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Quantitative Risk Assessment of City Gas Distribution Networks in India: Enhancing Safety with PHAST Modeling

Journal of Electrical Systems

Abstract: - City Gas Distribution (CGD) networks in India have evolved remarkably since their inception in the 1960s and 1970s, expanding from their initial industrial use in metropolitan areas like Mumbai, Delhi, Surat, Indore, and Mathura to serve domestic, commercial, and industrial consumers across multiple cities. This paper presents a comprehensive Quantitative Risk Assessment (QRA) of CGD networks in Indian cities, emphasizing safety, reliability, and sustainability. The scope includes a QRA of all existing infrastructures and facilities within the geographical areas of each CGD network. By analyzing historical incident data and utilizing advanced modeling techniques, potential hazards are identified, their probabilities estimated, and their consequences evaluated. The study highlights the critical importance of implementing robust risk mitigation measures to enhance the safety and reliability of CGD networks, ensuring sustainable urban energy distribution. Additionally, the integration of eco-friendly fuels like compressed biogas and LNG is addressed, underscoring the need for continuous improvement in risk management practices. Risk assessments were conducted using PHAST-8.22 software, and risk reduction measures were proposed based on the assessed risk levels. The adopted methodology includes the study of pipeline and terminal operations, examination of operating parameters, hazard identification, probability-based risk analysis, and the formulation of risk reduction strategies.

Keywords: City Gas Distribution, Quantitative Risk Assessment, Risk Mitigation, Pipeline Operations, Hazard Identification, Sustainable Energy, PHAST-8.22.

1. INTRODUCTION

City Gas Distribution (CGD) networks in India have grown significantly since their inception in the 1960s and 1970s, initially serving industrial consumers around Mumbai and expanding to cities like Bharuch, Ankleshwar, and Surat through pioneers such as Gujarat Gas Company Ltd. Subsequent expansions by Mahanagar Gas Limited in Mumbai and Indraprastha Gas Limited in Delhi extended services to residential, commercial, and industrial sectors. Recent advancements include the addition of over a million PNG connections, establishment of numerous CNG stations across various cities, and expansion into new regions like Daman & Diu, Bhubaneswar, and Jalandhar. The CGD infrastructure includes high-pressure steel pipelines for the primary network and MDPE pipelines for lower-pressure distribution. This research focuses on conducting a comprehensive Quantitative Risk Assessment of Indian CGD networks to enhance safety, reliability, and sustainability using advanced modeling and historical incident analysis.

Process Description

The city gas distribution infrastructure includes underground Steel and MDPE pipelines, which necessitate ongoing vigilance for smooth operations. GAIL Limited, authorized by PNGRB in various cities, has extensively developed CGD infrastructure to support its business operations. This infrastructure enables GAIL to supply piped natural gas to domestic, commercial, and industrial customers, while also providing CNG for vehicles in the transport sector. The CGD infrastructures mainly encompass the following:

a) Steel Pipeline infrastructure: At CGS, natural gas is received at the Pressure more than 19 Kg/cm2G. The same is regulated to 19 Kg/cm2G and supplied to CGD entity downstream of CGS after the measurement of the same through the gas meters. The gas is transported through the Steel Pipeline at 19 kg/cm2G within the city

b) MDPE Pipeline Infrastructure:

i. MDPE Pipeline: MDPE pipelines to transport gas at low pressure from the DRS to customer points, serving domestic, commercial, and industrial sectors. The DRS regulates gas pressure from 19 Kg/cm2G to 4 Kg/cm^{2}G,

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ensuring efficient distribution through MDPE pipelines at 4 Kg/cm2G pressure downstream.

ii. District Regulatory Stations (DRS): The city gas distribution system includes filtration, regulation, and metering systems for gas. Gas pressure is reduced to distribution levels (typically 4 bar or 6 bar as per design) in the District Regulating Station (DRS) for transmission and supply. The DRS is directly connected to the main steel pipeline.

iii. Meter Regulating Stations (MRS): It includes regulators and meters to measure gas supplied to consumers, adjusting pressure to meet specific plant or unit needs in millibars. It serves as the custody transfer point for customers, ensuring seamless gas flow into their downstream pipelines.

iv. Gas Meters: Meters installed at consumer premises measure both gas flow and consumption, serving as custody transfer meters. Consumer billing is based on readings from these meters, which are installed in commercial and residential buildings.

v. Regulators: Regulators adjust gas pressure to desired levels and are installed at commercial and residential consumer locations. They ensure gas is delivered at the appropriate low pressure required for kitchen burners.

vi. Risers: It is a vertical GI pipe, connects from the transition fitting to the regulator and extends straight up to the top of the building, enabling individual house connections for PNG supply.

vii. Transition Fittings (TF): TF is an arrangement used to connect MDPE pipe at one end and GI pipe at the other end. It facilitates the connection of MDPE pipes to GI pipes for supplying PNG to various customers.

c) CNG: CNG stations use compressors—either engine-driven (1200 SCMH capacity) or motor-driven (650 SCMH capacity)—to raise gas pressure from 14-19 Kg/cm2 to 255 Kg/cm2. Gas stored in cascades at 250 Kg/cm2 is dispensed at 200 Kg/cm2 to vehicles via stainless steel tubes in city gas distribution networks.

2. QUANTITATIVE RISK ASSESSMENT

2.1 Introduction

Quantitative Risk Assessment (QRA) plays a critical role in evaluating safety performance by using quantitative methods to anticipate, assess, and mitigate potential hazards in operational systems. It identifies potential failure scenarios, analyzes root causes, and evaluates the consequences and likelihood of incidents occurring, prioritizing risks based on severity and probability. In City Gas Distribution networks, QRA focuses on understanding the risks associated with natural gas distribution, including potential leaks and catastrophic failures. It aims to quantify risks, assess impacts on people and property, and recommend effective risk mitigation strategies to enhance safety.

2.2 Risk Concept

Risk, generally defined, quantifies potential economic loss or human injury based on the likelihood and severity of occurrence. It consists of two key factors: the magnitude of potential consequences and the probability of those consequences happening. Risk assessments commonly yield results in terms of Individual Risk, concerning the impact on individuals, and Societal Risk, which evaluates the broader impact on groups or communities.

Risk Assessment categorizes risks into:

Individual Risk: Measures the probability of fatalities from accidents at specific sites or along transport routes.

