Appendix J

Quantitative Risk Assessment

Prepared by

Ramboll Hong Kong Limited

SECTION 16 PLANNING APPLICATION FOR PROPOSED RESIDENTIAL DEVELOPMENT AT LOTS 1027, 1029, 1030, 1034 S.A, 1034 S.B, 1039 (PART), 1040, 1042 RP, 1043 RP, 1044 RP (PART), 1045, 1047, 2233 (PART), 2251 S.A RP, 2256 RP, 2315 (PART) AND 2316 RP (PART) IN D.D. 92 AND ADJOINING GOVERNMENT LAND (NEW LOT TO BE KNOWN AS LOT 2644 IN D.D. 92), KWU TUNG SOUTH, SHEUNG SHUI, THE NEW TERRITORIES

QUANTITATIVE RISK ASSESSMENT FOR HIGH PRESSURE TOWNGAS PIPELINE

Date	**September 2025**
Prepared by	**Vico Woo** **Consultant**
Signed	
Reviewed by	**Stephen Pang** **Principal consultant**
Signed	
Approved by	**Herve Bonnel** **Partner**
Signed	
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Ramboll Hong Kong Limited

21/F, BEA Harbour View Centre
56 Gloucester Road, Wan Chai, Hong Kong

Tel: (852) 3465 2888
Fax: (852) 3465 2899
Email: hkinfo@ramboll.com

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CHAPTERS

TABLES

FIGURES

APPENDICES

EXECUTIVE SUMMARY

A residential development is proposed at Lots 1027, 1029, 1030, 1034 S.A, 1034 S.B, 1039 (Part), 1040, 1042 RP, 1043 RP, 1044 RP (Part), 1045, 1047, 2233 (Part), 2251 S.A RP, 2256 RP, 2315 (Part) and 2316 RP (Part) in D.D. 92 and Adjoining Government Land (New Lot to be known as Lot 2644 in D.D. 92), Kwu Tung South, Sheung Shui, the New Territories.

A Quantitative Risk Assessment (QRA) has been prepared to assess risk posed by the high pressure town gas pipeline in the vicinity of the Subject Site and include recommendations, if necessary, for mitigation measures, protection works and other measures and works to be carried out and implemented within the Subject Site to ensure compliance with the risk guidelines as described in Section 4.4, Chapter 12 of the Hong Kong Planning Standards and Guidelines (HKPSG).

The assessment of the risk posed by the existing high pressure town gas pipeline (HPTGP) running along Kwu Tong South, in the vicinity of the Subject Site during Construction Phase (2031) and Operational Phase (2032), are in compliance with Hong Kong Risk Guidelines [1] for the planning submission.

Key study findings are summarized as below:

Individual Risk

The individual risk contours of 1E-08 and 1E-09 per year were identified for the existing HPTGP and within the proposed study zone. The predicted individual risk level is well below the individual risk criteria as 1E-05 per year from Hong Kong Risk Guidelines.

Societal Risk

The societal risks for the Construction Phase (2031) and Operational Phase (2032) of the Proposed Development are within “Acceptable” region based on Hong Kong Risk Guidelines[1].

Conclusion

It can be concluded that the societal risk and individual risk associated with the existing HPTGP are in compliance with Hong Kong Risk Guidelines [1]. As such, no mitigation measures are required.

1. INTRODUCTION

1.1 Background

1.1.1 This Quantitative Risk Assessment (QRA) was prepared for the Subject Site as the proposed residential Development at Lots 1027, 1029, 1030, 1034 S.A, 1034 S.B, 1039 (Part), 1040, 1042 RP, 1043 RP, 1044 RP (Part), 1045, 1047, 2233 (Part), 2251 S.A RP, 2256 RP, 2315 (Part) and 2316 RP (Part) in D.D. 92 and Adjoining Government Land (New Lot to be known as Lot 2644 in D.D. 92), Kwu Tung South, Sheung Shui, the New Territories.

1.1.2 The Proposed Development is located at various lots and the adjoining Government land in D.D.92, Kwu Tung South (the Application Site). It falls within the Approved Kwu Tung South Outline Zoning Plan (OZP No. S/NE-KTS/18, gazetted on 14.1.2022) and is currently zoned "Comprehensive Development Area" (CDA). A planning application for proposed houses (Application No. A/NE-KTS/484) at the Application Site was approved by the Town Planning Board on 05/02/2021 (the Approved Development).

1.1.3 This QRA is prepared to assess risk posed by the high pressure gas pipeline and all gas installations in the vicinity of the proposed development and to recommend mitigation measures if required, protection works and other measures and works to be carried out and implemented within the lot to ensure compliance with the risk guidelines as described in Section 4.4, Chapter 12 of the Hong Kong Planning Standards and Guidelines (HKPSG) if required.

1.2 Project Location, Proposed Development and Site Environs

1.2.1 The Application Site is located at the northern part within an area known as Kwu Tung South and is to the immediate south of the Kwu Tung North New Development Area (KTN NDA). It is bounded by Kwu Tung Road to the north, Hang Tau Road to the east and an existing footpath to the south connecting to the river. To the immediate west of the Application Site, there are some planting areas and an abandoned meander established under the rehabilitation works of River Beas, which was managed by the Agriculture, Fisheries and Conservation Department (AFCD). The site is accessible by the existing Hang Tau Road. **Figure 3-2** shows the location of the Application Site and its environs.

1.2.2 The Proposed Development has an area of about 19,591 m^2 which consists of three residential towers (excluding 1 level of basement). The indicative master layout plan of the Proposed Development is shown in **Figure 3-1**.

1.2.3 The target completion year is by 2032.

1.3 Scope of Work and Objectives

1.3.1 The objective of this QRA Study is to evaluate if the risks posed from the existing HPTGP running along Kwu Tung South, in the vicinity of the proposed residential development during Construction Phase (2031) and Operational Phase (2032) are in compliance with Hong Kong Risk Guidelines in terms of individual risk and societal risk.

1.3.2 The scope of work for this QRA Study includes:

- 1.6 km high pressure town gas pipeline

1.3.3 The following scenarios were assessed in this QRA Study:

- Operational Phase – to consider the existing HPTGP, the projected surrounding population within the proposed study zone and the additional population introduced from the proposed residential development in operational year 2027.

1.3.4 The detailed tasks included:

- To identify all potential hazardous scenarios associated with the existing HPTGP to the surrounding off-site population;
- To carry out a QRA Study expressing risks in terms of both individual risk and societal risk;
- To evaluate the risk level by comparing with Hong Kong Risk Guidelines [1] in terms of individual risk and societal risk, respectively; and
- To identify and assess practicable and cost effective risk mitigation measures, if required.

1.4 Report Structures

1.4.1 The remainder of this report is structured as follows:

- Section 2: summarises the proposed QRA methodology adopted for this QRA Study;
- Section 3: describes the Proposed Residential Development and the existing HPTGP running along Kwu Tong South;
- Section 4: summarises the proposed population estimation approach, the off-site population within the proposed study zone for the HPTGP, and the meteorological data obtained from the proximity weather station;
- Section 5: identifies the set of hazardous scenarios related to the HPTGP operation;
- Section 6: presents the frequency assessment of hazardous scenarios;
- Section 7: presents the consequence assessment of hazardous outcomes;
- Section 8: describes the risk summation and risk measure of Hong Kong Risk Guidelines;
- Section 9: summarises the study findings for both individual risk and societal risk;
- Section 10: presents the conclusions; and
- Section 11: lists references cited in this QRA Study.

2. PROPOSED QUANTITATIVE RISK ASSESSMENT METHODOLOGY

The elements of this QRA Study are depicted in **Figure 2-1**, and each of the elements is depicted as follows:

2.1 Hazard Identification

This QRA Study concerns the fire and toxic hazards associated with the town gas being transported in the HPTGP. The associated failure may be partial or catastrophic as a result of corrosion, fatigue, etc. These failures are taken into account for the detailed analysis in this QRA Study.

2.2 Frequency Analysis

This task involves the frequency analysis for each of the identified hazardous scenarios. Frequency analysis includes quantification of the frequency of the initiating events (e.g. pipework failure), and conducts event tree analysis to model the development of an event to its final outcomes (flash fire, jet fire, fire ball, toxicity if not being ignited).

2.3 Consequence Analysis

Consequence analysis involves the modelling of the physical effects, and *SAFETI 8.9* [5], was adopted in this QRA Study. Consequence modelling results were used to establish levels of harm to critical equipment at varying distances from the identified hazards. Probit equations are used to relate levels of harm to exposure.

2.4 Risk Summation and Assessment

Risk summation was conducted using *SAFETI 8.9* which calculates the risk based on different failure outcomes, failure event location, and weather conditions prevailing proximity to the HPTGP. This step involves the integration of consequence and frequency data to give the risk results in terms of the required risk measures.

The products of the frequency and consequence for each outcome event above are summed and the total risks are expressed in individual risk and societal risk terms. Individual risk results were presented as iso-risk contours overlaid on the HPTGP plot plan. The acceptability of the risks for the off-site population was compared with Hong Kong Risk Guidelines [1].

2.5 Risk Mitigation

Practical and cost-effective risk mitigation measures based on this QRA Study are recommended, if required, to demonstrate the risks are ALARP.

3. PROPOSED RESIDENTIAL DEVELOPMENT AND HPTGP DESCRIPTION

3.1 Proposed Residential Development

The proposed residential development is located at the Kwu Tung South, and bounded by Kwu Tung Road, Hang Tau Road and an existing footpath to the south connecting to the river. The development has an area of about 19,591 m^2 and comprises of three 16-storey residential towers.

The Master Layout Plan (MLP) of the proposed residential development is depicted in **Figure 3-1**, while its location and environs are depicted in **Figure 3-2**.

Figure 3-3 presents the location of proposed residential development, proposed study zone and the existing HPTGP.

3.2 Existing High Pressure Town Gas Pipeline

With reference to IGEM/TD/2 [16], "The site-specific F-N curve should be compared to the IGEM/TD/1 F-N Criterion envelope. As the F-N criterion envelope relates to 1.6 km length of gas pipeline, the site-specific F-N curve is obtained by factoring risk values by a factor equal to 1.6 km divided by the site interaction distance."

Based on the information provided by Hong Kong China Gas Company (HKCG), the existing HPTGP in the vicinity of the proposed residential development is 600 mm in diameter, operating at a pressure of 35 barg and running along Kwu Tong South, with pipeline length greater than 1.6 km.

A proposed highest risk 1.6 km pipeline segment with higher population density, with the location of interest (the proposed residential development) located at about the centre of the 1.6 km pipeline, running along San Tam Road with the following population groups selected and adopted in this QRA Study for the detailed risk analysis. The risks were then compared with the Hong Kong Risk Guidelines [1].

- Residential Buildings;
- Industrial Buildings;
- Schools; and
- Leisure Areas.

The selected segment of the existing HPTGP within the proposed study zone is depicted at the Population Map of **Appendix 3-1**, and **Table 3-1** shows the technical specifications of the existing HPTGP, which were provided by HKCG.

Table 3-1 Technical Specification for the existing HPTGP running along Kwu Tong South

Parameter	Specification
Pipe Diameter (Nominal)	600 mm (High Pressure)
Pipe Length	Around 3.2km gas main alignment with the centre of the Proposed Development
Design Pressure	35 barg
Maximum Operating Pressure	35 barg
Hydraulic Test Pressure	900 psi

Parameter	Specification
Air Test Pressure	100 psi
Pipe Material	Steel
Pipe Wall Thickness	12.7 mm
External Coating	400 Micron Fusion Bonded Powder Epoxy
Internal Coating	50 Micron of Two Pack Epoxy Flow Coating
Jointing Method	Butt Welding
Year of Construction	1986 – 1989
Non-Destructive Test of Jointing	100% X-Ray
Backfilling Material	Surrounded by 150 mm Thick Zone, 2 Fresh Water Sand Plus Selection Soil
Cathodic Protection	Sacrificial Anode at about 300 m Interval
Minimum Depth	1.1 m
Material Grading (Pipe/ Fitting)	API 5L X 42/ X 52
Welding Specification	BGC/PS/P2
Isolation Valves (Cameron Full Bore Ball Valve)	Upstream: BV24066 Castle Peak Road – Chau Tau Downstream: BV24118 & BV16116 Fairview Park Boulevard Roundabout
Pipe Length between Isolation Valves	6.2 km

3.3 Physical Properties

3.3.1 Physical Properties of Town Gas

The HKCG pipeline network within the proposed study zone is designed to supply town gas produced at the Tai Po Gas Production Plant to consumers. The composition of town gas and other physical properties is given in **Table 3-2**.

Table 3-2 Gas Composition & Other Physical Property Data of Town Gas

Parameter	Details
Composition • Hydrogen • Methane • Carbon dioxide • Carbon monoxide	 49.0% volume 28.5% volume 19.5% volume 3.0% volume
Average molecular weight	15.1 kg kmol^{-1}
Density	0.5 (at atmospheric condition) (kg m^{-3})
Specific heat ratio	1.3
Gross Calorific Value	17.3 MJ m^{-3} (28.0 MJ kg^{-1})

3.4 Safety System Description

3.4.1 Pipeline Leak Detection/Shutdown System

The HKCG pipeline network and stations are monitored and controlled through the supervisory control and data acquisition (SCADA) system by the grid control centre, which is manned twenty four (24) hours a day by competent control engineers.

In case of abnormal pressure variation over the network, an alarm will be initiated and the grid control engineer will take immediate action for investigation and remedy. Emergency team is always on stand-by and they will arrive at the scene within thirty (30) minutes in case of emergency.

Also, safety measures such as regular trench inspections, safety briefings contractors and companies planning excavation work in the vicinity of the HKCG pipeline network, are currently implemented by HKCG.

4. SURROUNDING POPULATION

4.1 Population Consideration

The population surrounding the existing HPTGP consists of residential buildings, leisure facilities, and public facilities such as public roads. The population considered in this QRA Study is summarised in **Appendix 3-1**.

The population data within the proposed study zone was estimated based on online available population data mentioned at Section 4.1.5 or population estimation assumption as presented at **Table 4-2**.

4.1.1 Proposed Study Zone

The proposed study zone for the existing HPTGP is defined as 200 m from the pipeline alignment based on 1% fatality thermal radiation distance. The approach to determine the proposed study zone is consistent with IGEM/TD/2[16].

4.1.2 Types of Population Considered

Three (3) types of population were considered in this QRA Study:

- Pedestrian population on footpaths and pavements next to hazardous facilities;
- Road traffic population; and
- Building population.

The population estimation methods for each type of population are outlined in the following section. For areas not supported by surveys or where information is not available from other pertinent sources of information, the assumptions were made based on consultant's best judgment.

4.1.3 Pedestrian Population

Pedestrian flow on the pavement was assessed by a site survey conducted in November 2024. The site survey was aimed to collect site specific information such as the width of pavement, surrounding conditions of the public traffic roads etc. The results from the survey were analysed and used to calculate population densities for all pavements within the proposed study zone. Based on the population data from the site survey, the population density can be calculated from the following equation.

No existing building population was identified for the proposed development sites, it was conservatively assumed 100% growth for the pedestrian within the proposed study zone for the operation phase of the proposed development.

$$\text{Pedestrian population (persons m}^{-2}\text{)} = P / t / v / W$$

where:

P is the number of pedestrians passing a given point (person);
t is the total time the survey is carried out (second);
W is the pavement width (m); and
v the average walking velocity of pedestrian (m s^{-1}).

