APPENDIX 7.03 HIGH PRESSURE (HP) UNDERGROUND TOWN GAS TRANSMISSION PIPELINES

TABLE OF CONTENT

List of Annex

1 INTRODUCTION

1.1 Background

1.1.1.1 The High Pressure (HP) underground town gas transmission pipeline to Sha Tin originates at the Tai Po Gas Production Plant, runs subsea along Tolo Harbour and Shing Mun River to the offtake and pigging station in City One, Sha Tin. The HP underground town gas transmission pipeline continues towards Ma On Shan along Tate's Cairn Highway and Sai Sha Road, and arrives the downstream Sai O pigging station. According to the information provided by the Hong Kong and China Gas Company (HKCG), the length of HP underground town gas transmission pipeline between the 2 pigging stations is approximately 7.8km, of which 1.9km lies in the vicinity of the proposed transport route of explosives between A Kung Kok Shan Road and the Project Site. **Figure 1.1** shows the location plan of the study.

1.1.1.2 Along this section, there is also a pair of 750mm diameter twin HP submarine town gas transmission pipelines running along Shing Mun River, which is more than 150m away from the proposed transport route of explosives as well as the Project Site. The Project also proposed to install 2,000mm diameter emergency outfall by pipe jacking method across Shing Mun River Channel, HKCG has been consulted on the potential impact to the gas pipelines during construction and operation of the sewerage pipes. Advice from HKCG including to provide a minimum vertical separation of 10m between the gas pipelines and the sewerage pipes, and to control the vibration acting on the gas pipelines to less than 25mm/sec peak particle velocity and the peak magnitude over the gas pipelines to less than 0.2mm will be incorporated to the design of the sewerage pipes during detailed design stage. Taking into consideration the separation distance and the design of the sewerage pipes, the HP submarine town gas transmission pipelines will not be further considered in this study. **Figure 1.2** shows the alignment of the proposed emergency outfall.