Societal Risk: Evaluates the cumulative risk to communities from incidents causing multiple fatalities. Tools like F-N curves track these risks over time or distance.

Assessing societal risk involves subjective judgments and considers various factors to determine acceptable risk levels. This approach is crucial in sectors like city gas distribution for effective risk management.

3. METHODOLOGY

Hazard identification and risk assessment involve several sequential steps:

I. Identification of the Hazard: By assessing the properties of distributed gases, evaluating equipment setup and maintenance, and considering external factors such as third-party interference and environmental conditions. This comprehensive evaluation aims to anticipate and mitigate risks, ensuring the safety, reliability, and protection of the distribution network and local communities. Recognizing potential sources of harm or danger, such as specific equipment failures or process vulnerabilities.

II. Assessment of the Risk: Potential impacts on personnel, infrastructure, and the environment are evaluated through identifying accident scenarios, assessing their likelihood, and analyzing consequences. Risks are evaluated against specific criteria to determine their acceptability, guiding the implementation of necessary measures to mitigate risks and uphold safety standards. Evaluating the likelihood and consequences of identified hazards to determine their overall risk level.

III. Elimination or Reduction of the Risk: In CGD, risk reduction focuses on minimizing the likelihood and impact of accidents through proactive measures. This includes enhancing operational safety to protect personnel, infrastructure, and the environment. By systematically addressing these opportunities, CGD operators ensure effective risk mitigation and uphold high safety standards across the distribution network.

IV. Assessment of Risks: The assessment of risks is based on the consequences and likelihood. Consequence assessment involves evaluating potential damages from incidents like pressurized pipeline ruptures, which can cause Jet fire, Flash fire and explosions. Likelihood assessment estimates incident probabilities using historical data or advanced models such as fault trees, ensuring accurate risk prediction in this study.

3.1 Reduction of the Risk in CGD:

Implementing measures to mitigate risks, aiming to prevent incidents or minimize their impact. The key aspects of risk assessment and risk reduction in City Gas Distribution are:

a) Assessment of Risk in City Gas Distribution: Evaluates potential consequences and the likelihood of incidents such as equipment failures or gas leaks. Consequence estimation assesses damage or harm, guiding preventive and emergency response measures to maintain CGD system safety.

b) Likelihood Assessment in CGD: Estimates incident frequencies using historical data or advanced models like fault trees. Software models analyze data to predict probabilities of incidents, aiding in planning preventive actions and enhancing operational safety.

c) Risk Assessment Integration: Combines consequences and likelihood to measure overall risk. By estimating risks associated with scenarios, CGD operators make informed decisions to mitigate risks and enhance system reliability.

d) Risk Reduction Measures in CGD: Focuses on prevention through safer designs and asset integrity management, aiming to lower incident likelihood. Detection systems and emergency procedures like shutdowns and firefighting help control and mitigate incidents, ensuring prompt response to emergencies.

3.2 Scale of Qualitative Risk Analysis

Qualitative Risk Analysis provides valuable insights by assessing the impact of potential scenarios on organizations and employees, focusing on consequences that may not be easily quantifiable in monetary terms. This approach involves evaluating both the severity and likelihood of undesirable events to determine appropriate actions for risk reduction or mitigation. Risk is the product of probability P and severity S.

In this method, risks are evaluated using a straightforward formula:

$R = P \times S$

were,

P- Probability of occurrence, categorized into ranges from very low to very high.

S- Severity of consequences, ranging from no injury to serious financial or health impacts.

Table 1: Probability of Occurrence

P	**Probability Range**	**Meaning**
1	< 0.0001	Very low
2	0.001 – 0.0001	Low

Table 2: Severity of Consequences

S	**Loss**	**Harms**
1	< 1000 EUR	No injury
2	1000 - 10,000 EUR	Minor injuries

3	0.01 – 0.001	Moderate
4	0.1 – 0.01	High
5	> 0.1	Very high

3	10,000 - 100,000 EUR	Serious injuries

The resulting risk (R) reflects the combined assessment of probability and severity, helping prioritize scenarios for necessary risk management actions. Understanding and managing these risks are crucial in sectors such as city gas distribution to ensure proactive measures are in place to address significant risks effectively.

Table 3: Risk Importance

Risk	**R = P x S**
1 - 3	Non-significant
3 - 7	Low significant
8 - 25	Significant

3.3 Risk Assessment Approach

The Risk Assessment Framework and Procedures for City Gas Distribution:

a) Identification of Hazards & Release Scenarios: Assess potential risks such as fire, explosion, hazardous material release, flash fires, jet fires, overpressure, and unconfined overpressure scenarios within the CGD system.

b) Identification of Maximum Credible Accident (MCA) Scenario: Determine the most severe incident realistically possible to understand the worst-case scenario for CGD operations.

c) Frequency Analysis: Utilize internationally recognized databases to analyze the likelihood of various events occurring, assessing the frequency of specific incidents.

d) Consequence Modelling and Analysis: Employ PHAST (Process Hazard Analysis software tool) or similar tools to model and analyze the potential impact of identified hazards on personnel and infrastructure, and to evaluate incident escalation.

e) Estimation of Individual Risk (IR) and Societal Risk (SR): Calculate the risk to individuals and communities based on the frequency and severity of potential incidents identified in the CGD network.

3.4 Factors for Identification of Hazards

In QRA for CGD networks, hazards are identified based on the properties of distributed materials, especially natural gas, and inherent pipeline risks. The focus is on potential events like leaks and major releases from pipeline and vessel fractures. This involves assessing interconnected pipelines and vessels sharing significant inventory, considering challenges in isolating these connections during emergencies. Data collection includes material composition, inventory, flow rates, pipeline conditions, and dimensions

Accidental releases of flammable liquids in CGD networks can cause significant harm to life and property. While fires from these incidents are usually localized and controllable, effective preventive measures and comprehensive emergency response plans are critical to minimizing risks and mitigating their impact on CGD operations.