4.1.4 Road Traffic Population

Road traffic population on the public roads was estimated from a combination of the following databases:

- A site survey conducted in November 2024
- Annual Traffic Census 2022 (ATC 2022) [20] (latest available census data at the time of preparation of this report)

A population density approach was adopted for estimating the population within vehicles on the road. The traffic density information adopted in this QRA Study was estimated based on the data in ATC 2022 to determine the distribution of vehicle types. The road population density can be calculated:

$$\text{Population Density (persons/m}^2\text{)} = AADT * P_{avg} / 1{,}000 / 24 / V * L$$

where:

AADT is Annual Average Daily Traffic from 2022 Annual Traffic Census;
P_{avg} is the average number of persons per vehicle;
V is the vehicle speed in km hr^{-1}; and
L is the road length in meter, based on actual road length data.

The average number of persons per vehicle can be calculated:

$$P_{avg} = \sum_{i=1}^{N} (f_i \times P_i)$$

where:

f_i is the fraction of vehicle type i (based on 2022 ATC); and
P_i is the mean occupancy of vehicle type i (based on 2022 ATC).

Typically, vehicle speed of 50 km hr^{-1} for non-highway route sections and vehicle occupants were conservatively assumed as outdoor with regards to consequence models (i.e. flash fire/ toxic cloud, etc.). Moreover, Fanling Highway has a speed limit of 100 km hr^{-1} and was consequently used in the QRA.

The traffic population at each public road within the proposed study zone was estimated using the average vehicle occupancy from Core Station 5003 "Kwu Tong South (from So Kwun Po Int to Wo Hop Shek Int)". Traffic growth rate was assumed from the average growth rate of AADT of the past 5 years, which is 5% and conservatively applied in this QRA.

4.1.5 Land and Building Population

The land and building population within the proposed study zone was estimated based on the following sources and verified by a site survey conducted in November 2024:

- Planning Data from Town Planning Board [18];
- Centamap (2015); and
- Geographic Information System (GIS) database (2015 data).

For those population which cannot be achieved by the above approach is made reference to the *EIA Study for Operation of the Existing Tai Lam Explosive Magazine at Tai Shu Ha, Yuen Long for Liantang/ Heung Yuen Wai Boundary Control Point Project, Register No.: AEIAR-193/2015* [17] to estimate the population in buildings (both existing buildings and approved developments) within the proposed study zone.

Buildings within or extended partly into the proposed study zone were included in this QRA Study. Rather than considering density-based averages of population, the analysis was based on individual buildings. The task of assessing population building-by-building is substantial but is necessary to accurately model the F-N pairs with high N values.

Building Identification

The Lands Department (LD) of the HKSAR Government maintains a GIS database of buildings in Hong Kong. To identify buildings within the proposed study zone, a recent GIS map layer containing all buildings (LD, 2015) is obtained. Additionally, the GIS building height information for most of the buildings (but usually not podiums or other similar structures) are available from the same source.

Building Attributes, Usage and Population Identification

There is no publicly available data on the population of individual buildings in Hong Kong. Therefore, to provide a basis for estimating the number of people in a building, it is necessary to identify each building's attributes and usage.

The buildings and structures in the GIS database are classified as: regular building (BP), building under elevated structure (BUP), open-sided structure (OSP), proposed building (PBP), podium (PD), podium under elevated structure (PDU), ruin (RU) and temporary structure (TSP). Using the above information, the information from property developers' websites as well as aerial photographs, the actual or likely usage category of buildings identified is determined and each building is assigned to one of the following building usage categories:

- Residential Building;
- Industrial Building;
- Car Park;
- Fire Station;
- Commercial Building;
- Kindergarten;
- Station; and
- Leisure.

It is noted that unless their usage could be determined from other available sources, the GIS categories OSP, TSP and RU, were assumed to be unpopulated.

Following this, the same information sources are used to sub-categorize buildings by other attributes, such as the number of floors. Details on the building attributes and categories and associated assumptions are presented below.

Number of Floors

Building height data is available from the GIS database for most buildings and the number of floors was estimated from these data, assuming three (3) m height per floor. For most of the high-rise residential buildings (excluding the housing estates) the floor number information, considered more accurate, is also available from the property developer website. When neither of the above information will be available, the number of floors will be estimated from 3-dimensional aerial photos. In the event of an absence of data from any of the above sources, such buildings are covered by site survey carried out.

Residential Buildings

Based on Population and Household Statistics Analysed by District Council District 2023, the average domestic household size for North District is 2.7, which was adopted to estimate the residential population within the proposed study zone in this QRA Study. For this QRA study, an average domestic household size of 3 was conservatively assumed for the proposed development.

According to latest Projections of Population Distribution 2023 – 2031 issued by Planning Department [23], the population of Tertiary Planning Unit (TPU) 547 is summarised in **Table 4-1**. According to the latest Project of Population Distribution 2023 – 2031 [23], the projected population up to year 2027 is available. For a conservative approach, growth factor of 1.062 was adopted in this QRA.

Table 4-1 Population Growth Factor for Residential of Tertiary Planning Unit 547

Year	2021[1]	2022[1]	2023[1]	2024[1]	2025[1]	2026[1]	2027[1]	2032[2]
TPU 547								
Population	14,300	13,900	14,100	14,000	15,100	14,700	14,400	15,186
Growth Factor	1.000	0.972	0.986	0.979	1.056	1.028	1.007	1.062

Note:

1. *Population number for year 2021 – 2027 is from Projections of Population Distribution 2023 – 2031.*
2. *Population number for year 2032 is projected from Projections of Population Distribution 2023 – 2031.*

For most of the high-rise residential buildings, the total number of units is available from the property developers' websites or Home Affairs Department of the HKSAR Government [14]. For all the remaining buildings, including the village houses and estate high-rises, the number of units per floor will be estimated from the floor area, assuming 1 unit per about 65 m^2 (700 square feet). Based on this assumption, small structures in village setting of area less than about 30 m^2 will be assumed to be unpopulated.

Other Buildings

While residential type buildings are well defined, less information is available for other types of buildings such as commercial, industrial, etc. The approach to estimate other building population generally follows that adopted in the EIA Study [17], and is based on typical Hong Kong building structure, usage, height, and typical capacity of public facilities. The details are presented in **Table 4-2**. In the application of typical values from **Table 4-2**, further refinements will be made based on building height and area and taking into account the maximum density of people in most non-residential building as one person per 9 m^2 (the Code of Practice for the Provision of Means of Escape in Case of Fire [21]).

Table 4-2 Building Population Assumptions

Category	Building Height /Size[1]	Assumption			Total
College / Secondary School		If number of classes and number of staff are not provided, it is assumed there will be 40 students per class, 4 classes per form and a total of 60 staff employed			1,020
Primary School		If number of classes and number of staff are not provided, it is assumed there will be 30 students per class, 4 classes per form and a total of 30 staff employed			750
Commercial		Floors	Units	People/Unit	
	H	10	20	2	400
	M	5	20	2	200
	L	2	10	2	40
Leisure	H	200 people for large sized leisure facility			200
	M	100 people for medium sized leisure facility			100
	L	50 people for small sized leisure facility			50
	LL	10 people for very small sized leisure facility			10

Note:

1. Legend for Building Height/Size
   - H for Tall/Large, 40 storeys;
   - M for Medium, 20 storeys;
   - L for Low/Small, 3-storey; and
   - LL for Very Low/Very Small

Using the above approach, a database providing characterization of each building by their broad attributes including population was developed.

4.2 Time Period and Occupancy

Since population can vary during different time periods, the analysis considered three (3) time categories (weekday day, weekend day and night). These are summarized in **Table 4-3**.

Table 4-3 Population Time Periods

Time Period	Description
Weekday Day	7am to 7pm, Monday – Friday
Weekend Day	7am to 7pm, Saturday – Sunday
Night	7pm to 7am, Monday – Sunday

The occupancy of buildings during each time period was based on assumptions as listed in **Table 4-4**. For vehicle and pavement populations, distribution across various time periods was based on site surveys.

Table 4-4 Population Distribution

Type	Occupancy (%)		
	Weekday Day	**Weekend Day**	**Night**
Industrial Building (1)	100%	10%	10%
Leisure (1)	70%	100%	0%
Carpark (1)	70%	70%	10%
MTR/bus terminus (1)	70%	50%	10%
Residential Building (1)	50%	80%	100%
Commercial (1)	100%	100%	10%
Substation (1)	100%	10%	10%
Pedestrian (1)	100%	100%	10%
Construction Site	100%	50%	0%
Petrol Station (1)	50%	50%	1%
Hotel (1)	50%	80%	90%
School (1)	100%	10%	0%

Notes:

1. *This population distribution table is based on the approved Safety Case Study Report for Towngas Transmission Network 2012 in 2015 [22].*
2. *The population fraction to be considered outdoor is assumed as 5% for the private residential area, 1% for the commercial area and 100% for vehicle.*

4.3 Protection Factors

Protection factors were used to factor down the population so that only those exposed are considered in the risk summation for certain types of incidents such as fireball, flash fire, jet fire and toxic incidents.

For example, the dimensions of the vapour cloud can be defined in terms of distances to lower flammable limit (LFL) in the case of flash fires and distances to 1% fatality concentration for toxic effects. Protection factors can be determined by considering the dimensions of the gas plume/flame envelope as a function of height and distance from source with respect to the height of each building. The proportion of the building outside of the gas plume is the protection factor.

Further details are given in the following paragraphs.

4.3.1 Height Protection Factors

Since the affected areas for jet fire and flash fire are limited (i.e. do not cover the entire building for high rise structures), a height protection factor is considered to exclude the population residing on higher floors of a building (higher than 10 m or 3 storeys). It is because the consequence of hazardous scenarios is less than 10 m height based on the detailed consequence modelling using *SAFETI 8.9*.

In case of fireball events, a protection factor is also applied so that those exposed population and fireball rise effect are considered in the risk summation. The population of the building above the top of the fireball is protected.

4.3.2 Indoor Protection Factors

A protection factor was also considered for effects from radiation and toxic gas for population indoors.

Protection for indoor population against all the fire events (jet fire and flash fire) and toxic effects was considered by assuming that the indoor fatality rate is about 10% of the outdoor fatality rate.

For persons within the fireball radius/ criteria zone, it is assumed that 50% of person would be killed and 50% indoor protection factor [13] should be applied in this QRA Study.

4.3.3 Shielding Factors

A shielding factor is generally used to take credit for the shielding of buildings by other buildings from fireball effects [13].

By superimposing the hazard zone from fireball events on an area map, a shielding factor should be derived for the house or building in the immediate vicinity, as follows:

- The proportion of the building within the fireball diameter, for buildings wholly within the fireball shielding is afforded only to the people at the back of the building;
- For buildings wholly outside the fireball, the proportion of the building not in the direct line of sight of the existing HPTGP is considered protected. Outside the fireball diameter, only radiant heat effects are considered. Radiant heat from the flame surface travel in straight lines and therefore only affects that part of a building directly in front; and
- For buildings which are partly inside and partly outside the fireball diameter, that proportion of the building outside the fireball diameter is considered shielded by the rest of the building.

4.4 Ignition Factors

In order to calculate the risk from flammable materials, information is required on the ignition sources which are present in the area over which a flammable cloud may drift.

The probability of a flammable cloud being ignited as it moves downwind over the sources can be calculated. The ignition source has three factors:

- Presence factor is the probability that an ignition source is active at a particular location;
- Ignition factor defines the "strength" of an ignition source. It is derived from the probability that a source will ignite a cloud if the cloud is present over the source for a particular length of time; and
- The location of each ignition source is specified. This allows the position of the source relative to the location of each release to be calculated. The results of the dispersion calculations for each flammable release are then used to determine the size and mass of the cloud when it reaches the source of ignition.

The ignition sources are site specific. The typical ignition sources are road vehicles and the population nearby.

Roads are line ignition sources in *SAFETI 8.9*. The presence factor for a line source is determined based on traffic densities, average speed along the road and the length of the road element. The location of the line source is drawn onto the site map in *SAFETI 8.9*. Probability of ignition for a vehicle is taken as 0.4 in 60 seconds based on TNO Purple Book [12].

SAFETI 8.9 will automatically allow for people acting as ignition sources. These are based on the population data. The presence of such sources (e.g. cooking, smoking, heating appliances, etc.) is derived directly from the population densities in the area of concern.

The details of probability of delayed ignition should be referred to *Assumption Number 1.2.5* in **Appendix 4-1**.

4.5 Meteorological Data

The proximity weather station to the existing HPTGP is Ta Kwu Ling Weather Station. Therefore, wind speed, wind stability and direction data taken from Ta Kwu Ling Weather Station between 2019 and 2023 were adopted for this QRA Study.

With reference to "*Guidelines For Quantitative Risk Assessment, CPR 18E (Purple Book)*"[12] at least six (6) representative weather classes are recommended to be used in QRA Study, covering the stability conditions of stable, neutral and unstable, low and high wind speed. At least the following six (6) weather classes have to be covered in terms of Pasquill classes.

Stability class	**Wind speed (1)**
B	Medium
D	Low
D	Medium
D	High(2)
E	Medium
F	Low

Note:

(1): Low wind speed corresponding to 1 – 2 m/s
Medium wind speed corresponding to 3 – 5 m/s
High wind speed corresponding to 8 – 9 m/s

(2): WIND speed higher than 5 m/s is assumed to be wind speed category "High".

The details of meteorological data analysis can be referred to *Assumption 1.1.1* in **Appendix 4-1.**

The probability of each weather state for each direction during the day and night are rationalized for analysis based on the requirements presented in "*Guidelines For Quantitative Risk Assessment, CPR 18E (Purple Book)* [12]. Based on the analysis on raw data, the summary of meteorological data is shown in
Table 4-5, which was used for this QRA Study. The meteorological data adopted has been evaluated with the latest "Summary of Meteorological and Tidal Observations in Hong Kong: from Hong Kong Observatory and it was confirmed the meteorological data used is still valid. [24]

The wind speeds are quoted in units of meters per second, (m/s). The atmospheric stability classes refer to:

A – Turbulent
B – Very Unstable
C – Unstable
D – Neutral
E – Stable
F – Very Stable

Atmospheric stability suppresses or enhances the vertical element of turbulent motion. The vertical element of turbulent motion is a function of the vertical temperature profile in the atmosphere (i.e the greater the rate of decrease in temperature with height, the greater the level of turbulent motion). Category D is neutral and neither enhances nor suppresses turbulence.

