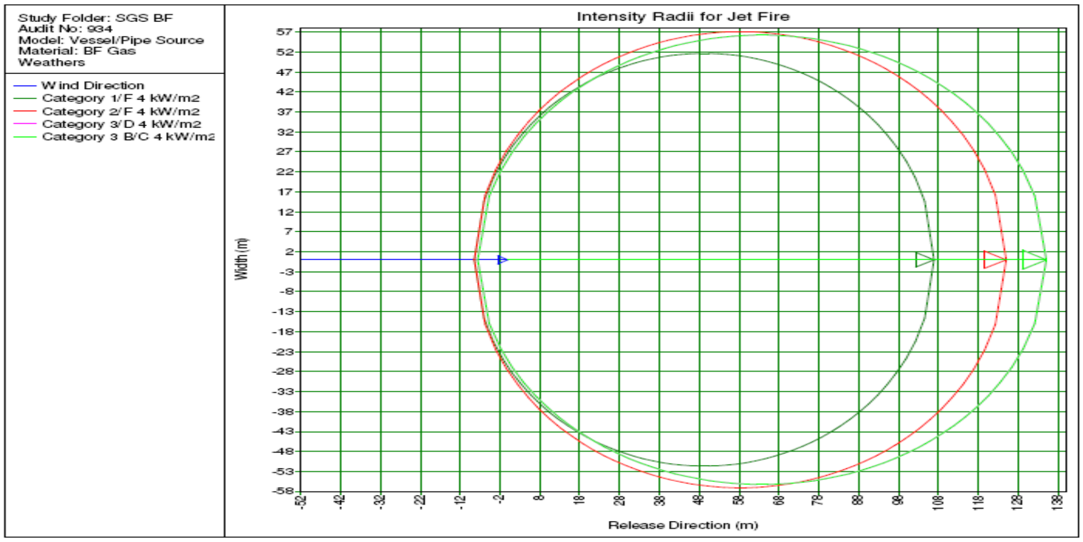


Figure 7.6 : Delayed Explosion Worst Case Radii

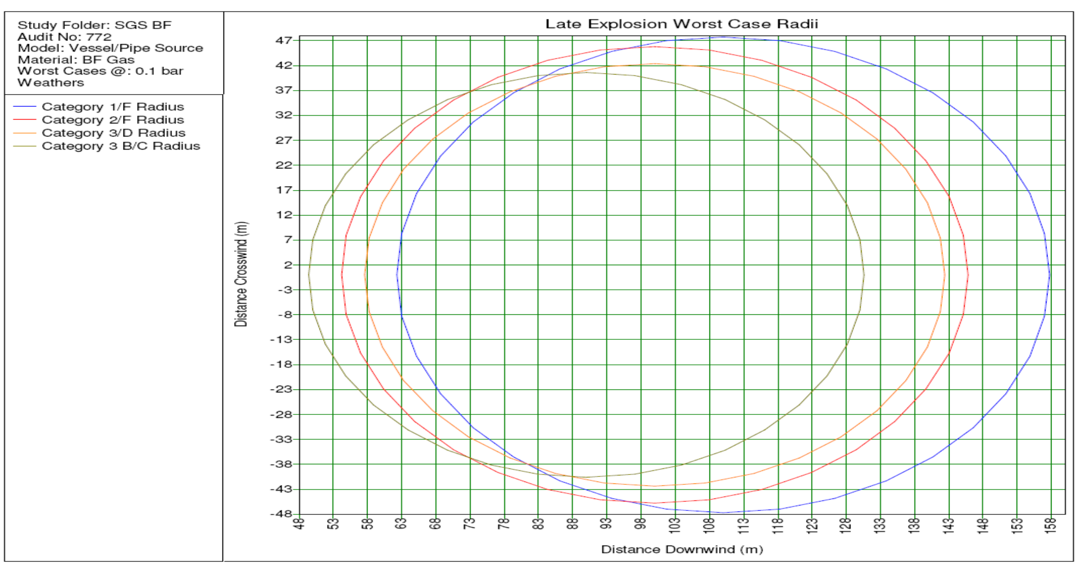