Table 4: Hazard Causes, Consequences, and Proposed or Inherent Safeguards

Site Area	Hazard Cause	Hazard Consequence	Proposed/Inherent Safeguard
Pipeline	External interference	Leak/rupture, ignition, jet fire, flash	- Install pipeline marker signs at regular intervals - Periodic pipeline surveillance - Control and isolate risk areas immediately via the regional control centre

			- Main pipeline paths chosen to be outside residential areas - Increase awareness about the pipeline in nearby communities through patrol squads - Coordinate with local and concerned authorities about pipeline path and maps during new projects or constructions - Ensure pipeline thickness matches the population class near highly populated areas - Ensure integrity through systematic operation and maintenance activities as per Rule
Pipeline	Construction error	Leak/rupture, ignition, jet fire, flash	- Conduct hydrostatic tests before operating - Apply up-to-date internal testing systems to discover and fix defects early - Repeat internal testing periodically and compare results with previous tests
Pipeline	Ground Movement, Earthquake	Leak/rupture, ignition, jet fire, flash	- Ensure land is flat with no subsidence potential - Use Horizontal Directional Drilling for waterway crossings - Use flexible pipes that can adapt to the ground beneath them

Table of common causes of hazardous events categorized into man-made, natural calamities, and extraneous factors:

Table 5: Common Causes of Hazardous Events

Man-made	**Natural Calamities**	**Extraneous**
Heavy Leakage	Flood	Riots/Civil Disorder/Mob Attack
Fire	Earthquake	Terrorism
Explosion	Cyclone	Sabotage
Failure of Critical Control System	Outbreak of Disease	Bomb Threat
Design deficiency	Excessive Rains	War/Hit by Missiles
Unsafe acts	Tsunami	Abduction
Inadequate maintenance		Food/Water Poisoning

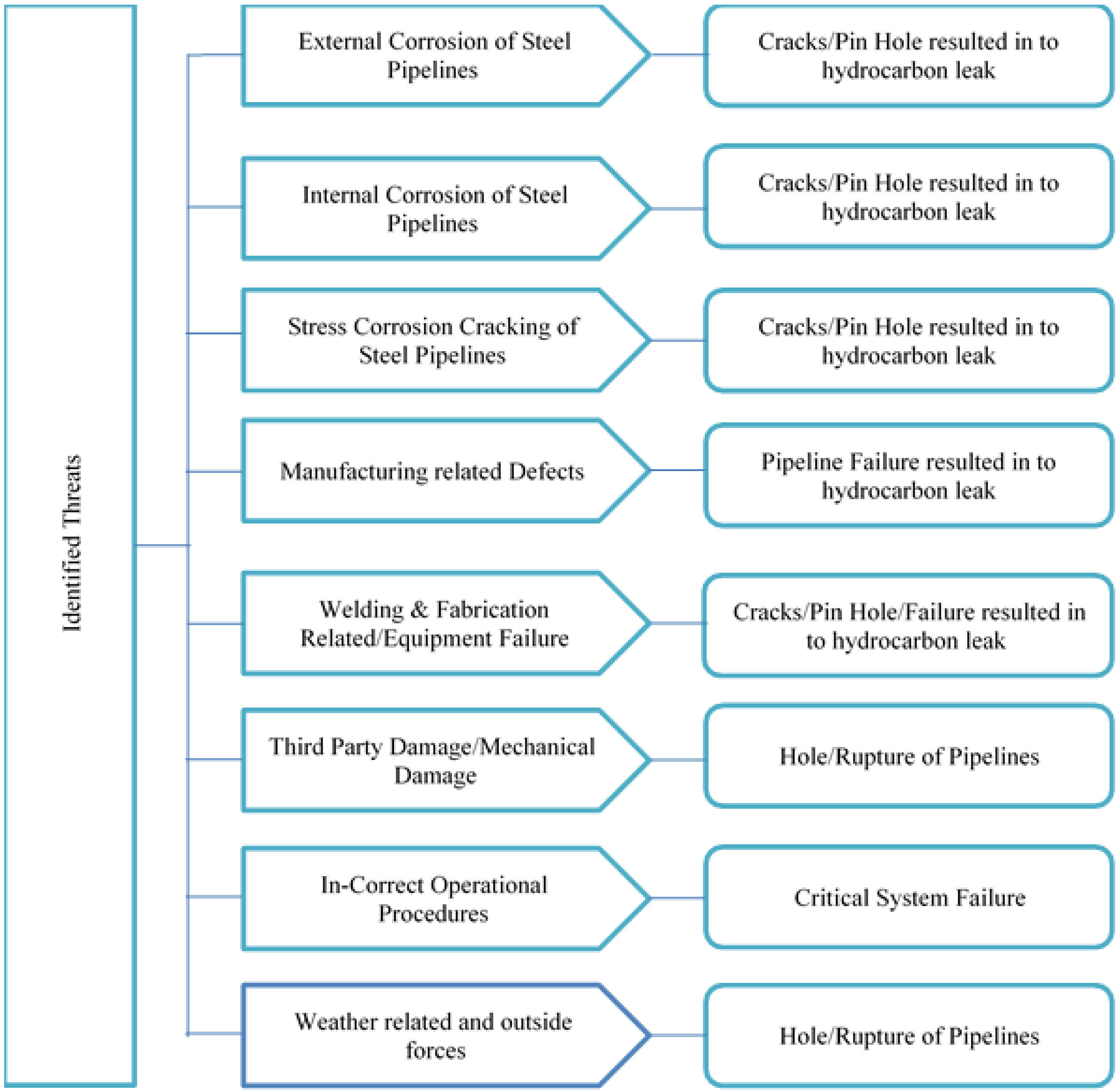

Figure No.1 Eight Categories of Pipeline Threats

3.5 Consequence analysis

Consequence analysis involves the selection of events and incidents that align with study objectives and data requirements. It's essential to include both accident-initiated and non-accident-initiated events, considering various release sizes. This approach refines risk assessments by elucidating the impacts and contributions of small versus large releases, thereby enhancing the overall understanding of potential consequences.

3.6 Types of Outcome Events

The analysis identifies probabilities associated with sequences of events leading to hazardous scenarios and their subsequent modeling. This study encompasses the following anticipated outcomes: Jet fires, Flash fires (FF), Overpressure incidents, BLEVE (Boiling Liquid Expanding Vapor Explosion), Pool fires, Vapor Cloud Explosions (VCE), and Toxicity incidents. Each scenario plays a crucial role in assessing potential risks and their impacts on safety within the city gas distribution network.

3.8 Frequency Analysis

After identifying potential release scenarios, the next step involves estimating failure frequencies using international standard databases:

- Base Failure Frequencies Identification: Initial failure rates sourced from standard databases.

- Total Failure Frequencies Calculation: Incorporating adjustment factors, if applicable, to determine comprehensive failure frequencies.