Table 4-5 Meteorological Data from Ta Kwu Ling Weather Station (Year 2019 - Year 2023)

		Probability												
		Day						**Night**						
	Wind Speed (m/s)	2.5	1.5	3.6	6.7	2.9	1.1	1.0	1.2	3.9	6.9	2.9	1.1	
Direction (degree)	**Atmospheric Stability**	B	D	D	D	E	F	B	D	D	D	E	F	**Total (%)**
0		3.07	0.85	1.91	0.10	0.11	0.59	0.00	0.40	1.67	0.06	0.58	1.89	**11.23**
30		1.56	0.53	1.07	0.22	0.10	0.37	0.00	0.11	1.06	0.21	0.47	1.40	**7.12**
60		1.22	0.33	0.22	0.01	0.02	0.32	0.00	0.07	0.17	0.03	0.11	1.72	**4.22**
90		8.03	2.03	3.39	0.05	0.36	1.24	0.00	0.22	1.78	0.07	1.40	7.73	**26.30**
120		2.86	1.36	1.98	0.02	0.38	1.32	0.00	0.16	1.90	0.02	1.82	9.14	**20.98**
150		0.95	0.44	0.16	0.00	0.02	0.56	0.00	0.06	0.12	0.00	0.16	5.13	**7.60**
180		1.05	0.40	0.18	0.00	0.01	0.41	0.00	0.04	0.04	0.00	0.03	3.29	**5.45**
210		2.48	0.49	0.69	0.00	0.02	0.35	0.00	0.03	0.08	0.00	0.17	2.62	**6.92**
240		1.88	0.33	0.18	0.00	0.00	0.22	0.00	0.04	0.03	0.00	0.04	1.47	**4.20**
270		0.82	0.15	0.02	0.00	0.00	0.09	0.00	0.02	0.00	0.00	0.00	0.65	**1.75**
300		0.61	0.16	0.01	0.00	0.00	0.11	0.00	0.06	0.00	0.00	0.01	0.62	**1.57**
330		0.99	0.29	0.07	0.00	0.02	0.20	0.00	0.19	0.02	0.00	0.06	0.84	**2.67**
	Total (%)	**25.52**	**7.36**	**9.87**	**0.41**	**1.06**	**5.78**	**0.00**	**1.40**	**6.86**	**0.39**	**4.85**	**36.49**	**100.00**

5. HAZARD IDENTIFICATION

5.1 Main Hazards from the HPTGP

The main hazard associated with the existing HPTGP is loss of containment leading to an accidental town gas leak. Town gas is flammable and explosive due to the presence of methane and hydrogen, and carbon monoxide respectively. Town gas is also toxic due to presence of carbon monoxide.

5.2 Flammable & Toxic Effects of Town Gas

5.2.1 Flammable Effects

Town gas contains mainly hydrogen, methane and carbon monoxide which are flammable. The respective LFL for hydrogen, methane and carbon monoxide are summarised below:

- LFL for hydrogen is 4% (volume);
- LFL for methane is 5.3% (volume); and
- LFL for carbon monoxide is 12.5% (volume).

The LFL for the town gas mixture is estimated to be 5.5% (volume).

5.2.2 Toxicity

Town gas also contains carbon monoxide which is toxic in nature. Carbon monoxide is a chemical asphyxiant, and it can combine with haemoglobin in the blood displacing oxygen.

The Immediately Dangerous to Life and Health (IDLH) value for carbon monoxide is 1,200 ppm [1].

5.3 Review of Pipeline Incidents

A review of major international failure/ accident databases was undertaken to identify past incidents involving transmission gas pipelines. The following databases have been reviewed:

- US Gas Pipeline Incident Database, 1984 to 2013 [3]; and
- European Gas Pipeline Incident Database, EGIG 1970 to 2016 [4].

The objective of such review is to identify the causes and consequences of the pipeline failures.

5.4 Causes of Loss of Containment

5.4.1 High Pressure Town Gas Pipeline

The principal causes for loss of containment of pipeline, based on an analysis of wide incident database (see Section 5.3), are:

- Corrosion – internal and external;
- Third party interference during road construction, due to work on other underground utilities, construction work on adjoining areas, etc.;
- Material defect;
- Construction defect;

- Improper operations;
- Defect caused by pressure cycling; and
- External – flooding, subsidence, etc.

The contribution of each of the above causes to the overall failure frequency taken from foreign database is discussed in detail. Appropriate factors were applied to reflect the actual operating condition of the HPTGP.

6. FREQUENCY ANALYSIS

Approach to frequency analysis was based on the application of world-wide historical data for similar systems modified suitably to reflect local factors. Although it may be preferable to use local data to estimate failure frequencies, such data are not sufficient enough to provide statistically significant results.

6.1 Failure Rate for the HPTGP

6.1.1 Failure Rate for HKCG HPTGP

There is no any historical record of failure for the HPTGP. Therefore, failure frequency of gas transmission pipeline was extracted from US and EGIG databases for analysis and projection. Based on the detailed analysis as explained at *Section 6.1.3,* the modified failure rates based on application of the US and EGIG data to the HKCG system are 2.30×10^{-5} and 8.81×10^{-6} per km-year, respectively. Both modified US and EGIG failure rates data are at the similar order of magnitude of 10^{-5} per km-year.

It is noted that HKCG operates and maintains its pipelines to very stringent standards. The failure rate of HKCG's gas pipeline is considered to be within the modified failure rates, i.e. between 2.30×10^{-5} and 8.81×10^{-6} per km-year and at a lower side. A pipeline failure rate of 10^{-5} per km-year was, therefore, proposed and adopted in this QRA Study. This proposed pipeline failure rate is also same as the proposed failure rate for underground high pressure town gas pipeline stipulated in "Guidance Note for High Pressure Town Gas Installations in Hong Kong" published from Electrical and Mechanical Services Department (EMSD)[25].

6.1.2 Analysis of Local Failure Database for HKCG HPTGP

HKCG commenced operations on high pressure transmission network at 35 barg operating pressure in 1986 and the total length of high pressure network currently in operation in Hong Kong is around 205 km. The total pipeline operating years is therefore estimated as 32 × 205 = 6,560 km-year, assuming the current length of the network for the past 32 years. In reality, the network would have gradually expanded over the years and therefore the total pipeline operating years may be only about 50% of the above figure. The data on km-year is therefore not statistically significant to estimate failure frequencies. In comparison, the US Gas Pipeline database is based on a total pipeline operating data of 14.0 million km-year.

6.1.3 Analysis of International Failure Database for Gas Pipeline

The approach proposed in this QRA Study is to consider international failure databases and derive an appropriate failure frequency for the HKCG HPTGP taking into account specific pipeline design and environment features. The main failure databases considered are the failure database for US natural gas pipelines and the failure database for European gas pipelines.

The relevant international databases reviewed in this QRA Study are:

- US Gas Transmission & Gathering Pipelines, 1984 to 2013 [3]; and
- The European Gas Pipeline Incident data Group (EGIG), 1970 to 2016 [4].

The operating km-year for US gas transmission pipeline between 1984 and 2013 is 14.0 million km-year while for European gas pipelines between 1970 and 2016, it is 4.41 million km-year. It can be seen that in comparison to HKCG's operating experience, these databases are based on a much larger operating experience world-wide and therefore are more representative in terms of inclusion of various possible failure modes.

An extensive review and analysis of these databases were conducted to derive failure rates appropriate to the HPTGP for this QRA Study. A brief description of the databases is included in the following paragraphs.

Analysis of US Gas Failure Data

The US Department of Transportation (DOT) Research and Special Administration maintains databases for pipelines incidents (reportable) in the United States and pipeline mileage data. Under the reporting requirements, events involving a gas release that causes death, injury or damage in excess of US$50,000 needs to be reported. Due to the nature of reporting, it is possible that minor incidents of leaks are underrepresented.

The US Gas Pipeline Incident Database has been filtered to consider only onshore transmission pipelines and only those failures involving the body of the pipeline. There have been 2,359 incidents involving loss of containment during the period from 1984 to 2013. The total pipeline km-year during this period is 1.4×10^7, and this gives a failure rate of $2,359 / (1.4 \times 10^7) = 1.69 \times 10^{-4}$ per km-year.

A breakdown of the 2,359 pipeline incidents according to cause of failure is summarised at **Table 6-1**. Some of the pipeline failure causes are not applicable to the pipeline at this QRA Study while others may be more relevant. These are discussed in the following paragraphs.

Table 6-1 Summary of US Gas Onshore Transmission Pipeline Incidents by Cause 1984-2013

Cause of Failure	Description of Cause	No. of Incidents	%
1 EXTERNAL FORCE		**918**	**38.9%**
1.1 Weather		188	8.0%
1.1.1 Earth Movement	Subsidence, landslides, earthquake	109	4.6%
1.1.2 Temperature		11	0.5%
1.1.3 Heavy Rain/ Flood		34	1.4%
1.1.4 Lightning		19	0.8%
1.1.5 High Wind		11	0.5%
1.1.6 Cold Weather	Thermal stress, frozen components, frost heave	4	0.2%
1.2 Excavation Damage		613	26.0%
1.3 Other Forces Damage	Previous damaged pipe, vandalism, Damage by fire/explosion, vehicle not engaged in excavation, previous mechanical and intentional damage	117	5.0%
2 CORROSION		**453**	**19.2%**
2.1 External	Failure of coating/ CP	273	11.6%
2.2 Internal		180	7.6%

Cause of Failure	Description of Cause	No. of Incidents	%
3 WELDS, MATERIALS & EQUIPMENT FAILURE	Environment-cracking related, body of pipe, pipe seam, butt & fillet weld, joint, fitting or component, malfunction of control/relief equipment, threaded connection or coupling failure, non-threaded connection failure	**529**	**22.4%**
4 INCORRECT OPERATIONS	Includes incorrect valve position	**47**	**2.0%**
5 OTHER	Miscellaneous and unknowns	**412**	**17.5%**
TOTAL		**2,359**	**100%**

Discussion on Failure Causes Relevant to the HKCG HPTGP

Weather

Cold weather and high wind which contributes 0.2% to overall failures is not relevant for the HKCG HPTGP and therefore is excluded. Lightning is also considered not relevant since the transmission pipelines are buried while the above ground stations are installed with lightning protection facilities and thus a 100% reduction factor is assumed. In addition, since the pipeline is buried, failure due to temperature issues is not applicable and a 100% reduction factor is assumed.

Subsidence/ Landslides

Buried pipelines are not affected by debris deposition due to landslides. However, if buried pipelines are within the initiation zone of a landslide, earth movement could cause rupture. Therefore, failures due to landslides are not expected. Landslides which contribute to 90% of failures are therefore excluded. However, incidents due to subsidence are considered.

Subsidence could occur due to excavations in the vicinity. Earth movement due to earthquakes could affect the pipeline (see paragraph below).

Earthquakes

Large earthquakes may cause varying degrees of damage to the pipeline. The magnitude of the earthquake (peak ground acceleration) required to catastrophically rupture the pipeline is estimated at 0.6 g/MMS-XI. This is equivalent to an average vulnerability of general building stock in Hong Kong (i.e. low rise buildings up to 10 storeys).

The pipeline failure frequency used in this QRA Study is derived based on US DOT database, which accounts for failures due to earthquakes. A 90% reduction is therefore assumed.

Flooding

The pipeline is buried with minimum 1.2 m (1.5 m for the laid section of 4.36 km) earth cover and no portion of the pipeline is exposed; and therefore a 100% reduction is assumed.

Third Party Damage

The potential for third party damage depends on the surrounding environment. Also, wall thickness, design factor, buried depth and impact protection such as concrete cover, all have a combined influence on whether third party activity could cause damage to the pipeline and if so, the nature of damage (a full bore rupture or hole leak).

The databases for transmission pipelines in the US and Europe mainly consist of those in rural areas and therefore have a design factor of 0.72, the requirement under ASME/ANSI B31.8 for gas pipelines [9], BS 8010 [10] and IGEM/TD/1 [11]. Also, the US gas pipeline database may include pipelines with earth cover less than 1.1 m (ANSI/ASME B31.8 requires only 0.6 m as minimum cover for Location Class 1 and 0.75 m for Location Classes 1, 2 and 3) and therefore, application of these failure rates to the HKCG HPTGP may be conservative.

The wall thickness of HKCG HPTGP is 12.7 mm while the design factor is 0.3. The gas pipeline is also normally buried at 1.1 m deep and is extra protected by the steel capping for those with shallow cover. The potential for damage due to third party is therefore significantly reduced. The only hazard is third party activity involving utilities, construction work. Potential misjudgement by the contractor or carelessness could cause damage to the pipeline. Other reasons for a low probability of third party damage in Hong Kong include:

- Most of the high pressure gas main are laid under expressways/ carriageways where excavation is strictly controlled;
- It is a legal offence to damage a gas pipe without taking safety precautions while carrying out the works; and
- Self-initiated trench inspection work has greatly enhanced the co-ordination with construction work in the vicinity of gas main resulting in more than 86% reduction of third party since 1998.

It is worthwhile to note that about 30% of the incidents due to third party damage in the US [3] occurred despite prior notification to the pipeline operator. The pipeline operator therefore needs to follow up with site visits and inspection. Given the high standards of operation and maintenance of HKCG HPTGP, a 90% reduction of this failure cause is assumed.

External Corrosion

The US Gas Pipeline Incident Database includes pipelines which are not protected. The HKCG HPTGP is protected by protective epoxy coating and sacrificial anode cathodic protection system. Therefore, the failure rate corresponding to cathodically protected pipeline is adopted. A 50% reduction is therefore assumed.

Failure Rate vs Age of Pipeline

The US Gas Pipeline Incident Database includes pipelines of various ages. Increase in failures due to ageing is observed principally due to external corrosion and fatigue, but the failure database does not contain sufficient information to perform a statistical analysis. The age of pipelines that have failed is available but no data is provided on the age of all the pipelines that are in operation. The normal design life for a pipeline is considered as 40 years, however, it can be observed from the incident database that pipelines as old as 60 years are also in operation. Therefore, it is concluded that the age of pipeline has no relation to their failure rate and hence not considered in the failure rate data.

Internal Corrosion

The gas transported by the pipeline consists of mainly dry hydrogen and methane. There are no other components which could cause internal corrosion. Furthermore, the pipelines are generally protected by an internal coating which also enhances their protection from internal corrosion.

Internal corrosion which constitutes 7.6% of all failures in the database is therefore discounted for the HKCG HPTGP.

Welds & Materials

Welds and materials constitute a significant 22.4% of failures. There has been no incident involving HKCG gas pipelines due to poor welding or material defect. HKCG adopt 100% non-destructive testing (NDT) as per IGEM/TD/1 which is more stringent than ANSI B31.8 which requires only a minimum of 75% of the welds to be inspected by NDT for pipeline operating at 20% SMYS or more in class 4 location. Based on these factors, a 90% reduction is assumed for this category.

Other Forces Damage

Previous damaged pipe, vandalism, damage by fire/ explosion, vehicle not engaged in excavation, previous mechanical and intentional damage are not anticipated as these kinds of damage are likely specific to aboveground pipelines. Since aboveground pipelines of HKCG are found in only pressure regulating stations. All pressure regulating stations are surrounded by boundary walls/ fences and usually unmanned. Based on this reason, a 90% reduction is assumed for this category.

Incorrect Operations

These failure cases mentioned include the malfunction of control or relief equipment, etc. This is not applicable to HKCG HPTGP because they are in general all welded and normally do not consist of any equipment such as relief, control, etc., therefore a 90% reduction factor is assumed for failures due to the HPTGP.

Conclusions

The discussion above on the applicability of various failure causes in the US Gas Onshore Transmission Pipeline Failure Database to the HKCG HPTGP and the modification factors to be considered in are summarised in **Table 6-2**. The modified failure rate is derived as 2.30×10^{-5} per km-year based on 322 incidents in 1.40×10^{7} pipeline km-year.