Figure 7.7 : Delayed Explosion Worst Case Radii

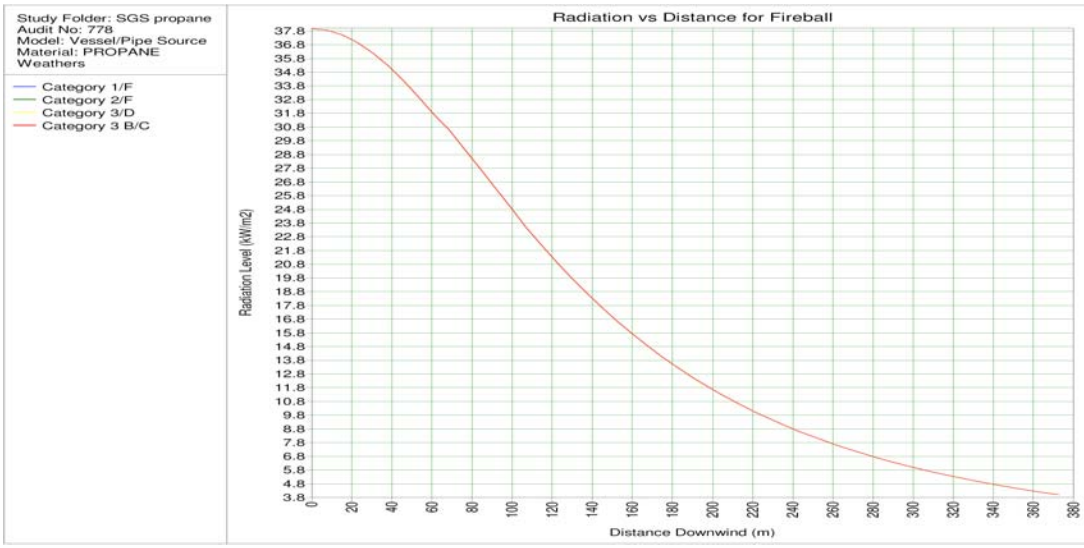


Figure 7.8 : Radiation vs Distance for Fireball

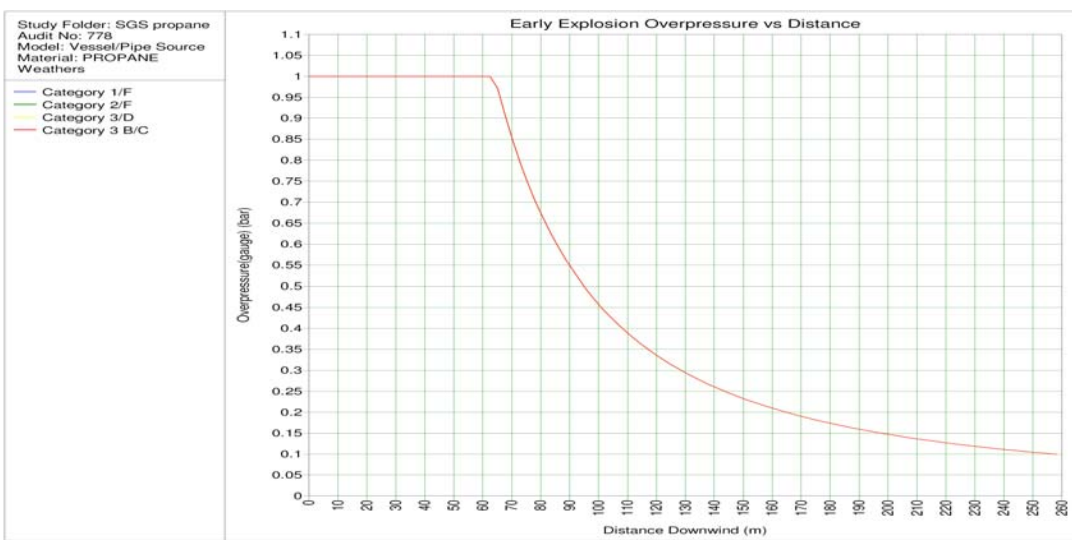