Selection Criteria: Damage criteria establish relationships between incident effects and consequences, categorized as:

- Heat Radiation Effects: Impact on materials and individuals due to heat exposure.
- Explosion Effects: Structural and human damage resulting from explosions.
- Toxic Exposure Effects: Consequences arising from exposure to toxic substances, affecting health and property.

These criteria aid in assessing human injuries and property losses, guiding mitigation strategies in hazardous scenarios.

Types of Exposure in Consequence Analysis: Consequence analysis categorizes exposure into three main types:

- Heat Radiation: Effects from fire-related heat radiation.
- Explosions: Impact from explosive events.
- Toxic Effects: Consequences from exposure to toxic substances or combustion products.

Understanding these relationships is crucial for evaluating exposure severity. Criteria for damage estimation include:

Heat Radiation Effects: Fire impacts on individuals primarily manifest as burns, categorized into first, second, and third-degree burns. The severity of burns due to heat radiation depends on:

- Radiation Energy: Intensity of heat measured in kW/m².
- Exposure Duration: Duration of heat exposure in seconds influencing heat absorption.
- Skin Protection: Clothing presence affecting skin tissue protection.

This version succinctly captures the essential aspects of frequency analysis, selection criteria for damage assessment, and types of exposure in consequence analysis.

Table No.6 Failure Frequency Data

Failure Mode	***Pressure (Bar)***	***Source of Base Data***	***Total Failure Frequencies (Per km per year)***	***Source of Hole Distribution***	***Probability of Pinhole***	***Probability of Hole***	***Probability of Rupture***	***Pinhole Frequencies (Per km per year)***	***Hol`e Frequencies (Per km per year)***	***Rupture Frequencies (Per km per year)***
Internal Corrosion - All sections	*All*	*CONCAWE Crude oil*	*3.07E-08*	*CONCAWE*	*0.59*	*0.34*	*0.07*	*1.81E-08*	*1.04E-08*	*2.15E-09*
External Corrosion - All sections	*All*	*EGIG 7*	*3.07E-08*	*EGIG 7*	*1*	*0*	*0*	*3.00E-08*	*0*	*0*

Material & Construction Defects - All sections	*All*	*EGIG 7*	*6.36E-06*	*IGEM*	*0*	*0.17*	*0*	*5.28E-06*	*1.08E-06*	*0*
Accidental External Interference - Buried sections	*100*	*-*	*2.24E-09*	*-*	*0*	*0.98*	*0.02*	*0*	*2.19E-09*	*5.35E-11*
Accidental External Interference - Buried sections	*150*	*-*	*4.46E-09*	*-*	*0*	*0.85*	*0.16*	*0*	*3.77E-09*	*6.92E-10*
Accidental External Interference - Tunnelled Section	*100*	*-*	*0*	*-*	*0*	*0*	*0*	*0*	*0*	*0*
Ground Movement	*All*	*PD 8010-3*	*0*	*-*	*0*	*0*	*1*	*0*	*0*	*0*

Table No.7 Summary for Sections

Section Type	Total Failure Frequencies (Per km per year)	Hole Frequencies (Per km per year)	Rupture Frequencies (Per km per year)
Buried Sections	1.14E-05	1.41E-06	2.20E-09
Tunnelled Section	1.14E-05	1.41E-06	2.15E-09

This analysis of failure frequencies provides crucial insights into the risks associated with various pipeline failure scenarios in city gas distribution networks, enabling targeted risk mitigation strategies.

Table No. 8 - Effects due to Incident Radiation Intensity

Radiation KW/m2	**Damage To Equipment**	**Damage To People**
1.2		Solar heat at noon

1.6	PVC insulated cables damaged	Minimum level of pain threshold
4.0	***	Causes pain if duration is longer than 20 secs. But blistering is unlikely
6.4	***	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	***	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.
37.5	Severe damage to plant	100% lethality in 1 minute. 50% lethality in 20 secs. 1% lethality in 10 secs.

Reference: Techniques for Assessing Industrial Hazards by World Bank

3.9 Assumptions for the Study

In conducting the Quantitative Risk Assessment (QRA) for City Gas Distribution (CGD) networks, several key assumptions are made to evaluate potential hazards and their impacts effectively. These assumptions provide a foundation for assessing risks associated with jet fires, flash fires, and explosion-overpressure scenarios:

a) Jet Fire:

1. It is assumed that lethality is 100% for individuals directly exposed to the flame.

2.The lethality outside the flame area varies depending on the distance from the heat radiation.

b) Flash Fire:

1. Lethality is assumed to be 100% for individuals caught outdoors in the immediate vicinity of the fire.
2. Within the flammable cloud indoors, a 10% lethality rate is assumed.
3. No fatalities are anticipated outside the area affected by the flash fire.
4. A release time of 600 seconds (10 minutes leak duration) is considered.

c) Explosion - Overpressure:

1. Two primary physical effects are anticipated:

- A flash fire propagating throughout the explosive cloud.
- A blast wave with peak overpressures originating from the ignition source.

2. Criteria for lethality due to the blast wave include:

- A peak overpressure of 0.1 bar is expected to cause serious damage to approximately 10% of housing or structures.
- Falling fragments from destroyed buildings are estimated to result in one fatality for every eight individuals exposed.

These assumptions are integral to the comprehensive evaluation of risks within CGD networks, guiding the assessment of potential consequences and informing strategies for risk mitigation and emergency response planning.

The following damage criteria may be distinguished with respect to the peak overpressures resulting from a blast wave:

Table No. 9 - Damage due to Overpressure

Overpressure Level	Unit	Impact
0.1	Bar	Shattering of glass
0.3	Bar	Repairable damage to station equipment & structure
1	Bar	Major damage to station equipment structure

the key assumptions for the study as per CPR 18 E Purple Book:

1. Overpressure > 0.3 bar: Approximately 50% lethality.
2. Overpressure > 0.2 bar: Results in 10% fatalities.
3. Overpressure < 0.1 bar: No fatalities.
4. 100% lethality assumed within the explosive cloud area.