Table 6-2 Modification of US Gas Onshore Transmission Pipeline Failure Data

Cause of Failure	No. of Incidents	%	Reduction factor	No. of incidents considered
1 EXTERNAL FORCE	**918**	**38.9%**		**85**
1.1 Weather	188	8.0%		11
1.1.1 Earth Movement	109	4.6%	90%	11
1.1.2 Temperature	11	0.5%	100%	0
1.1.3 Heavy Rain/ Flood	34	1.4%	100%	0

1.1.4 Lightning	19	0.8%	100%	0
1.1.5 High Wind	11	0.5%	100%	0
1.1.6 Cold Weather	4	0.2%	100%	0
1.2 Excavation Damage	613	26.0%	90%	62
1.3 Other Forces Damage	117	5.0%	90%	12
2 CORROSION	**453**	**19.2%**		**137**
2.1 External	273	11.6%	50%	137
2.2 Internal	180	7.6%	100%	0
3 WELDS, MATERIALS & EQUIPMENT FAILURE	**529**	**22.4%**	**90%**	**53**
4 INCORRECT OPERATIONS	**47**	**2.0%**	**90%**	**5**
5 OTHER	**412**	**17.5%**	**90%**	**42**
TOTAL	**2359**	**100%**		**322**

Analysis of EGIG Data

The EGIG is an industry group of nine (9) companies comprising all of the major gas transmission system operators in Western Europe.

The EGIG database for the period 1970 to 2016 includes 1,366 incidents against the total exposure of 4.11×10^6 km-year [4]. This gives an overall frequency of 3.10×10^{-4} per km-year. The major causes of incidents are given in **Table 6-3**.

Table 6-3 EGIG Incidents Breakdown by Causes

Cause	Proportion (1970 to 2016)
External Interference	46.49%
Corrosion	16.79%
Construction Defects/ Material Failure	16.46%
Ground Movement	4.52%
Hot Tap	8.39%
Others	7.34%

External interference remains the main cause of incidents with gas leakage.

Incidents due to corrosion occur mainly in thin-walled pipelines (less than 10 mm). With regard to external corrosion, pitting is the major contributor. All the incidents with internal corrosion are caused by manufactured gas and not due to natural gas. Although town gas is also a manufactured gas, it has been found that it has no corrosive property and therefore, no internal corrosion has been indicated in the HPTGP.

Construction defects and material failures are more frequent in lines constructed before 1963. Significant improvements in construction methods since 1980's have contributed to substantial reduction in failures due to this cause.

The EGIG database provided a more detailed breakdown of the database depending on the diameter of the pipeline as well as the thickness of the pipeline. This is very useful in determining the failure rate that is most relevant to the pipeline at this QRA Study. As the diameter and wall thickness of the pipeline considered in this study are 750 mm and 12.7 mm, respectively, the accident involving pipelines in the category of 23 to 34 inches and 10 to 15 mm are considered. The revised failure frequencies breakdown in terms of failure causes are included in **Table 6-4**.

Similar to the US database, appropriate modification factors are applied to each of the failure cause categories in **Table 6-4** based on consideration of parameters relevant to the HKCG HPTGP.

Table 6-4 EGIG Incidents - Breakdown of Failure Frequency (1970 - 2016)

Cause	**Frequency per year**	**Reduction Factor Applied**	**Resultant Frequency**
External Interference for Diameter Class 575 mm to 850 mm (23” to 34”)	3.00×10^{-5}	90%	3.00×10^{-6}
Corrosion for Wall Thickness 10 to 15 mm	1.25×10^{-6}	50%	6.25×10^{-7}
Construction Defects/ Material Failure for Pipes Constructed in 1984 to 2013	1.50×10^{-5}	90%	1.50×10^{-6}
Ground Movement	1.40×10^{-5}	90%(2)	1.40×10^{-6}
Hot Tap by Error (1)	2.60×10^{-5}	100%	0.00
Others	2.28×10^{-5}	90%	2.28×10^{-6}
Total	$\mathbf{1.09 \times 10^{-4}}$		$\mathbf{8.81 \times 10^{-6}}$

Notes:

(1) *The practice of hot tapping is not adopted by HKCG and hence not considered relevant.*

(2) *Based on EGIG database, flood, landslide and lightning contributed to about 90% of ground movement; hence based on the discussion in this section, a reduction factor of 90% is applied.*

Conclusions

The modified frequency derived from the EGIG database is 8.81 x 10^{-6} per km per year.

6.2 Pipeline Hole Size Distribution Adopted in this QRA Study

6.2.1 Hole Size Distribution for HKCG HPTGP

Based on the detailed review of international failure database for the HPTGP, the summary of hole size distribution is presented at **Table 6-5**. The detailed review and explanation for the hole size distribution adopted in this QRA Study are summarised at *Sections 0* and *6.2.3.*

Table 6-5 Hole Size Distribution for the HPTGP

Category	**Hole Size**	**Proportion**
Rupture	Full bore	1%
Puncture	100 mm	19%
Hole	50 mm	30%
Leak	25 mm	30%
	10 mm	20%
Total		**100%**

6.2.2 Review of International Failure Database for Gas Pipeline

It is difficult to estimate the hole sizes caused by pipeline damage from incident databases since there is no clear definition on how the incidents must be classified, whether as rupture, puncture or leak and how these have been reported.
The hole size distribution presented in US Gas Onshore Transmission Pipeline Failure Data (1984 – 2013) is as follows:

Line Rupture	28.0%
Leak	35.0%
Other	37.0%

The hole size distribution presented in EGIG data (1970 - 2013) for diameter class 575 mm to 850 mm (23” to 34”) is as follows:

Line Rupture	15.7%
Hole	19.3%
Pinhole/ Crack	65.1%

The hole size distribution presented in UK Health and Safety Executive (UK HSE) [15] for pipework whose diameter is ranged from 500 mm to 1,000 mm is as follows:

Line Rupture	3.2%
Puncture (1/3 pipework diameter > 100 mm)	8.1%
Leak (25 mm)	32.3%
Pin (4 mm)	56.5%

The hole size distribution presented in UK HSE [15] for above ground transfer pipeline is as follows:

Line Rupture (> 100 mm)	2.4%
Large Hole (>75 ≤ 110 mm)	12.4%
Small Hole (>25 ≤ 75 mm)	25.1%
Pin (≤ 25 mm)	60.0%

However, UK HSE failure database has no particular failure database for underground (buried) pipeline.

6.2.3 Pipeline Hole Size Distribution Analysis

Pipeline Line Rupture Scenario Probability

The probability of line rupture scenario from the US is relatively high about 30% while that from EGIG database for diameter class 575 mm to 850 mm (23” to 34”) is about 15%. However, based on HKCG historical failure database, the scenario of line rupture for the HPTGP has never occurred. Also, based on UK HSE [15] failure database, the probability of a line rupture scenario for pipework whose diameter is ranged from 500 mm to 1,000 mm and above ground transfer pipeline are 3.2% and 2.4%, respectively.

Due to design factor of 0.3 on the HPTGP, it is less likely to have leaks propagating to a line rupture scenario; therefore, it is recommended the probability of a line rupture scenario of 1% was adopted in this QRA Study.

Pipeline Puncture (100 mm) Scenario Probability

According to UK HSE [15], the probability of a puncture (100 mm) scenario is relatively low, about 10% for both pipework and above ground transfer pipeline. However, it is not possible to identify the probability of a puncture (100 mm) scenario from both US and EGIG database. Nevertheless, it is conservatively assumed the probability of a puncture (100 mm) scenario for the HPTGP as 19% adopted in this QRA Study.

Pipeline Hole (50 mm) Scenario Probability

The probability of a small hole (>25 - ≤ 75 mm) scenario is about 25% for above ground transfer pipeline from UK HSE failure database [15] and 65.1% from EGIG database, but the probability of hole size (50 mm) scenario is not available from US database and UK HSE failure database for pipework whose diameter is ranged from 500 mm to 1,000 mm. It is recommended the probability of a small hole size (50 mm) scenario as 30% adopted in this QRA Study.

Pipeline Leak (25 mm) Scenario Probability

Based on US database, and UK HSE failure database [15] for pipework whose diameter is ranged from 500 mm to 1,000 mm, the probability of a leak (25 mm) scenario is 35%, and 32.3%, respectively. Therefore, it is reasonable to assume the probability of a leak (25 mm) scenario as 30% adopted in this QRA Study.

Pipeline Small Leak (10 mm) Scenario Probability

The probability of a pin hole (≤25 mm) scenario is 60.0% based on UK HSE failure database for above ground transfer pipeline, and that of pin (3.2 mm) scenario is 56.5% from UK HSE failure database for pipework. Since both database show relatively high failure frequencies for a small leak scenario, it is more suitable to recommend the probability of a small leak scenario (10 mm) as 20% adopted in this QRA Study for the HPTGP.

6.3 Event Tree Analysis

An event tree analysis (ETA) was performed to model the development of each event from the initial release to the final outcome. The event tree takes into consideration whether there is an immediate ignition, a delayed ignition, or no ignition. Orientation of the release is also considered. A generic event tree for the underground HPTGP is depicted in **Figure 6-1**. The possible outcomes include jet fires, flash fires, fireballs, and toxic releases.

The various branches in the event trees are discussed in the following sections.

6.3.1 Orientation of Release

The consequences of a gas release are dependent on the release rate and the orientation of the release. Failures that occur on the top portion of the pipeline result in vertical jet releases (unobstructed) and are governed by momentum jet dispersion/ momentum jet fires. Failures that occur from the bottom portion of the pipeline lose momentum due to impingement/ obstruction with the surrounding earth (for buried sections of pipeline) and therefore are governed by buoyant plume rise followed by Gaussian dispersion. For releases from flanges and valves, the release may be horizontal or inclined in addition being vertical. The probability of orientation of releases considered in this QRA Study is listed in **Table 6-6**.

Table 6-6 Probability of Orientation of Release

Equipment/ Pipework	Vertical	Horizontal	Inclined (45°)
Pressurised Gas Pipeline (buried)	0.5	-	0.5

6.3.2 Ignition Probability

The potential for ignition depends not only on the presence of ignition sources but it is also a function of release rate and duration of release. Larger releases are more likely to be ignited than smaller releases. Similarly, releases that continue for a longer duration have a higher probability of ignition than short duration releases.

Based on a number of sources, Cox et al. [2], an ignition probability was estimated based on spill size for gas and liquid releases as given in **Table 6-7**.

Table 6-7 Ignition Probability for Plant Releases

Leak Release Rate	Probability of Ignition	
	Gas	Liquid
Minor (<1 kg s^{-1})	0.01	0.01
Major (1 to 50 kg s^{-1})	0.07	0.03
Massive (>50 kg s^{-1})	0.30	0.08

6.4 Event Outcome Frequencies

Combining the failure rates with leak size distribution and probabilities for release orientation and ignition probability allows the frequency of each event outcome to be calculated.

7. CONSEQUENCE ANALYSIS

Consequence analysis was involved the following steps:

- Source term modelling; and
- Physical effects modelling.

The source term modelling comprises the application of appropriate discharge rate models to define the release rate, release duration and the quantity of release. The source term modelling output forms the inputs to physical effects modelling such as the dispersion and fire modelling.

7.1 Source Term

The gas dispersion modelling of *SAFETI 8.9* was adopted to estimate the release rates, which were used to determine the immediate ignition probability.

7.2 Physical Effects Modelling

The hazardous scenarios following a release may include:

- Fireball;
- Jet fire;
- Flash fire; and
- Unignited dispersion leading to toxic effects (only 35 barg operating pressure).

7.2.1 Fireball Effects

A release caused by a line rupture of the HPTGP may give rise to a fireball scenario upon an immediate ignition. Due to the transient nature of a release for high pressure condition, the mass of flammable gas entering the fireball for the HPTGP (35 barg) is difficult to estimate. A method proposed by D A Carter in [6] is to calculate at each time step the quantity of fuel that can be consumed in a fireball scenario with the same burning time as the time since the start of the release. The size of the fireball is determined by equating these two values.

Numerical modelling was carried out to estimate the release rate and the mass released for different duration. The mass/duration correlation in the fireball model used in HSE's MISHAP98 model [7], is given as,

$$M = Max\left[(29t/\ \ 4.5A)^3, (29t/\ \ 8.2A)^6\right]$$

where:

M is the flammable gas mass in tonnes;
t is the duration in seconds; and
A is a substance-specific factor.

Substance-specific factor is derived from the stoichiometric combustion equation and is equal to 30.4 for natural gas.

Based on the above, the fireball mass is estimated as about 15 tonnes with a duration of about 12 seconds for the HPTGP at high pressure condition of 35 barg.

The consequence analysis for fireball scenario was conducted by *SAFETI 8.9* [5] with Roberts (HSE) method as the calculation method, which adopts the following equation for estimation of fireball diameter.

$$R = A \times M^{1/3}$$

where:

R is the radius of fireball;
A is a substance-specific factor; and
M is the mass of the fireball.

Persons caught in the open within the fireball diameter are assumed to be 100% fatality. Due to the presence of multi-storey buildings, consideration of fireball rise is critical in estimating the potential for causing injury/fatality to persons at higher levels.

Lihou and Maund [8] suggest a simple relationship to calculate the height of rising methane fireballs:

$$H = 10t$$

where,

t is the duration of fireball, seconds; and
H is the final height, metres.

Based on consequence modelling by *SAFETI 8.9*, the final height of fireball scenario is about 71.5 m and therefore all the floors in a multi-storey building are most likely to be engulfed by the rising fireball.

However, since the release associated with the line rupture scenario was dominated by momentum effects, the initial height of the fireball is likely to be at some elevation from the ground level considerably mitigating the effects at /near ground level.

7.2.2 Jet Fire Effects

Jet fires result from ignited releases of pressurised flammable gas or superheated/ pressurised flammable liquid. The momentum of the release carries the materials forward in form of a long plume entraining air to give a flammable mixture. Combustion in a jet fire occurs in the form of a strong turbulent diffusion flame that is strongly influenced by the momentum of the release.

7.2.3 Flash Fire Effects

In the event that a release is not ignited immediately, the gas will disperse with the wind and may subsequently be ignited if it reaches an ignition source. Portions of the cloud within flammability limits will then burn in a flash fire. The dispersion distance to the LFL will be used as the hazard footprint. Dispersion modelling was performed using *SAFETI 8.9* for the representative weather conditions at a particular site surrounding.

7.2.4 Toxic Effects of Carbon Monoxide

In case the released gas is not ignited, the dispersing cloud may cause toxic effect to people due to the presence of carbon monoxide in town gas. The concentration corresponding to each fatality level can be derived from Probit equation assuming an exposure time of thirty (30) minutes, which is summarised in Assumption Number 1.3.5 in **Appendix 4-1.**

8. RISK SUMMATION & EVALUATION

The hazardous scenarios, the associated frequencies, meteorological data, population data, and suitable modelling parameters identified were input into *SAFETI 8.9*. All risk summation was modelled using *SAFETI 8.9*. The inputs to the software comprise of:

- Release cases file detailing all identified hazardous scenarios, and their associated frequencies and probabilities;
- Release location of hazardous scenarios either at given points or along given routes;
- Weather probabilities file that details the local meteorological data according to a matrix of weather class (speed/stability combinations) and wind directions;
- Population data with the number of people and polygonal shape as well as indoor faction; and
- Ignition sources with ignition probabilities in a given time period.

8.1 Risk Measures

The two (2) types of risk measures considered in this QRA Study are societal risk and individual risk.

8.1.1 Societal Risk

Societal risk is defined as the risk to a group of people due to all hazardous scenarios arising from a hazardous installation or activity. The simplest measure of societal risk is the rate of death or potential loss of life (PLL), which is the predicted equivalent fatality per year. The PLL is calculated as follows:

$$PLL = f_1N_1 + f_2N_2 + f_3N_3 + \ldots\ldots + f_nN_n$$

where:
f_n is the frequency; and
N_n the number of fatalities associated with the nth hazardous scenarios.