Figure 7.9 : Early Explosion Overpressure vs Distance

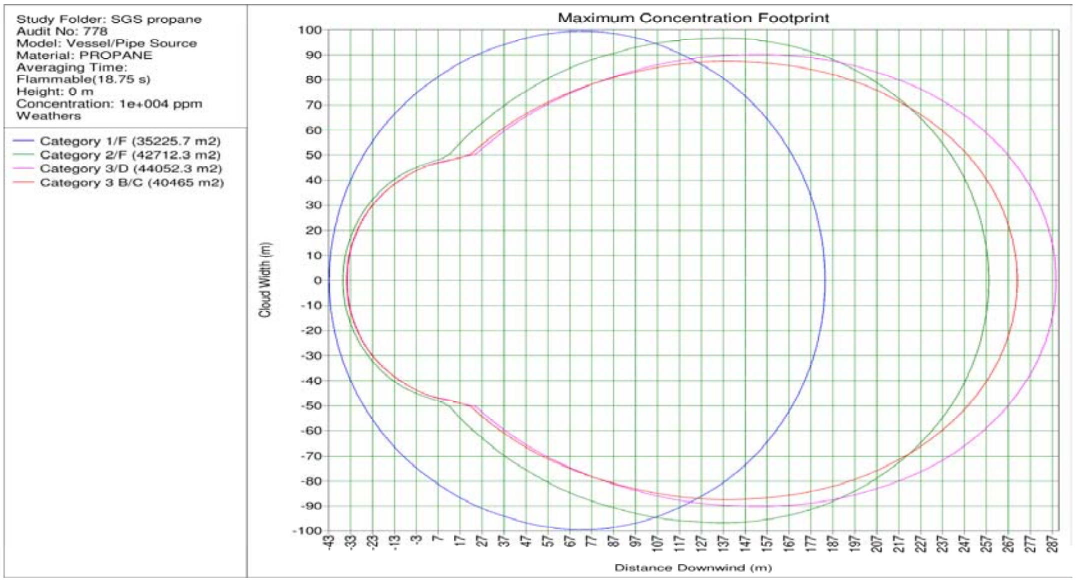


Figure 7.10 : Maximum Concentration Footprint