3.10 Weather Probabilities

The tendency of the atmosphere to resist or enhance vertical motion and thus turbulence is termed as stability. Stability is related to both the change of temperature with height (the lapse rate) driven by the boundary layer energy budget, and wind speed together with surface characteristics (roughness). There are 6 representative weather classes:

Table No. 10 weather classes

Stability Class	Wind Speed
B	Medium
D	Low
D	Medium
D	High
E	Medium
F	Low

B – Unstable

D – Neutral

E – Stable

F – Very Stable

Wind speeds are categorized as:

- **Low:** 1-2 m/s
- **Medium:** 3-5 m/s
- **High:** 8-9 m/s

Weather Conditions and Wind Speed Classification

The study utilizes Pasquill-Turner stability classes to categorize atmospheric conditions based on observed meteorological data. The stability classes C, C/D, and D are allocated to stability class D due to their similar characteristics. Wind speeds are categorized as follows:

- Below 2.5 m/s: Low wind speed
- Between 2.5 m/s and 6 m/s: Medium wind speed
- Above 6 m/s: High wind speed

The average wind speed within each weather class is determined from observed data. For instance:

- 1.5 F: Stable conditions at night with moderate clouds and light to moderate winds, with an average wind velocity of 1.5 m/s.
- 1.5 D: Neutral conditions with little sunlight and high wind, or overcast and windy nights, also with an average wind velocity of 1.5 m/s.
- 5.0 D: Neutral conditions characterized by little sunlight and high wind, or overcast and windy nights, with an average wind velocity of 5.0 m/s.

Stable weather conditions typically exhibit the longest distance for the dispersion of substances released into the atmosphere.

Table No. 11 - Risk Acceptance Criteria

Authority And Application	**Maximum Tolerable Risk (Per Year)**	**Negligible Risk (Per Year)**
VROM, The Netherlands (New)	1.0E-6	1.0E-08
VROM, The Netherlands (existing)	1.0E-5	1.0E-08
HSE, UK (existing-hazardous industry)	1.0E-4	1.0E-06
HSE, UK (New nuclear power station)	1.0E-5	1.0E-06
HSE, UK (Substance transport)	1.0E-4	1.0E-06
PNGRB, India	1.0E-3	1.0E-06

3.11 Facilities For Evaluation –

Table No. 12 City Geographical Area

<table>
<tr><td>Date of grant of authorization</td><td colspan="3">01.04.2021</td></tr>
<tr><td>Date of commencement of operations</td><td colspan="3">23.08.2021</td></tr>
<tr><td>Number of customers connected with PNG supplies</td><td colspan="3"></td></tr>
<tr><td rowspan="2">Domestic</td><td>MDPE Infrastructure for Household (Nos.)</td><td>Household registered (Nos.)</td><td>Total No. of Household Connected</td></tr>
<tr><td>13064</td><td>5894</td><td>958</td></tr>
</table>

<table>
<tr><td rowspan="2">Actual to be compared with number committed in the bid or fixed by the board</td><td>Schedule for infrastructure creation for Household
(Nos.)</td><td>Actual infrastructure created for household (Nos.)</td><td colspan="2">Actual Connections (Nos.)</td></tr>
<tr><td>14981</td><td>13064</td><td colspan="2">958</td></tr>
<tr><td>Commercial</td><td colspan="4">Nil</td></tr>
<tr><td>Industrial</td><td colspan="4">Nil</td></tr>
<tr><td>DRS/MRS</td><td colspan="4">Nil</td></tr>
<tr><td rowspan="2">Pipe line length in KM</td><td colspan="2">Steel</td><td colspan="2">MDPE</td></tr>
<tr><td colspan="2">35.75</td><td colspan="2">196.21</td></tr>
<tr><td rowspan="7">Details for all types of pipelines based on material (steel or PE),
diameter, pressure rating, etc.).</td><td colspan="2">1. 12”/8”/6”/4” Steel Line Pipe
2. Grade: API-5L X-56 / X-52</td><td colspan="2">1. Size: 125mm /90mm /63 mm / 32 mm / 20 mm PE Pipelines
2. Grade: PE-100 SDR11.</td></tr>
<tr><td>Steel Dia</td><td>Steel Pipeline Laid (Km)</td><td>MDPE Laying (mm)</td><td>Total Laid (Km)</td></tr>
<tr><td>4”</td><td>10.51</td><td>MDPE-20</td><td>12.67</td></tr>
<tr><td>6”</td><td>8.36</td><td>MDPE-32</td><td>89.26</td></tr>
<tr><td>8”</td><td>11.89</td><td>MDPE-63</td><td>52.97</td></tr>
<tr><td>12”</td><td>4.99</td><td>MDPE-90</td><td>11.14</td></tr>
<tr><td>Total</td><td>35.75</td><td>MDPE-125</td><td>30.15</td></tr>
<tr><td rowspan="3">CNG dispensing stations of the entity (in cubic meter of dispensing capacity and
number).</td><td colspan="2">Total No of CNG station</td><td colspan="2">Total Dispensing capacity</td></tr>
<tr><td>RO</td><td>Online</td><td colspan="2" rowspan="2">250 SCMH</td></tr>
<tr><td>4</td><td>0</td></tr>
<tr><td>Details of Mother station & Daughter Stations</td><td colspan="2">Total No. of Mother Stations 0</td><td colspan="2">Total No. of Daughter Stations-0</td></tr>
</table>

3.12 Scenarios

This section documents the consequence-distance calculations, which have been computed for the accident release scenarios considered.

In risk Assessment studies contributions from low frequency - high severity effect as well as high frequency - low severity events are distinguished. Following are the potential Loss of Containment scenarios envisaged for the Pipeline.

S.No	**Type of Facility**	**Considered Credible Failure Scenarios**
1.	Steel Pipeline	Underground & Above Ground Pipeline Leak (5mm, 20mm & FBR) Leakage in DRS
2.	MDPE	Underground & Above Ground Pipeline Leak (5 mm, 20mm & FBR) Leakage in MRS

3.	CNG Station	Failure of Pipeline to Compressor • Leakage from Compressor Unit • Failure of Pipeline Compressor to Cascade • Leakage from Cascade • Leakage from Pipeline Compressor to Dispenser • Leakage from Pipeline Dispenser to Vehicle • Leakage from Mobile cascade
4.	Mobile Cascade	Failure(s) of Tubing Over turning of mobile cascade followed by leakage & fire
5.	Odorization Unit	Leakage of odorant