Societal risk can also be expressed in the form of an F-N curve, which represents the cumulative frequency (F) of all hazardous scenarios leading to N or more fatalities. This representation of societal risk highlights the potential for accidents involving large numbers of fatalities.

8.1.2 Individual Risk

Individual risk may be defined as the frequency of fatality per individual per year due to the realisation of specified hazardous scenarios. Individual risk may be derived for a hypothetical individual present at a location 100% of time or a named individual considering the probability of his presence etc.

8.2 Risk Evaluation

The risks derived for the existing HPTGP during Operational Phase (2032) of the proposed residential development were evaluated by comparing against the risk criteria in Hong Kong Risk Guidelines [1].

8.2.1 Hong Kong Risk Guidelines

The individual risk criteria specify that the risk of fatality to an off-site individual should not exceed 10^{-5} per year. The individual risk is normally calculated in Hong Kong taking into account occupation or presence factors, protection factors etc. It is generally accepted that the same individual risk criteria should also apply for transport operations. The societal risk guidelines in Hong Kong are shown in **Figure 8-1**. There are three regions indicated on the figure:

- Unacceptable region;
- ALARP region where risk is tolerable providing it has been reduced to a level ALARP; and
- Acceptable region where risk is broadly acceptable.

From an analysis of the above risk results, the dominant contributors to risk were identified and measures to mitigate them may be specified. Such measures may either seek to reduce the likelihood of hazardous scenarios occurring or to reduce the impact of the hazardous scenarios should they occur, to ALARP.

9. RESULTS AND DISCUSSION

9.1 Individual Risk

The individual risk contours of 1E-08 and 1E-09 per year for the existing HPTGP are depicted in **Figure 9-1**.

The individual risk contour of 1E-09 is well confined within the proposed study zone of the HPTGP, all credible hazardous scenarios with frequency higher than 1E-09 per year were considered in this QRA Study. The predicted individual risk level is well below the individual risk criteria as 1E-05 per year from Hong Kong Risk Guidelines.

9.2 Societal Risk

Potential Loss of Life

The societal risks for the Construction Phase (2031) and Operational Phase (2032) of the proposed residential development were expressed in terms of PLL, which are 3.49E-06 and 3.86E-06 per year respectively for the existing HPTGP within the proposed study zone.

The detailed breakdown of PLL for Construction Phase (2031) and Operational Phase (2032) are presented in and the major risk contributor is fireball event from catastrophic rupture of high pressure towngas pipeline.

Table 9-1 Breakdown of Potential Loss of Life – Construction Phase 2031

Ranking	Scenario	Description	PLL
1	HPUGP_UG_Rup_FB	Fireball of catastrophic rupture of high pressure town gas pipeline	3.49E-06
2	HPUGP_UG_Rup_NFB	Flammable effect of catastrophic rupture of high pressure town gas pipeline	1.86E-09
3	HPUGP_UG_100mm_I	Flammable effect of 100 mm leak from high pressure town gas pipeline (Inclined Release)	1.41E-09
4	HPUGP_UG_50mm_I	Flammable effect of 50 mm leak from high pressure town gas pipeline (Inclined Release)	1.22E-09
5	HPUGP_UG_25mm_I	Flammable effect of 25 mm leak from high pressure town gas pipeline (Inclined Release)	7.08E-10
Other			1.26E-09
Total			**3.49E-06**

Table 9-2 Breakdown of Potential Loss of Life – Operational Phase 2032

Ranking	Scenario	Description	PLL
1	HPUGP_UG_Rup_FB	Fireball of catastrophic rupture of high pressure town gas pipeline	3.85E-06
2	HPUGP_UG_Rup_NFB	Flammable effect of catastrophic rupture of high pressure town gas pipeline	1.99E-09
3	HPUGP_UG_100mm_I	Flammable effect of 100 mm leak from high pressure town gas pipeline (Inclined Release)	1.41E-09
4	HPUGP_UG_50mm_I	Flammable effect of 50 mm leak from high pressure town gas pipeline (Inclined Release)	1.22E-09
5	HPUGP_UG_25mm_I	Flammable effect of 25 mm leak from high pressure town gas pipeline (Inclined Release)	7.08E-10
Other			1.26E-09
Total			**3.86E-06**

F-N Result

The F-N results for the existing HPTGP in comparison with Hong Kong Risk Guidelines [1] is presented in **Figure 9-2.** The societal risks for the Construction Phase (2031) and Operational Phase (2032) of the Proposed Development are within "Acceptable" region based on Hong Kong Risk Guidelines [1].

10. CONCLUSION

A QRA study was conducted to assess if the risks posed by the existing HPTGP for the Construction Phase (2031) and Operational Phase (2032) of the proposed residential development are in compliance with Hong Kong Risk Guidelines [1].

Individual Risk

The individual risk contours of 1E-08 and 1E-09 per year were identified for the existing HPTGP and within the proposed study zone. The predicted individual risk level is well below the individual risk criteria as 1E-05 per year from Hong Kong Risk Guidelines.

Societal Risk

The societal risks for the Construction Phase (2031) and Operational Phase (2032) of the Proposed Development are within “Acceptable” region based on Hong Kong Risk Guidelines [1].

Conclusion

It can be concluded that the societal risk and individual risk associated with the existing HPTGP are in compliance with Hong Kong Risk Guidelines [1]. As such, no mitigation measures are required.

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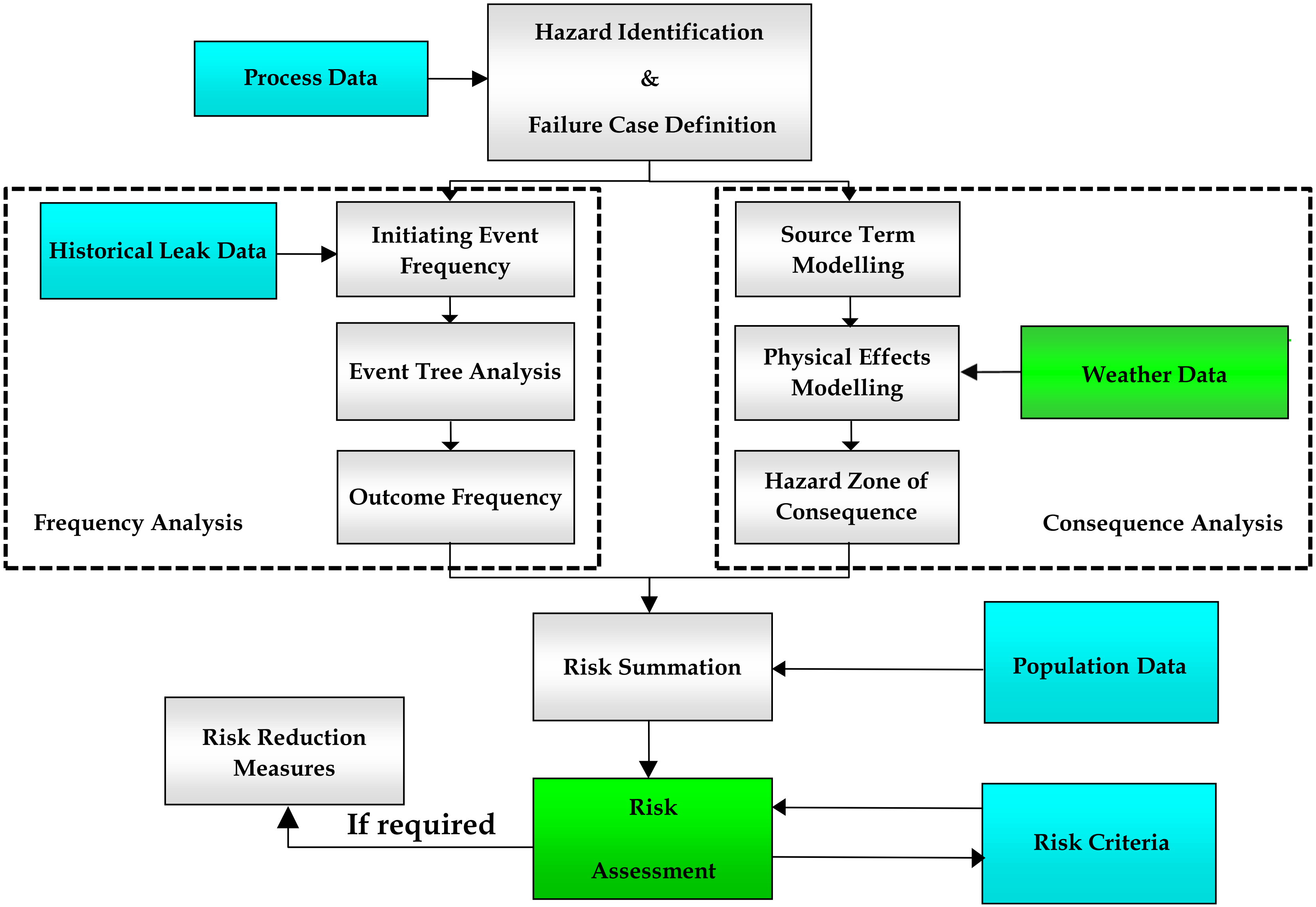


Figure: 2.1		RAMBOLL
Title: Quantitative Risk Assessment Methodology		Drawn by: VW Checked by: SP
Project: Section 16 Planning Application for Proposed Residential Development at Lots 1027, 1029, 1030, 1034 S.A, 1034 S.B, 1039 (Part), 1040, 1042 RP, 1043 RP, 1044 RP (Part), 1045, 1047, 2233 (Part), 2251 S.A RP, 2256 RP, 2315 (Part) and 2316 RP (Part) in D.D. 92 and Adjoining Government Land (New Lot to be Known as Lot 2644 in D.D. 92), Kwu Tung South, Sheung Shui, the New Territories QRA for High Pressure Town Gas Pipeline		Rev.: 3.0 Date: Jul 2025

Figure:	3.1	RAMBOLL
Title:	Master Layout Plan of the Proposed Development	Drawn by: VW Checked by: SP
Project:	Section 12A Planning Application for Proposed Residential Development at Lots 1027, 1029, 1030, 1034 S.A, 1034 S.B, 1039 (Part), 1040, 1042 RP, 1043 RP, 1044 RP (Part), 1045, 1047, 2233 (Part), 2251 S.A RP, 2256 RP, 2315 (Part) and 2316 RP (Part) in D.D. 92 and Adjoining Government Land (New Lot to be Known as Lot 2644 in D.D. 92), Kwu Tung South, Sheung Shui, the New Territories QRA for High Pressure Town Gas Pipeline	Rev.: 2.0 Date: Aug 2025

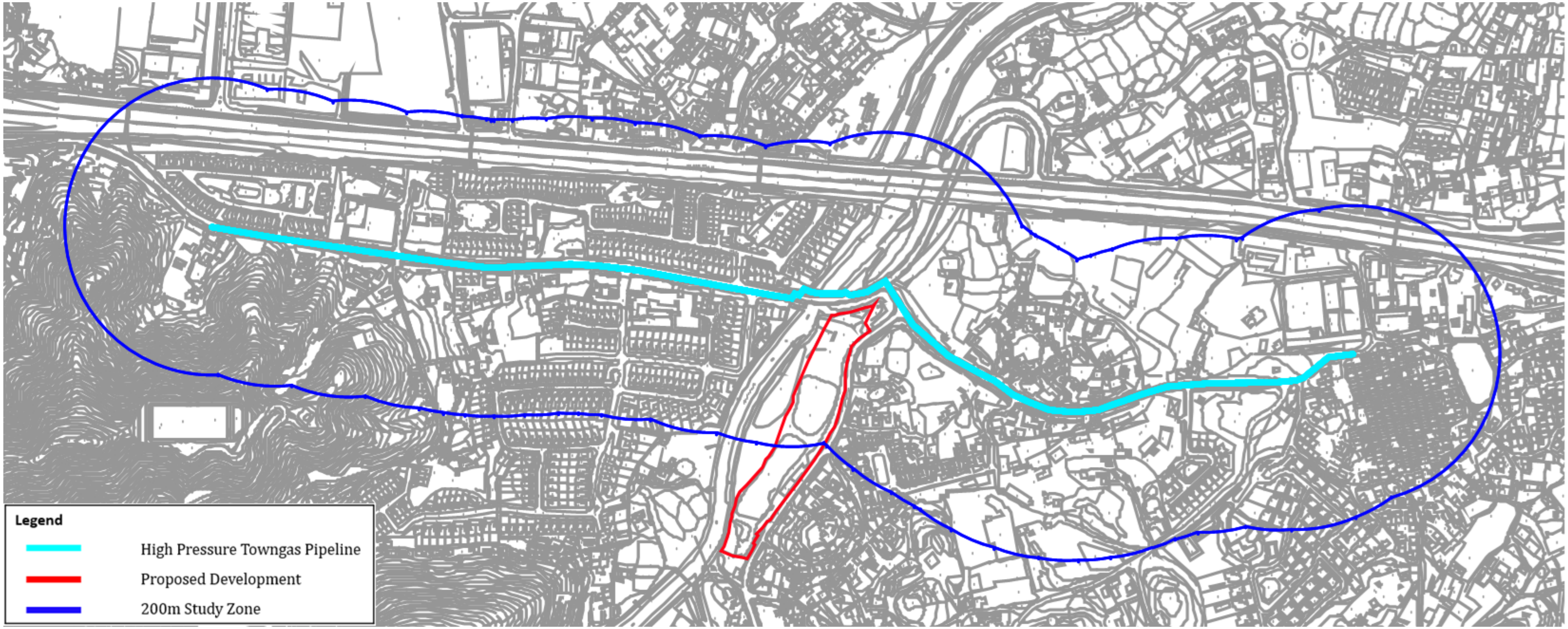


Figure: 3.2		RAMBOLL
Title: Location of Subject Site and its Environs		Drawn by: VW
		Checked by: SP
Project:	Section 16 Planning Application for Proposed Residential Development at Lots 1027, 1029, 1030, 1034 S.A, 1034 S.B, 1039 (Part), 1040, 1042 RP, 1043 RP, 1044 RP (Part), 1045, 1047, 2233 (Part), 2251 S.A RP, 2256 RP, 2315 (Part) and 2316 RP (Part) in D.D. 92 and Adjoining Government Land (New Lot to be Known as Lot 2644 in D.D. 92), Kwu Tung South, Sheung Shui, the New Territories QRA for High Pressure Town Gas Pipeline	Rev.: 3.0 Date: Jul 2025