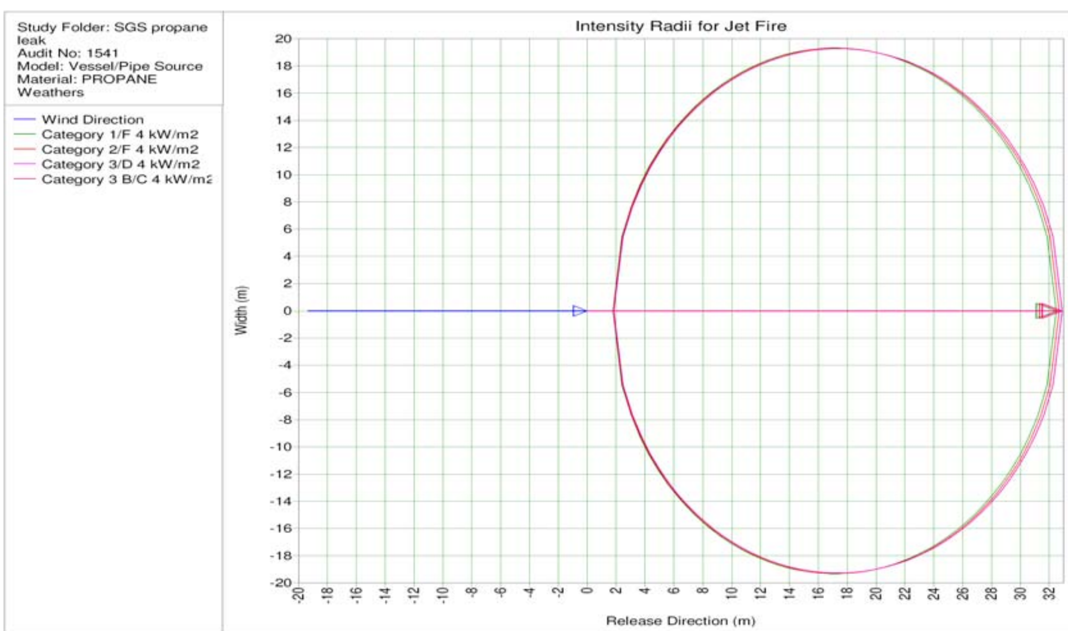


Figure 7.11 : Intensity Radii for Jet Fire

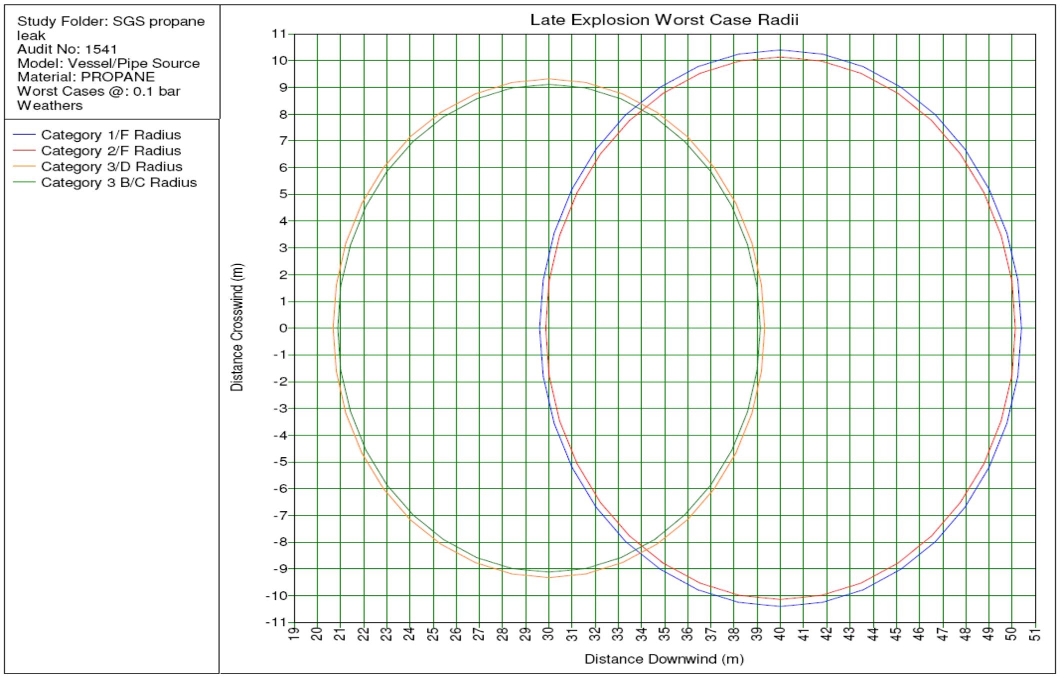


Figure 7.12: Late Explosion Worst Case Radii