4. CONSEQUENCE RESULTS

S.No	Type Of Structure	Dia / Storage	Leak size (mm)	Pressure	Release Rate Kg/s	Weather Category	Impact distance in meter						
							Flash fire	Jet Fire			UVCE VCE Overpressure level		
							100% LFL	4 kW/m2	12.5 kW/m2	37.5 kW/m2	0.1 bar	0.3 bar	1 bar
01	STEEL PIPELINE	4 inch	5	19 Bar	0.04	1.5 F	NR	NR	NR	NR	NR	NR	NR
					0.04	3 D	NR	NR	NR	NR	NR	NR	NR
			20		0.37	1.5 F	7.80	13.18	10.57	7.72	NR	NR	NR
					0.37	3 D	7.91	13.07	10.68	7.77	NR	NR	NR
			FBR		2.72	1.5 F	45.72	39.85	33.53	26.59	NR	NR	NR
					2.72	3 D	46.31	41.70	33.91	26.93	NR	NR	NR
02	STEEL PIPELINE	6 inch	5	19 Bar	0.09	1.5 F	NR	NR	NR	NR	NR	NR	NR
					0.09	3 D	NR	NR	NR	NR	NR	NR	NR
			20		0.63	1.5 F	11.42	13.78	10.97	8.06	NR	NR	NR
					0.63	3 D	12.07	13.76	11.17	8.40	NR	NR	NR
			FBR		5.12	1.5 F	64.40	58.75	51.74	40.37	NR	NR	NR
					5.12	3 D	65.54	60.60	53.78	41.25	NR	NR	NR
03	STEEL PIPELINE	8 inch	5	19 Bar	0.16	1.5 F	NR	NR	NR	NR	NR	NR	NR
					0.16	3 D	NR	NR	NR	NR	NR	NR	NR
			20		1.04	1.5 F	15.65	14.81	11.22	8.81	NR	NR	NR
					1.04	3 D	15.43	14.94	11.35	9.13	NR	NR	NR
			FBR		7.28	1.5 F	87.72	74.94	72.98	55.97	NR	NR	NR
					7.28	3 D	89.07	78.90	75.20	58.74	NR	NR	NR

S.No	Type Of Structure	Dia / Storage	Leak size (mm)	Pressure	Release Rate Kg/s	Weather Category	Impact distance in meter						
							Flash fire	Jet Fire			UVCE VCE Overpressure level		
							100% LFL	4 kW/m2	12.5 kW/m2	37.5 kW/m2	0.1 bar	0.3 bar	1 bar
04	STEEL	12 inch	5	19 Bar	0.36	1.5 F	21.92	11.43	5.03	NR	NR	NR	NR
					0.36	3 D	20.01	11.63	5.16	NR	NR	NR	NR

			20		2.34	1.5 F	30.91	21.20	16.05	12.60	NR	NR	NR
					2.34	3 D	29.60	21.38	16.25	13.07	NR	NR	NR
			FBR		16.38	1.5 F	125.56	107.26	104.47	80.11	NR	NR	NR
					16.38	3 D	127.49	112.94	107.64	84.07	NR	NR	NR
05	MDPE	20 MM	5	4 Bar	0.01	1.5 F	NR	NR	NR	NR	NR	NR	NR
					0.01	3 D	NR	NR	NR	NR	NR	NR	NR
			20		0.02	1.5 F	NR	NR	NR	NR	NR	NR	NR
					0.02	3 D	NR	NR	NR	NR	NR	NR	NR
			FBR		0.11	1.5 F	NR	NR	NR	NR	NR	NR	NR
					0.11	3 D	NR	NR	NR	NR	NR	NR	NR
06	MDPE	32 MM	5	4 Bar	0.01	1.5 F	NR	NR	NR	NR	NR	NR	NR
					0.01	3 D	NR	NR	NR	NR	NR	NR	NR
			20		0.03	1.5 F	4.64	4.60	NR	NR	NR	NR	NR
					0.03	3 D	5.14	4.90	NR	NR	NR	NR	NR
			FBR		0.26	1.5 F	6.23	6.13	NR	NR	NR	NR	NR
					0.26	3 D	6.35	6.55	NR	NR	NR	NR	NR
07	MDPE	63 MM	5	4 Bar	0.02	1.5 F	NR	NR	NR	NR	NR	NR	NR
					0.02	3 D	NR	NR	NR	NR	NR	NR	NR
			20		0.13	1.5 F	7.04	6.71	8.16	NR	NR	NR	NR
					0.13	3 D	7.15	7.05	8.50	NR	NR	NR	NR
			FBR		0.97	1.5 F	12.15	13.69	11.20	NR	NR	NR	NR
					0.97	3 D	12.35	13.84	11.72	NR	NR	NR	NR
08	MDPE	90 MM	5	4 Bar	0.03	1.5 F	NR	NR	NR	NR	NR	NR	NR
					0.03	3 D	NR	NR	NR	NR	NR	NR	NR
			20		0.26	1.5 F	6.23	7.44	5.79	NR	NR	NR	NR
					0.26	3 D	6.34	7.68	6.24	NR	NR	NR	NR
			FBR		1.96	1.5 F	15.94	26.06	15.14	13.08	NR	NR	NR
					1.96	3 D	16.31	26.94	15.84	13.64	NR	NR	NR
09	MDPE	125	5	4 Bar	0.05	1.5 F	NR	NR	NR	NR	NR	NR	NR
					0.05	3 D	NR	NR	NR	NR	NR	NR	NR
			20		0.53	1.5 F	6.13	7.34	5.88	NR	NR	NR	NR
					0.53	3 D	6.38	7.77	6.27	NR	NR	NR	NR
			FBR		3.91	1.5 F	27.67	29.14	23.02	18.77	NR	NR	NR
					3.91	3 D	28.97	30.75	23.28	20.34	NR	NR	NR
10	STEEL	2 inch	20	19 Bar	0.07	1.5 F	4.11	4.29	3.31	2.69	NR	NR	NR
					0.07	3 D	4.13	4.36	3.33	2.72	NR	NR	NR
11	MDPE	63 MM	20	4 Bar	0.10	1.5 F	4.41	4.60	3.55	2.88	NR	NR	NR
					0.10	3 D	4.43	4.67	3.57	2.92	NR	NR	NR

Location Specific Breach Analysis

Risk calculations consider breach points in pipelines and facilities, evaluating physical attributes like diameter, grade, operating pressure, and wall thickness. Graphs include:

- **Radiation vs Distance**: Shows radiation intensity up to the point where it becomes negligible.
- **Lethality Ellipse (Jet Fire)**: Displays net radiation and fire distance for Jet fires across different weather scenarios.
- **Flash Fire Envelope**: Illustrates the impact of flash fires on fire scenarios.