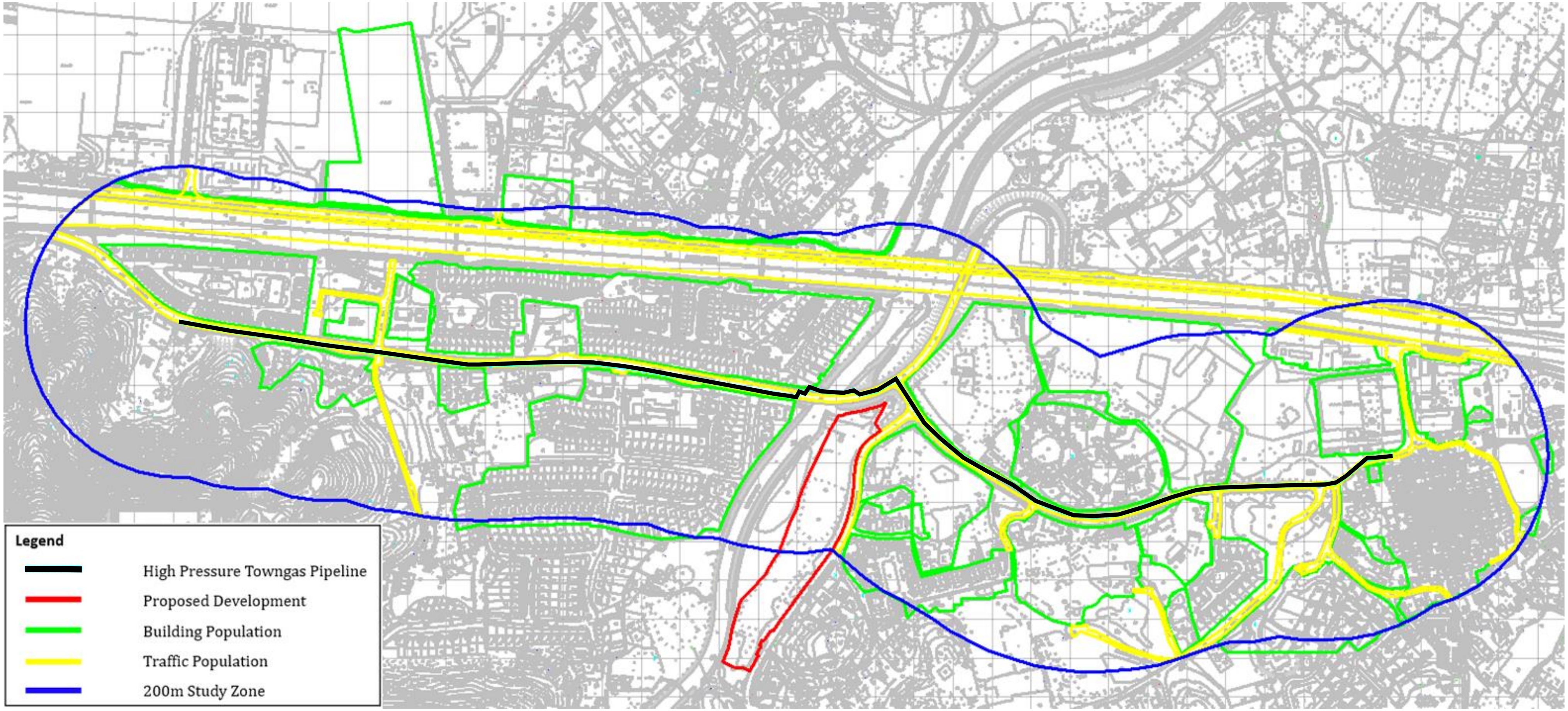


Figure: 3.3		RAMBOLL
Title: Location of the Proposed Residential Development		Drawn by: VW
		Checked by: SP
Project:	Section 16 Planning Application for Proposed Residential Development at Lots 1027, 1029, 1030, 1034 S.A, 1034 S.B, 1039 (Part), 1040, 1042 RP, 1043 RP, 1044 RP (Part), 1045, 1047, 2233 (Part), 2251 S.A RP, 2256 RP, 2315 (Part) and 2316 RP (Part) in D.D. 92 and Adjoining Government Land (New Lot to be Known as Lot 2644 in D.D. 92), Kwu Tung South, Sheung Shui, the New Territories QRA for High Pressure Town Gas Pipeline	Rev.: 3.0 Date: Jul 2025

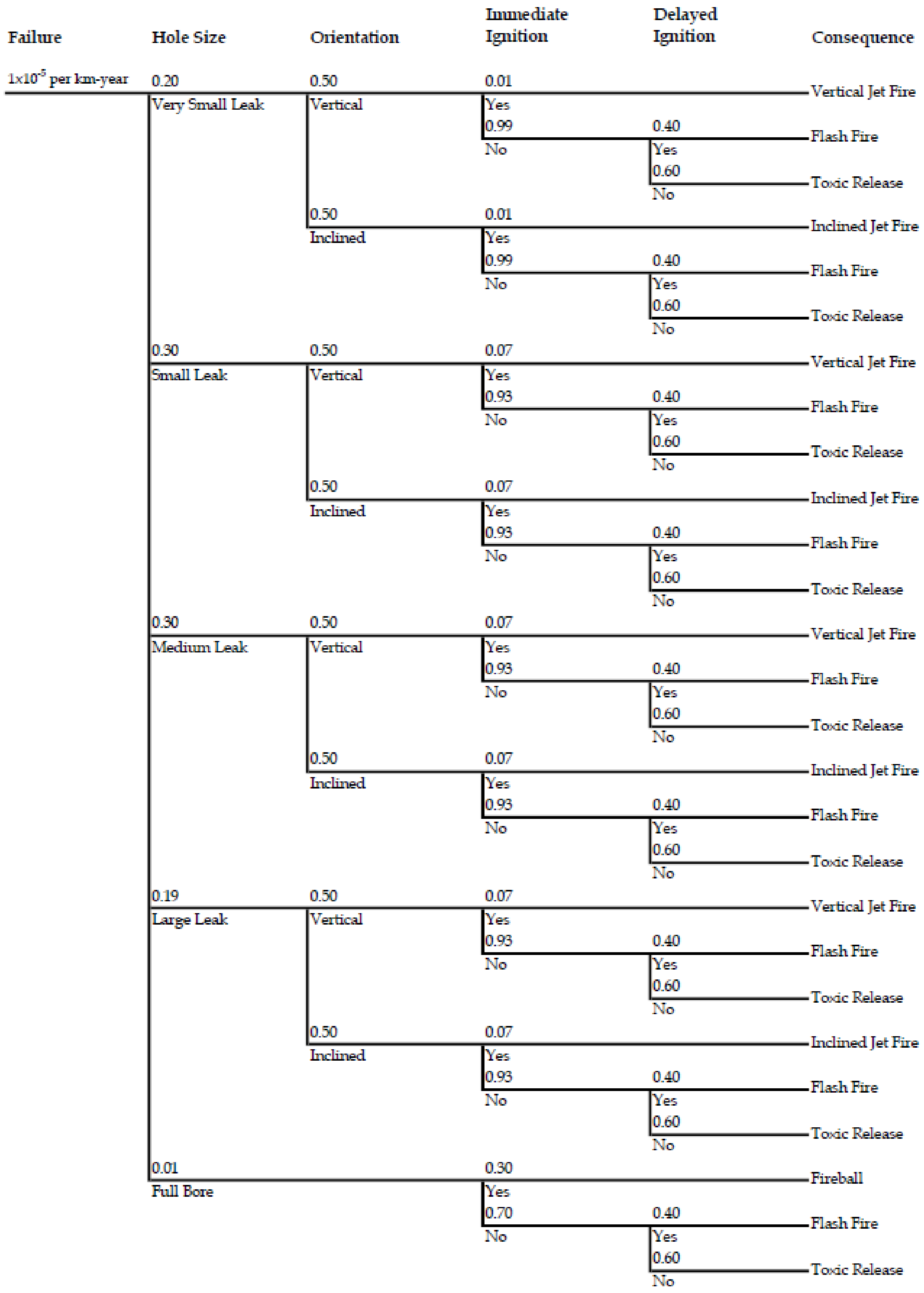


Figure:	6.1	RAMBOLL
Title:	Event Tree for Release from Underground High Pressure Town Gas Pipeline	Drawn by: VW Checked by: SP
Project:	Section 16 Planning Application for Proposed Residential Development at Lots 1027, 1029, 1030, 1034 S.A, 1034 S.B, 1039 (Part), 1040, 1042 RP, 1043 RP, 1044 RP (Part), 1045, 1047, 2233 (Part), 2251 S.A RP, 2256 RP, 2315 (Part) and 2316 RP (Part) in D.D. 92 and Adjoining Government Land (New Lot to be Known as Lot 2644 in D.D. 92), Kwu Tung South, Sheung Shui, the New Territories QRA for High Pressure Town Gas Pipeline	Rev.: 3.0 Date: Jul 2025

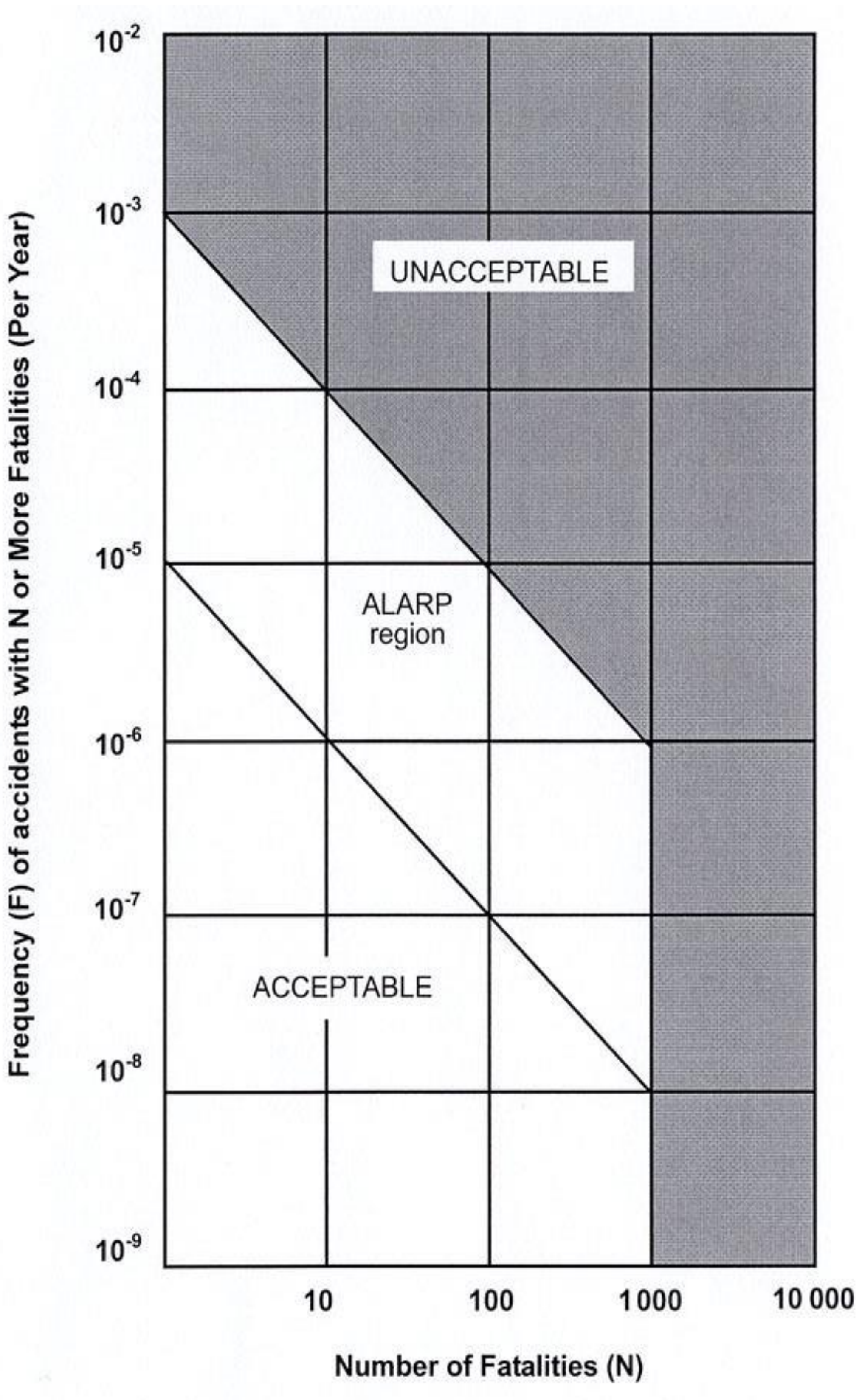


Figure:	8.1	RAMBOLL
Title:	Societal Risk Guidelines for Acceptable Risk Levels from Hong Kong Risk Guidelines	Drawn by: VW
		Checked by: SP
Project:	Section 16 Planning Application for Proposed Residential Development at Lots 1027, 1029, 1030, 1034 S.A, 1034 S.B, 1039 (Part), 1040, 1042 RP, 1043 RP, 1044 RP (Part), 1045, 1047, 2233 (Part), 2251 S.A RP, 2256 RP, 2315 (Part) and 2316 RP (Part) in D.D. 92 and Adjoining Government Land (New Lot to be Known as Lot 2644 in D.D. 92), Kwu Tung South, Sheung Shui, the New Territories QRA for High Pressure Town Gas Pipeline	Rev.: 3.0 Date: Jul 2025

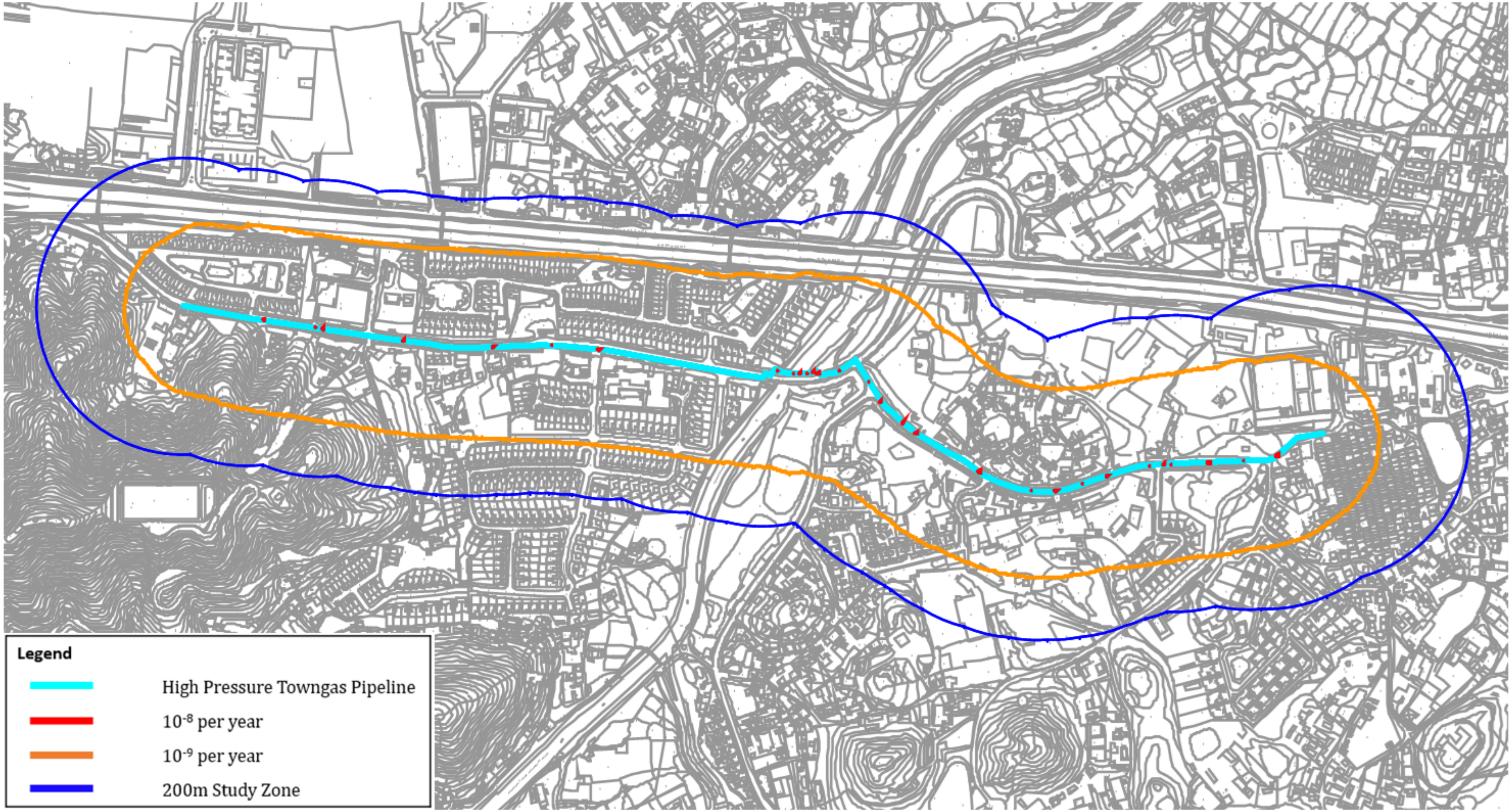


Figure:	9.1	RAMBOLL	
Title:	Individual Risk Contours of HPTGP	Drawn by:	VW
		Checked by:	SP
Project:	Section 16 Planning Application for Proposed Residential Development at Lots 1027, 1029, 1030, 1034 S.A, 1034 S.B, 1039 (Part), 1040, 1042 RP, 1043 RP, 1044 RP (Part), 1045, 1047, 2233 (Part), 2251 S.A RP, 2256 RP, 2315 (Part) and 2316 RP (Part) in D.D. 92 and Adjoining Government Land (New Lot to be Known as Lot 2644 in D.D. 92), Kwu Tung South, Sheung Shui, the New Territories QRA for High Pressure Town Gas Pipeline	Rev.: 3.0 Date: Jul 2025	