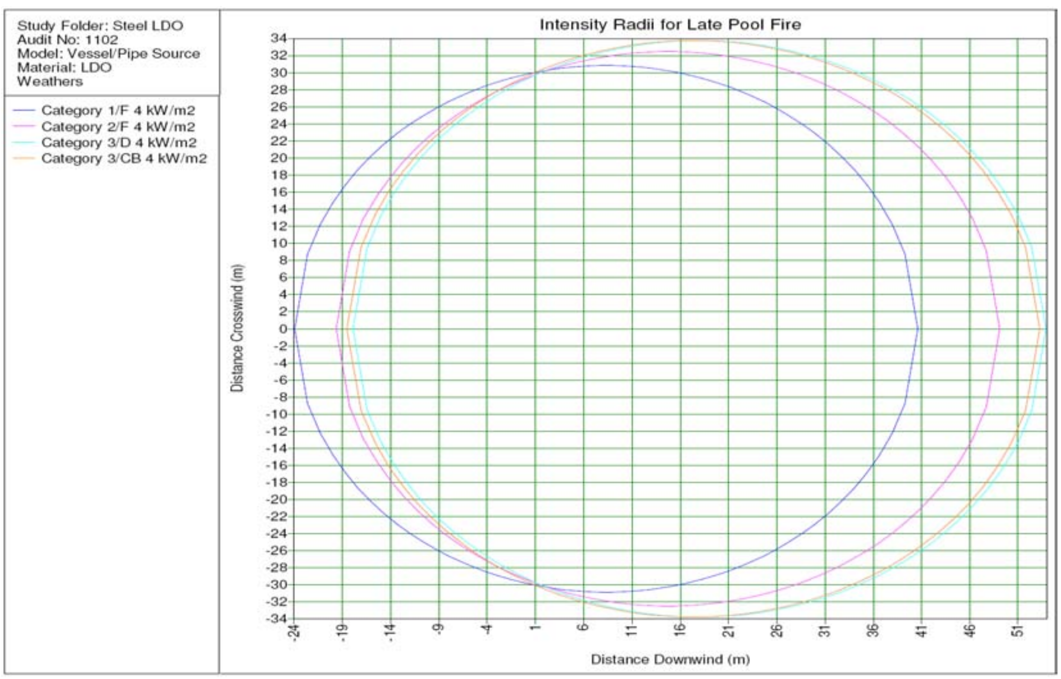


Figure 7.13: Thermal Intensity for Late Pool Fire

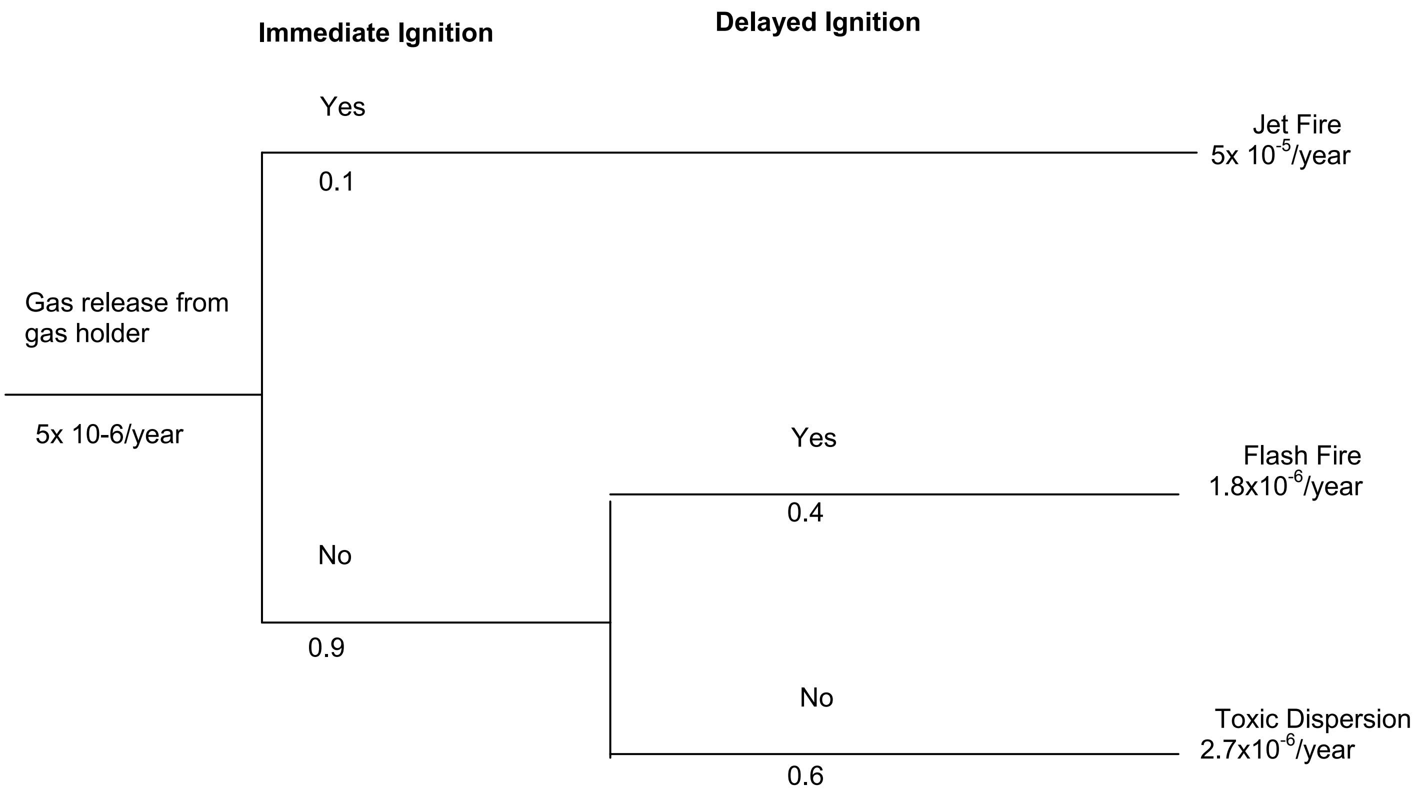