- **Explosion Worst Case Radii**: Graphs BLEVE distances for the scenario.
- **Explosion Overpressure vs Distance**: Displays UVCE overpressure effects along the pipeline under various weather conditions.

A. 20 MM

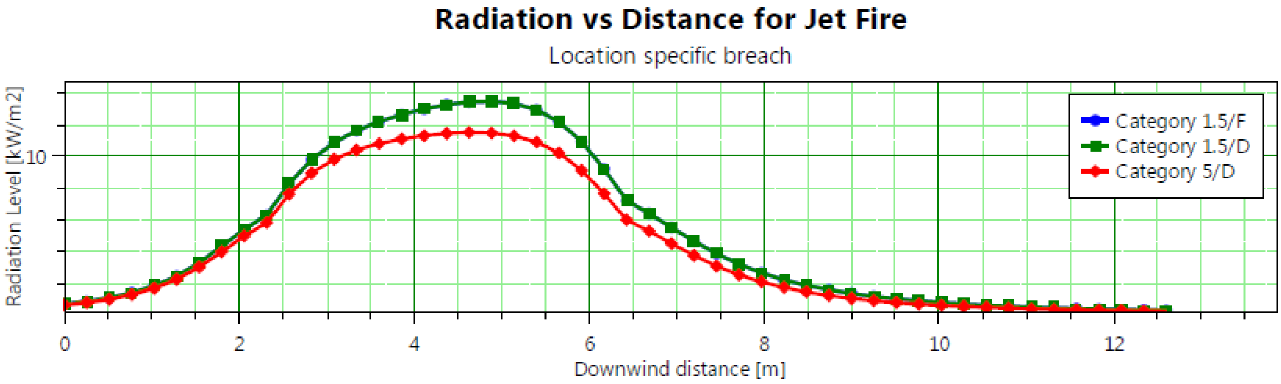

Figure No. 2 Radiation Vs Distance for Jet Fire

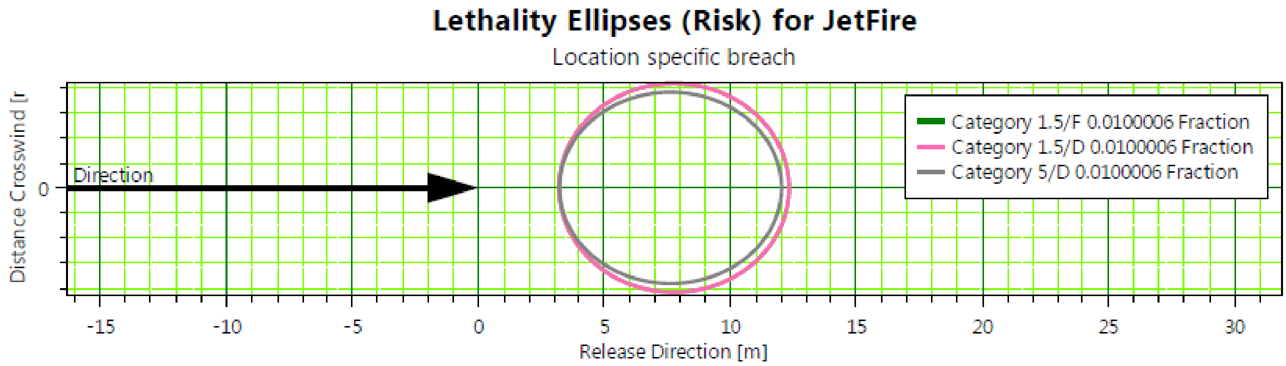

Figure No. 3 Lethality Ellipses (Risk) For Jet Fire

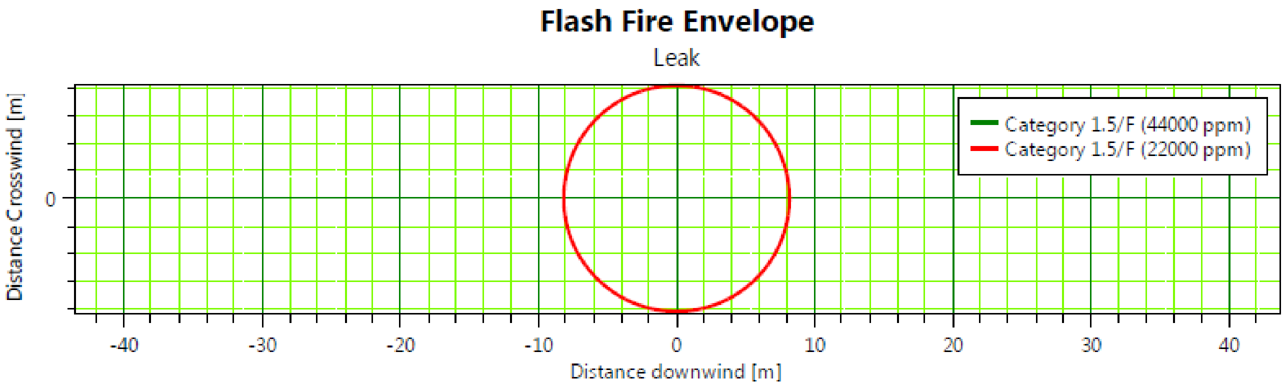

Figure No. 4 Flash Fire Envelope

The above figures depict outcome scenarios in case of a 20 mm leak hole in the section

B. FBR

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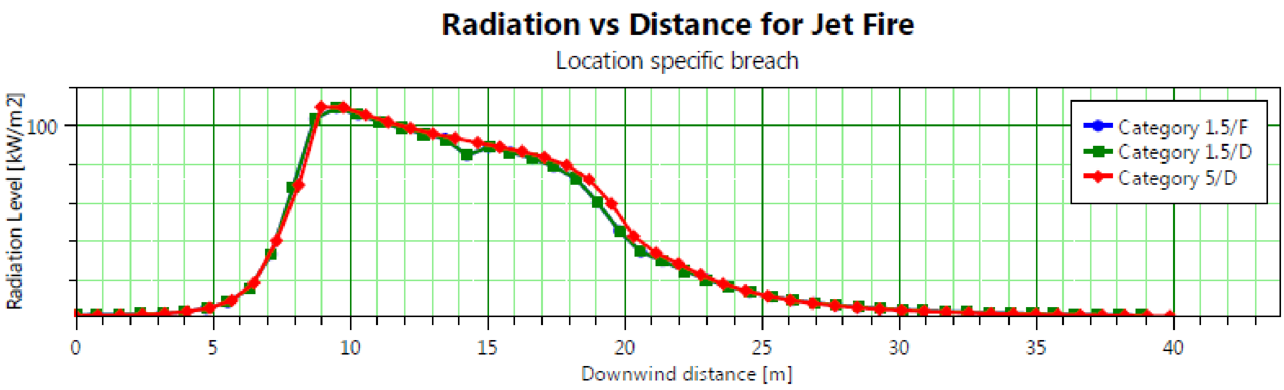