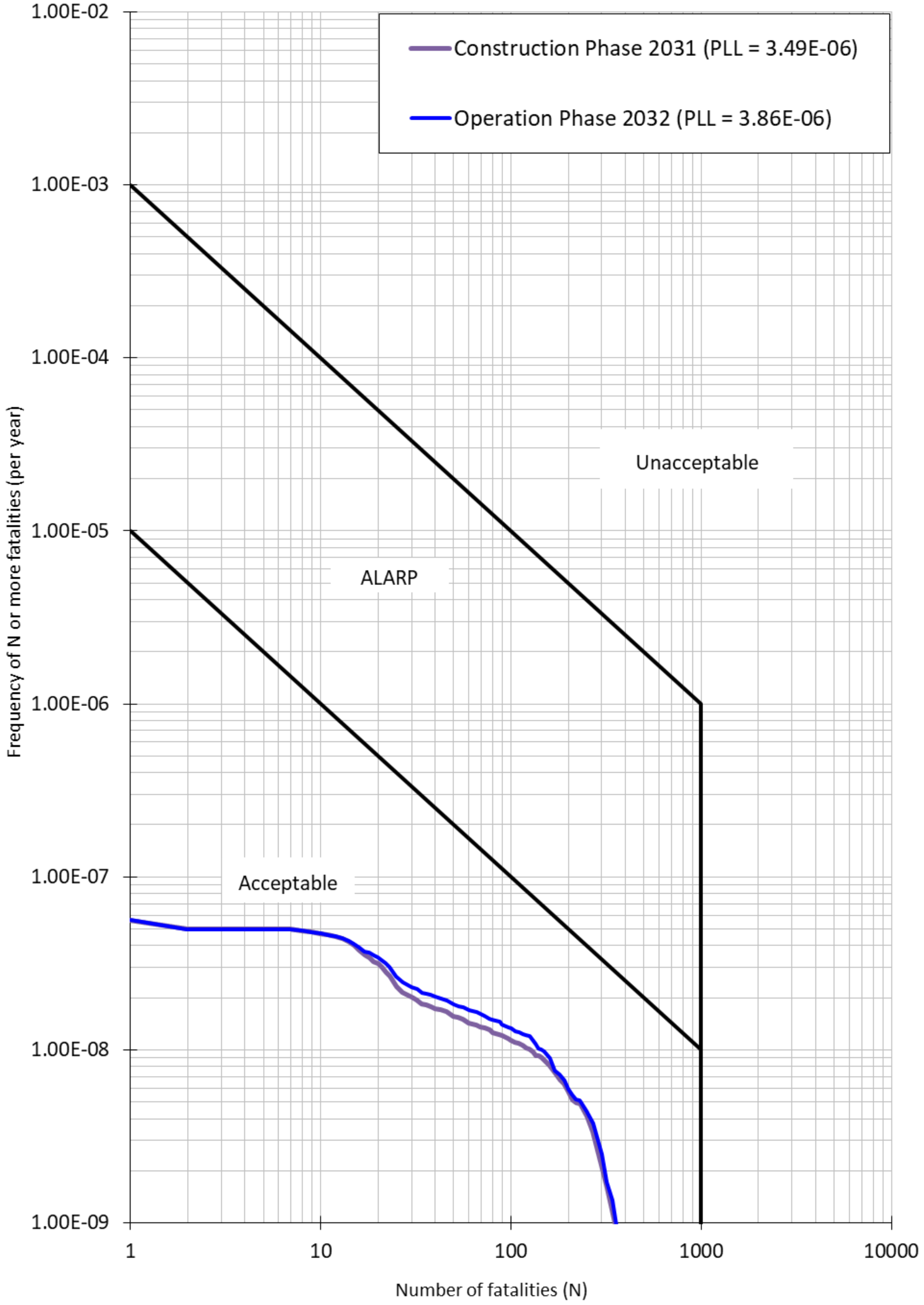
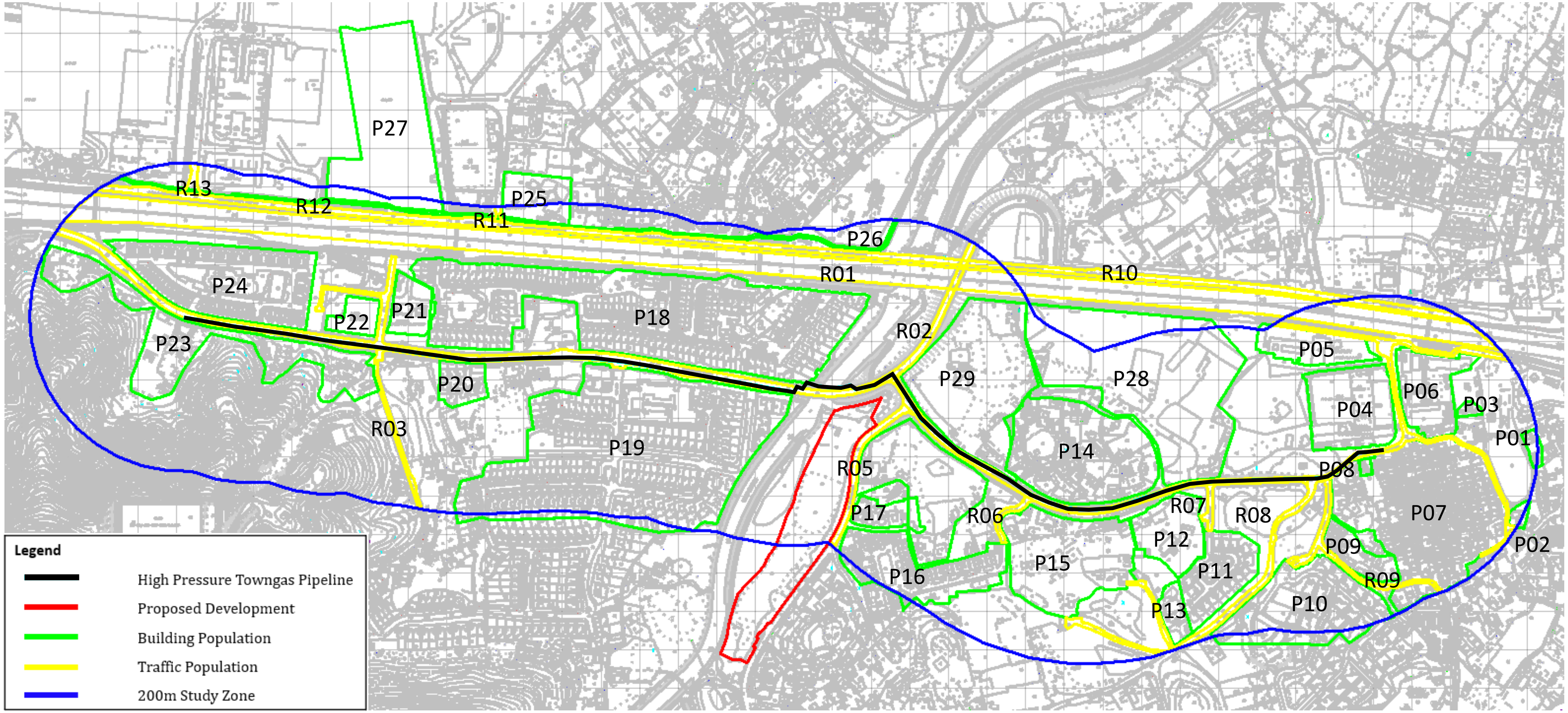


Figure:	9.2	RAMBOLL
Title:	F-N Curves in comparison with Hong Kong Risk Guidelines	Drawn by: VW Checked by: SP
Project:	Section 16 Planning Application for Proposed Residential Development at Lots 1027, 1029, 1030, 1034 S.A, 1034 S.B, 1039 (Part), 1040, 1042 RP, 1043 RP, 1044 RP (Part), 1045, 1047, 2233 (Part), 2251 S.A RP, 2256 RP, 2315 (Part) and 2316 RP (Part) in D.D. 92 and Adjoining Government Land (New Lot to be Known as Lot 2644 in D.D. 92), Kwu Tung South, Sheung Shui, the New Territories QRA for High Pressure Town Gas Pipeline	Rev.: 3.0 Date: Jul 2025

Appendix 3-1

Off-site Population within Proposed Study Zone and Population Map


P27
R13
R12
P25
R11
P26
R01
R10
P24
P21
P22
P18
R02
P23
P20
P29
P28
P05
P04
P06
P03
R03
P19
P14
P01
R05
P08
P17
R06
R07
R08
P07
P12
P09
P02
P15
P16
P11
R09
P13
P10
Legend
High Pressure Towngas Pipeline
Proposed Development
Building Population
Traffic Population
200m Study Zone

Ref	Name	2031 Construction Phase	2032 Operational Phase	Weekday Day	Weekend Day	Night	Fraction Indoors	No of Storeys	Remarks
P01	331-332, 338 Kam Tsin	9	9	50%	80%	100%	95%	3	It is based on generic assumptions and Population and Household Statistics Analysed by District Council District 2023
P02	Pond Side Lodge, 356 Kam Tsin	3	3	50%	80%	100%	95%	3	It is based on generic assumptions and Population and Household Statistics Analysed by District Council District 2023
P03	201-203,205 Kam Tsin	11	11	50%	80%	100%	95%	3	It is based on generic assumptions and Population and Household Statistics Analysed by District Council District 2023
P04	De La Salle Secondary School New Territories	901	854	100%	10%	0%	70%	6	It is estimated based on generic assumptions.
P05	Saint Paul House of Prayer, Sisters of St Paul de Chartres	105	100	70%	100%	0%	95%	2	It is estimated based on generic assumptions.
P06	Kam Tsin Village Ho Tung School	435	412	100%	10%	0%	70%	2	It is estimated based on generic assumptions.
P07	Kam Tsin Lane	834	840	50%	80%	100%	95%	3	It is based on generic assumptions and Population and Household Statistics Analysed by District Council District 2023
P08	Kam Tsin Village Children's Playground	11	10	70%	100%	0%	0%	0	It is estimated based on generic assumptions.
P09	119-136 Kam Tsin	43	43	50%	80%	100%	95%	3	It is based on generic assumptions and Population and Household Statistics Analysed by District Council District 2023
P10	The Royal Oaks	51	52	50%	80%	100%	95%	3	It is based on generic assumptions and Population and Household Statistics Analysed by District Council District 2023
P11	Ascot Park	46	46	50%	80%	100%	95%	3	It is based on generic assumptions and Population and Household Statistics Analysed by District Council District 2023
P12	Link Attempt Limited	42	40	100%	100%	10%	95%	0	It is estimated based on generic assumptions.
P13	18 Kam Tsin Road	3	3	50%	80%	100%	95%	3	It is based on generic assumptions and Population and Household Statistics Analysed by District Council District 2023
P14	Private Housing 1	185	186	50%	80%	100%	95%	3	It is based on generic assumptions and Population and Household Statistics Analysed by District Council District 2023
P15	Private Housing 2	97	97	50%	80%	100%	95%	3	It is based on generic assumptions and Population and Household Statistics Analysed by District Council District 2023
P16	Casas Domingo	71	72	50%	80%	100%	95%	3	It is based on generic assumptions and Population and Household Statistics Analysed by District Council District 2023
P17	Private Houses (Hang Tau Road)	43	43	50%	80%	100%	95%	3	It is based on generic assumptions and Population and Household Statistics Analysed by District Council District 2023
P18	Valais I	376	378	50%	80%	100%	95%	3	It is based on generic assumptions and Population and Household Statistics Analysed by District Council District 2023
P19	Valais II	271	272	50%	80%	100%	95%	3	It is based on generic assumptions and Population and Household Statistics Analysed by District Council District 2023
P20	Eden Place	23	23	50%	80%	100%	95%	3	It is based on generic assumptions and Population and Household Statistics Analysed by District Council District 2023
P21	Lady Ho Tung Welfare Centre	42	40	100%	100%	10%	95%	2	It is estimated based on generic assumptions.
P22	Kwu Tung Market Shopping Centre	42	40	100%	100%	10%	95%	2	It is estimated based on generic assumptions.
P23	Private Housing 3	57	57	50%	80%	100%	95%	3	It is based on generic assumptions and Population and Household Statistics Analysed by District Council District 2023
P24	Europa Garden	179	181	50%	80%	100%	95%	3	It is based on generic assumptions and Population and Household Statistics Analysed by District Council District 2023
P25	Home of Loving Faithfulness	66	67	50%	80%	100%	95%	3	It is based on generic assumptions and Population and Household Statistics Analysed by District Council District 2023
P26	Cycling Track	11	10	70%	100%	0%	0%	0	It is estimated based on generic assumptions.
P27	Construction Site	100	100	100%	50%	0%	0%	0	It is estimated based on generic assumptions.
P28	Site 4	7,249	7,249	50%	80%	100%	95%	21	From OZP: https://www2.ozp.tpb.gov.hk/gist/apply/en_tc/A_NE-KTS_506_TC.pdf
P29	Site A	2,719	2,719	50%	80%	100%	95%	20	From OZP: https://www2.ozp.tpb.gov.hk/gist/amend/en_tc/Y_NE-KTS_14_TC.pdf
P30	Site B	1,277	1,277	50%	80%	100%	95%	20	From OZP: https://www2.ozp.tpb.gov.hk/gist/amend/en_tc/Y_NE-KTS_14_TC.pdf
R01	Fanling Highway	177	186	100%	100%	20%	0%	0	It is based on site visit and ATC2022. No pedestrian was assumed along R01 (Fanling Highway). The parameters for traffic population are listed below: AADT: 62830; Distance: 1.83 km; Speed: 100 km/hr; and average occupancy: 1.5 people/vehicle
R02	Kwu Tung Road	28	29	100%	100%	20%	0%	0	It is based on site visit and ATC2022. 10 pedestrian was assumed along R02 (Kwu Tung Road). The parameters for traffic population are listed below: AADT: 4280; Distance: 1.35 km; Speed: 50 km/hr; and average occupancy: 1.5 people/vehicle
R03	Kwu Tung South Road	11	11	100%	100%	20%	0%	0	It is based on site visit and ATC2022. 10 pedestrian was assumed along R03 (Kwu Tung South Road). The parameters for traffic population are listed below: AADT: 428; Distance: 0.21 km; Speed: 50 km/hr; and average occupancy: 1.5 people/vehicle
R04	Kam Hang Road	11	11	100%	100%	20%	0%	0	It is based on site visit and ATC2022. 10 pedestrian was assumed along R04 (Kam Hang Road). The parameters for traffic population are listed below: AADT: 428; Distance: 0.61 km; Speed: 50 km/hr; and average occupancy: 1.5 people/vehicle
R05	Hang Tau Road	11	11	100%	100%	20%	0%	0	It is based on site visit and ATC2022. 10 pedestrian was assumed along R05 (Hang Tau Road). The parameters for traffic population are listed below: AADT: 42.8; Distance: 0.21 km; Speed: 50 km/hr; and average occupancy: 1.5 people/vehicle
R06	Kam Ka Street	11	11	100%	100%	20%	0%	0	It is based on site visit and ATC2022. 10 pedestrian was assumed along R06 (Kam Ka Street). The parameters for traffic population are listed below: AADT: 42.8; Distance: 0.08 km; Speed: 50 km/hr; and average occupancy: 1.5 people/vehicle
R07	Kam Tsin Path	11	11	100%	100%	20%	0%	0	It is based on site visit and ATC2022. 10 pedestrian was assumed along R07 (Kam Tsin Path). The parameters for traffic population are listed below: AADT: 42.8; Distance: 0.06 km; Speed: 50 km/hr; and average occupancy: 1.5 people/vehicle
R08	Kam Tsin Road	22	23	100%	100%	20%	0%	0	It is based on site visit and ATC2022. 10 pedestrian was assumed along R08 (Kam Tsin Road). The parameters for traffic population are listed below: AADT: 2760; Distance: 1.40 km; Speed: 50 km/hr; and average occupancy: 1.5 people/vehicle
R09	Kam Tsin South Road	11	11	100%	100%	20%	0%	0	It is based on site visit and ATC2022. 10 pedestrian was assumed along R09 (Kam Tsin South Road). The parameters for traffic population are listed below: AADT: 276; Distance: 0.27 km; Speed: 50 km/hr; and average occupancy: 1.5 people/vehicle
R10	Castle Peak Road - Kwu Tung	51	54	100%	100%	20%	0%	0	It is based on site visit and ATC2022. 10 pedestrian was assumed along R10 (Castle Peak Road - Kwu Tung). The parameters for traffic population are listed below: AADT: 10480; Distance: 1.27 km; Speed: 50 km/hr; and average occupancy: 1.5 people/vehicle
R11	Ho Sheung Heung Road	11	11	100%	100%	20%	0%	0	It is based on site visit and ATC2022. 10 pedestrian was assumed along R11 (Ho Sheung Heung Road). The parameters for traffic population are listed below: AADT: 1048; Distance: 0.20 km; Speed: 50 km/hr; and average occupancy: 1.5 people/vehicle
R12	Castle Peak Road - Chau Tau	26	27	100%	100%	20%	0%	0	It is based on site visit and ATC2022. 10 pedestrian was assumed along R12 (Castle Peak Road - Chau Tau). The parameters for traffic population are listed below: AADT: 10480; Distance: 0.49 km; Speed: 50 km/hr; and average occupancy: 1.5 people/vehicle
R13	Pak Sau Road	12	12	100%	100%	20%	0%	0	It is based on site visit and ATC2022. 10 pedestrian was assumed along R13 (Pak Sau Road). The parameters for traffic population are listed below: AADT: 1048; Distance: 0.39 km; Speed: 50 km/hr; and average occupancy: 1.5 people/vehicle
PDC	Proposed Development (Construction Phase)	100	-	100%	50%	0%	0%	0	It is estimated based on generic assumptions.
PD	Proposed Development	-	3,210	50%	80%	100%	95%	16	It is based on information provided by client. A larger flat number, 1070, and an average household size of 3 was used in this QRA conservatively.