Fig. 7.14 : Event Tree for Gas Release from the Gas Holder

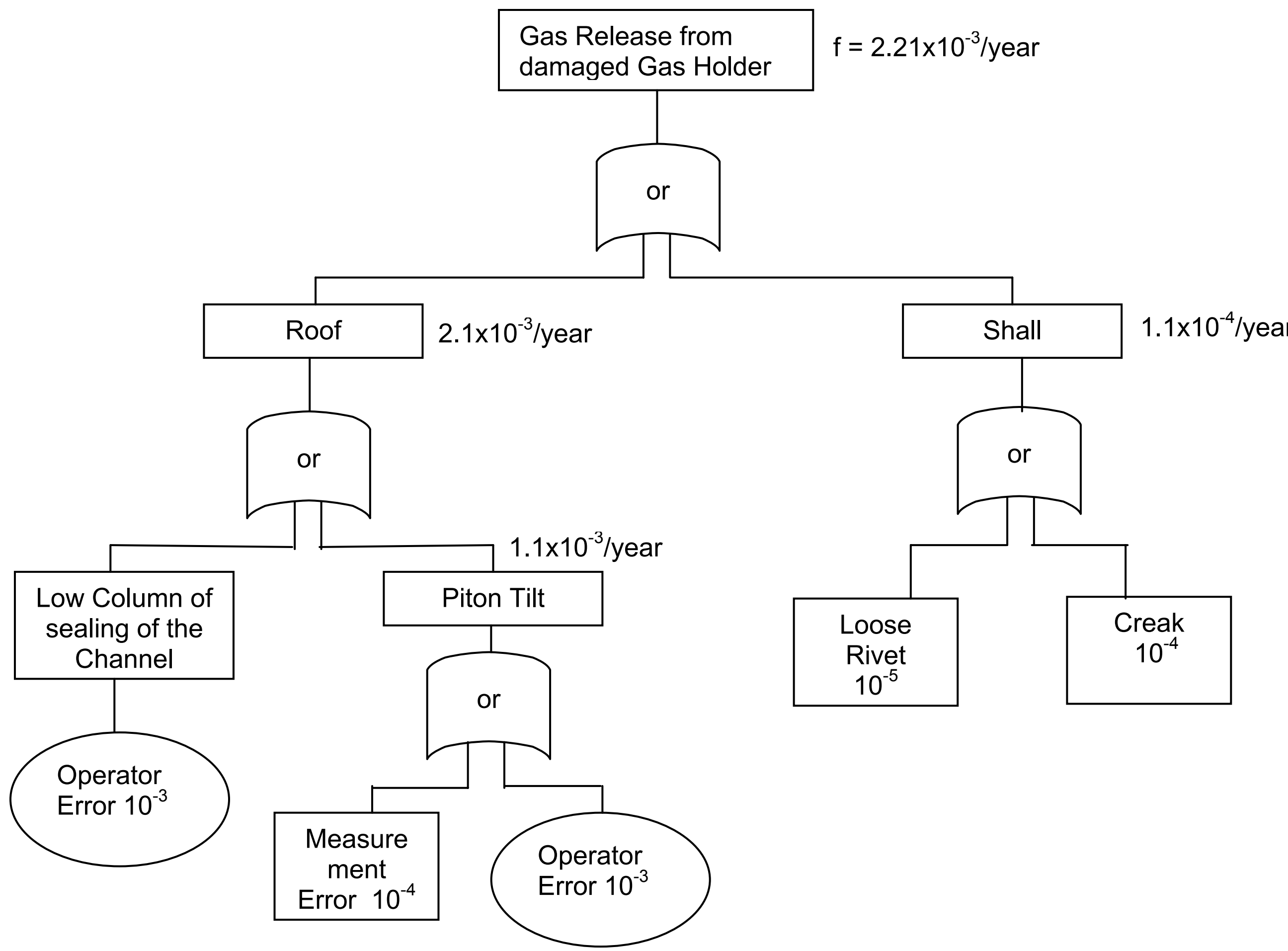


Figure 7.15: Fault Tree for Gas Release from the Gas Holder