Figure No. 5 Radiation Vs Distance for Jet Fire

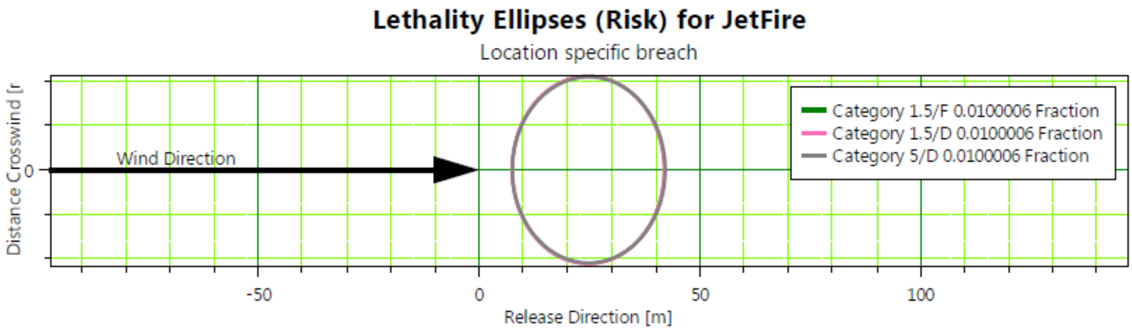

Figure No 6 Lethality Ellipses (Risk) for Jet Fire

The above figures depict outcome scenarios in case of for Jet Fire.

Societal Risk:

The research calculates the Total Potential Loss of Life (PLL) for the population as 8.08 x 10^-5 per year. Figure 6 illustrates the corresponding F-N Curve, which plots societal risk against the proposed risk criteria. The curve clearly indicates that the societal risk falls within the region of "ALARP" (As Low As Reasonably Practicable), signifying that the risks are reduced to levels that are deemed acceptable and tolerable according to established criteria.

This analysis underscores the effectiveness of the risk management strategies employed, demonstrating a conscientious approach to minimizing risks associated with the studied

Figure No. 6 below further provides the associated F-N Curve. The curve shows that the societal risk when compared to the proposed risk criteria is in ALARP region

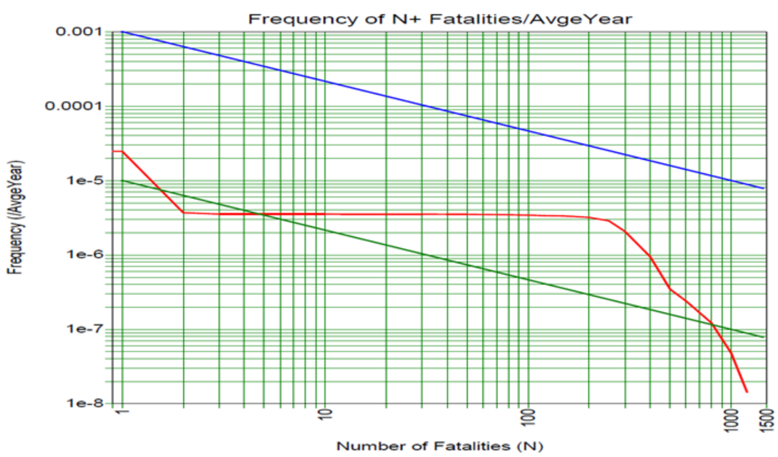

Figure No 6: F-N-Curve for NG Station (DBS) for Retail Outlet

Individual Risk / Location Specific Individual Risk (LSIR)

Individual Risk (IR) assesses the annual risk exposure for individuals consistently present in a defined area, encompassing the evaluation of all pertinent hazards to form a comprehensive risk profile for the installation. The risk is quantified as 10^-5 per year. The LSIR output from SAFETI is shown below:

TABLE NO. 13 – LSIR & ISIR VALUES (PIPELINE)

Risk Location	LSIR [/Avge Year]	ISIR [/Avge Year]	Risk Level
Steel Pipeline – 4”	5.32E-06	1.77E-06	Acceptable
Steel Pipeline – 6”	6.40E-06	2.13E-06	Acceptable
Steel Pipeline – 8”	6.54E-06	2.18E-06	Acceptable
Steel Pipeline – 12”	7.44E-06	2.48E-06	Acceptable
MDPE – 20 mm	1.10E-06	3.66E-07	Acceptable
MDPE – 32 mm	1.38E-06	4.58E-07	Acceptable
MDPE – 63 mm	1.59E-06	5.29E-07	Acceptable
MDPE – 90 mm	2.02E-06	6.73E-07	Acceptable
MDPE – 125 mm	3.08E-06	1.03E-06	Acceptable
Steel Pipeline Leakage in drs	2.58E-06	8.60E-07	Acceptable
MDPE Leakage in mrs	1.99E-06	6.64E-07	Acceptable

5. CONCLUSION

The Quantitative Risk Assessment (QRA) of City Gas Distribution (CGD) networks in Indian cities highlights the paramount importance of robust safety protocols and proactive risk management strategies. Despite significant advancements in CGD infrastructure and services, the study identifies persistent challenges in mitigating risks associated with gas leaks, equipment failures, and external interferences. The assessment provides crucial insights into the frequency and potential consequences of such incidents, advocating for enhanced preventive measures.

The findings underscore the necessity for improved pipeline designs, stringent maintenance protocols, and effective emergency response strategies to bolster safety across CGD operations. Moreover, the integration of eco-friendly fuels like compressed biogas and LNG presents new considerations in risk management, necessitating ongoing adaptation of safety practices. By prioritizing risk reduction initiatives and adhering rigorously to safety standards, CGD operators can ensure the dependable and sustainable distribution of natural gas.

This approach not only enhances urban energy security but also aligns with broader goals of environmental sustainability, reinforcing the critical role of proactive risk assessment in safeguarding public safety and infrastructure integrity in CGD networks.

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