Appendix 4-1

Assumptions for this QRA Study

1.1 SURROUNDING DATA ANALYSIS

1.1.1 *Meteorological Data*

Assumption Number: 1.1.1

As per Appendix 4.B of "*Guidelines For Quantitative Risk Assessment, CPR 18E (Purple Book)*" [3], at least six representative weather classes are recommended to be adopted in this QRA Study, covering the stability conditions of stable, neutral and unstable, low and high wind speed. At least the following six (6) weather classes have to be covered in terms of Pasquill classes.

Stability Class	Wind Speed (1)
B	Medium
D	Low
D	Medium
D	High
E	Medium
F	Low

(1): Low wind speed corresponding to 1 – 2 m s^{-1}
Medium wind speed corresponding to 3 – 5 m s^{-1}
High wind speed corresponding to 8 – 9 m s^{-1}

Several rules will be applied to classify the observations in the six weather classes:

1. Observations in the Pasquill stability classes A, A/B, B and B/C are grouped to class B while the wind speed of the weather class is equal to the average wind speed of the observations.

2. Observations in the Pasquill stability classes C, C/D, D are grouped to class D while the wind speed of the weather class is equal to the average wind speed of the observations. Wind speeds below 2.5 m s^{-1}, between 2.5 m s^{-1} and 6 m s^{-1} and above 6 m s^{-1} are classified as the wind speed categories low, medium and high respectively.

3. Observations in the Pasquill stability classes E and F are allocated on the basis of the wind speed. Wind speeds below 2.5 m s^{-1} and above 2.5 m s^{-1} are classified as weather classes F and E respectively. The wind speed in each weather class is equal to the average wind speed of the observations in the weather class.

Assumption Number: 1.1.1

The allocation of six (6) representative weather classes is shown in following figure.

<table>
<tr><th>Wind Speed</th><th>A</th><th>B</th><th>B/C</th><th>C</th><th>C/D</th><th>D</th><th>E</th><th>F</th></tr>
<tr><td>< 2.5 m s^{-1}</td><td colspan="3" rowspan="3">B medium</td><td colspan="3">D low</td><td colspan="2">F low</td></tr>
<tr><td>2.5 – 6 m s^{-1}</td><td colspan="3">D medium</td><td colspan="2" rowspan="2">E medium</td></tr>
<tr><td>>6 m s^{-1}</td><td colspan="3">D high</td></tr>
</table>

Data available can be separated for night-time and daytime, in which case, the period of the day attributed to daytime should have the daytime and night-time statistics added correctly.

The mean temperature of 23.3°C and relative humidity of 78% recorded at the Hong Kong Observatory between years 1981–2010 were used in the modelling.

1.1.2 *Surface Roughness*

Assumption Number: 1.1.2

The roughness parameter reflects the average roughness over which cloud is dispersing. For consequence modelling conducted using *DNV Phast Risk*, a value of 50 cm should be selected representing a conditions of parkland, bushes, and numerous obstacles.

Frequency Analysis

1.1.1 *Failure Frequency Database*

Assumption Number: 1.1.1

Regarding the HPTPG, the failure frequency is assumed as 10^{-5} per km-year adopted in this QRA Study.

1.1.2 Release Hole Size Considered in this QRA Study

Assumption Number: 1.1.2

The following representative leak sizes of the HPTGP should be proposed to consider in this QRA Study:

- Partial failure resulting in a 10 mm hole representing a minor leak;
- Partial failure resulting in a 25 mm hole representing a small leak;
- Partial failure resulting in a 50 mm hole representing a significant leak;
- Partial failure resulting in a 100 mm hole representing a large leak; and
- Full bore rupture release to represent an instantaneous rupture.

The hole size distribution considered for the HPTGP is as follows:

Category	Hole Size (mm)	Proportion
Line Rupture	Full bore	1%
Puncture	100 mm	19%
Hole	50 mm	30%
Leak	25 mm	30%
	10 mm	20%

1.1.3 Release Orientation Probability

Assumption Number: 1.1.3

The consequences of a release from the pipeline depend on the orientation of release. Failures that occur on the top portion of the pipeline result in vertical jet release (unobstructed) and are governed by momentum jet dispersion/ momentum jet fires.

Failures that occur from the bottom portion of the pipeline lose momentum due to impingement/ obstruction with the surrounding earth (for buried sections of pipeline) and therefore are governed by buoyant plume rise followed by Gaussian dispersion, which is considered as inclined orientation release.

The probability of orientation of release from hole up to 100 mm size considered in this QRA Study is listed in following table.

Orientation of release may not be relevant for full bore failures, which are more likely to result in an upward release following the displacement of each cover. Therefore, full bore failures are considered completely unobstructed.

Equipment/ Pipeline	**Vertical**	**Horizontal**	**Inclined (45°)**
Pressurised Gas Pipeline (buried)	0.5	-	0.5

1.1.4 Ignition Probability

Assumption Number: 1.1.4

The potential for ignition depends not only on the presence of ignition sources but it is also function of release rate and duration of release. Larger releases are more likely to be ignited than smaller release. Similarly, release that continue for a longer duration have a higher probability of ignition than short duration releases.

Based on Cox, Lees, Ang et al [1], the ignition probability is estimated based on spill size for gas and liquid release as given in following table. The immediate ignition is estimated based on release rate from Cox et al. [1].

Leak Size	**Probability of Ignition**	
	Gas	**Liquid**
Minor (< 1 kg s^{-1})	0.01	0.01
Major (1 to 50 kg s^{-1})	0.07	0.03
Massive (> 50 kg s^{-1})	0.30	0.08

1.1.5 Probability of delayed ignition

Assumption Number: 1.1.5

As per Appendix 4.A of "Guidelines For Quantitative Risk Assessment, CPR 18E (Purple Book)" [3], the probability of ignition a time interval of one minute for a number of sources is listed as following table:

Source	Probability of Ignition in one minute
1. Point Source	
motor vehicle	0.4
flare	1.0
outdoor furnace	0.9
indoor furnace	0.45
outdoor boiler	0.45
indoor boiler	0.23
ship	0.5
ship transporting flammable materials	0.3
fishing vessel	0.2
pleasure craft	0.1
diesel train	0.4
electric train	0.8
2. Line Source	
transmission line	0.2 per 100 m
road	Note 1
railway	Note 1
3. Area Source	
chemical plant	0.9 per site
oil refinery	0.9 per site
heavy industry	0.7 per site
light industrial warehousing	as for population
4. Population Source	
residential	0.01 per person
employment force	0.01 per person

Note 1:
The ignition probability for a road or railway near the establishment or transport route under consideration is determined by the average traffic density. The average traffic density, d, is calculated as:

$d = NE/v$

where:

N: number of vehicles per hour (hr^{-1})

E: length of a road or railway selection (km)

v: average velocity of vehicle ($km\ hr^{-1}$)

1.2 CONSEQUENCE ANALYSIS

1.2.1 *Source Term Modelling*

Assumption Number: 1.2.1

Most leak sources are at ground level or near ground level. However, taking into account that most release consists of light ends which are buoyant, 1.0 m is considered an accurate representative height for modelling purposes in this QRA Study.

The averaging time considered for dispersion modelling is 18.75 seconds.

1.2.2 Fireball Effect

Assumption Number: 1.2.2

With regard to fireball, a 100% fatality is assumed for any person outdoors within the fireball radius.

Fatality rates due to exposure to thermal radiation from fireball to persons without protective clothing should be determined by "Guidelines For Quantitative Risk Assessment, CPR 18E (Purple Book)" [3] Probit function, as follows:

$$Pr = -36.38 + 2.56 \times \ln(Q^{4/3} \times t)$$

where

Pr Probit corresponding to the probability of death (-)

Q heat radiation ($W\ m^{-2}$)

t exposure time (s)

The exposure time, *t*, is limited to maximum of twenty (20) seconds.

1.2.3 Jet Fire Effect

Assumption Number: 1.2.3

Fatality rates due to exposure to thermal radiation from jet fire to persons without protective clothing should be determined by "Guidelines For Quantitative Risk Assessment, CPR 18E (Purple Book)" [3] Probit function, as follows:

$$Pr = -36.38 + 2.56 \times \ln(Q^{4/3} \times t)$$

where

Pr Probit corresponding to the probability of death (-)

Q heat radiation ($W\ m^{-2}$)

t exposure time (s)

The exposure time, *t*, is limited to maximum of twenty (20) seconds.

1.2.4 Flash Fire Effect

Assumption Number: 1.2.4

With regard to flash fires, a 100% fatality is assumed for any person outdoors within the flash fire envelope. The extent of the flash fire is considered to be the distance to 100% of LFL.

1.2.5 Toxicity Effect (Carbon Monoxide)

Assumption Number: 1.2.5

In case the released gas is not ignited, the dispersing cloud may cause toxic effect to people due to the presence of carbon monoxide. Fatality rates due to toxic exposure is determined by the Probit function, as follows:

$$Y = a + b \times \ln(C^n \times t)$$

Where:

Y is the Probit corresponding to the probability of death;

a, b, n are the constants describing the toxicity of a substance;

C is the concentration of the toxic material in mg m^{-3} or ppm, and

t is the exposure time in minutes.

For this QRA Study, a is taken as -7.4, b is taken as 1 and n is taken as 1 for concentration in mg m^{-3} based on Purple Book.

The exposure time was taken as thirty (30) minutes for off-site public if it is assumed that no breathing apparatus for off-site public.

1.2.6 *Protection Factor*

Assumption Number: 1.2.6

Protection factors are used to factor down the population so that only those exposed to hazardous scenarios are considered in the risk summation for certain types of incidents such as fireball, jet fire, flash fire and toxic incidents.

Three types of protections are considered in this QRA Study:

1. Height Protection Factors

Since the affected areas for jet fire and flash fire are limited (i.e. do not cover the entire building for high rise structures), a height protection factor is considered to exclude the population residing on higher floors of a building (higher than 10 m or 3 storeys). It is because the consequence of hazardous scenarios is less than 10 m height based on *PHAST Risk* modelling.

In case of fireball scenario, no such protection factor is applied as the diameter of the fireball and the rise of fireball likely engulfs the whole building height if the buildings along the route are mainly low to medium rise.

2. Indoor Protection Factors

A protection factor is considered for effects from thermal radiation and toxic gas for indoor population. Protection for indoor population against all fire scenarios including jet fire, flash fire and fireball) and toxic effects is considered by assuming that the indoor fatality rate is about 10% of the outdoor fatality rate.

For persons within the fireball radius, it is assumed 50% of the outdoor fatality rate.

3. Shielding Protection Factors

A shielding factor is generally used to take credit for the shielding of buildings by other buildings from fire effects.

By superimposing the hazard zone from fireball scenario on an area map, a shielding factor is derived for the houses or buildings in the immediate vicinity, as follows:

- An indoor protection factor of 50% is applied to the closet buildings, i.e. which stand facing directly the pipeline route; and
- A shielding factor of 50% is applied only to these buildings located behind the closet buildings along the pipeline route.

2 REFERENCE

[1] Cox, IChemE, *Lees and Aug, Classification of Hazardous Locations*, 1990.

[2] ERM's in house database, Failure Rate Evaluation Tool (FRET).

[3] Purple Book, *Guidelines for Quantitative Risk Assessment*, 1999.