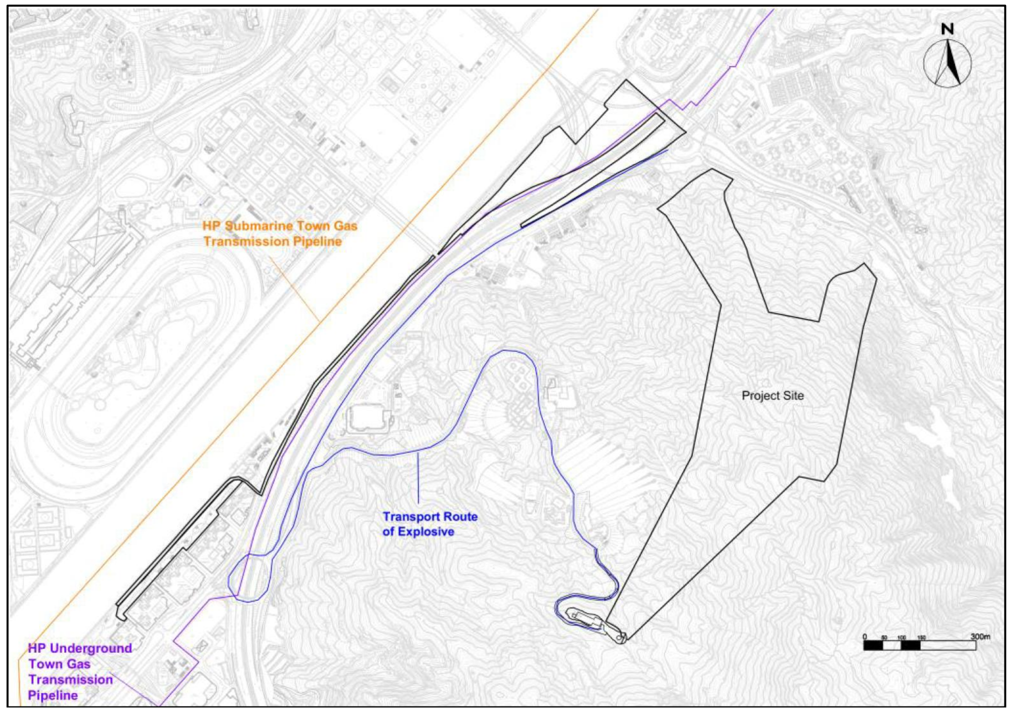


Figure 1.1 Location Plan of the Study

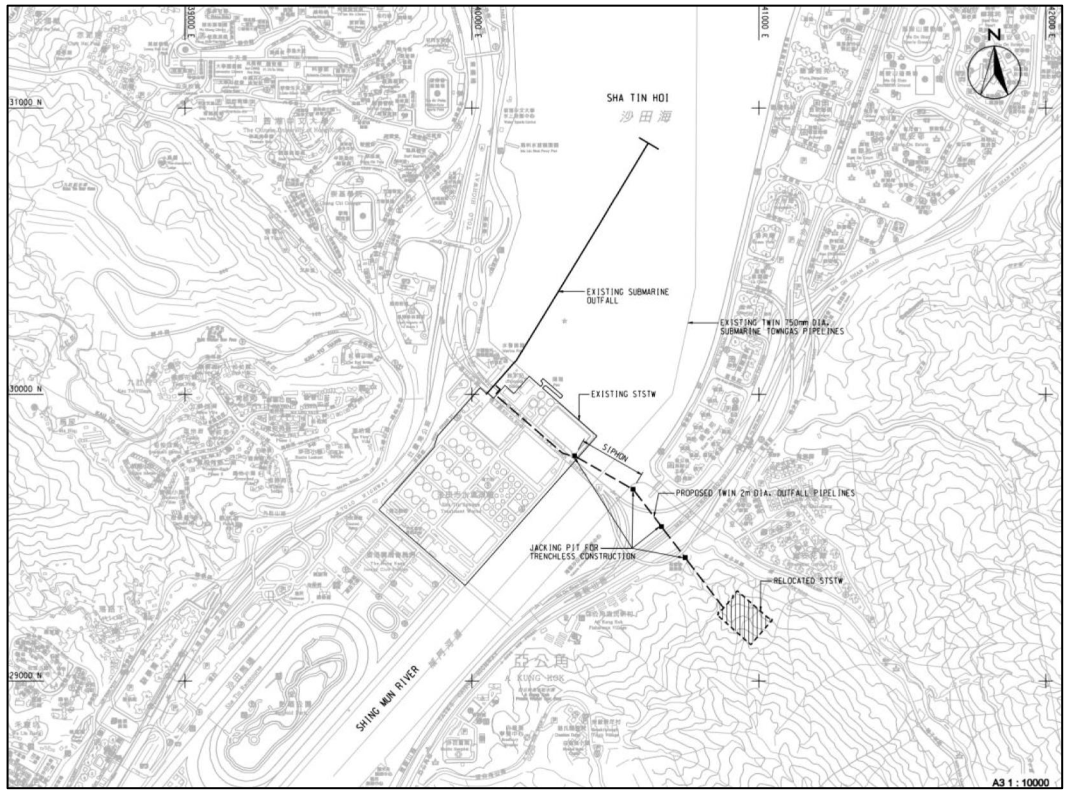


Figure 1.2 Alignment of the Proposed Emergency Outfall of Relocated STSTW

1.2 Hazard to Life Assessment Objectives and Risk Criteria

1.2.1 Objectives

1.2.1.1 The Hazard to Life Assessment requirements as detailed in Appendix G of the EIA Study Brief are shown below:

(a) Identify hazardous scenarios associated with the operation of HP underground town gas transmission pipelines and then determine a set of relevant scenarios to be included in a Quantitative Risk Assessment (QRA);

(b) Execute a QRA of the set of hazardous scenarios determined in (a), expressing population risks in both individual and societal terms;

(c) Compare individual and societal risks with the criteria for evaluating Hazard to Life stipulated in Annex 4 of the TM; and

(d) Identify and assess practicable and cost-effective risk mitigations.

1.2.2 EIAO-TM Risk Criteria

1.2.2.1 Annex 4 of the EIAO-TM specifies the Individual and Societal Risk Guidelines. The Hong Kong Government Risk Guidelines (HKRG) per the EIAO TM Annex 4 states that the individual risk is the predicted increase in the chance of fatality per year to an individual due to a potential hazard. The individual risk guidelines require that the maximum level of individual risk should not exceed 1 in 100,000 per year i.e. 1 $x10^{-5}$ per year. Societal risk expresses the risks to the whole population. It is expressed in terms of lines plotting the cumulative frequency (F) of N or more deaths in the population from incidents at the installation. Three F-N risk lines are used in the HKRG that demark “Acceptable” or “Unacceptable” societal risks. To avoid major disasters, there is a vertical cut-off line at the 1000 fatality level extending down to a frequency of 1 in a billion years. The

intermediate region indicates the acceptability of societal risk is borderline and should be reduced to a level which is “as low as reasonably practicable” (ALARP). It seeks to ensure that all practicable and cost effective measures that can reduce risk will be considered. The HKRG is presented graphically in **Figure 1.3** below.

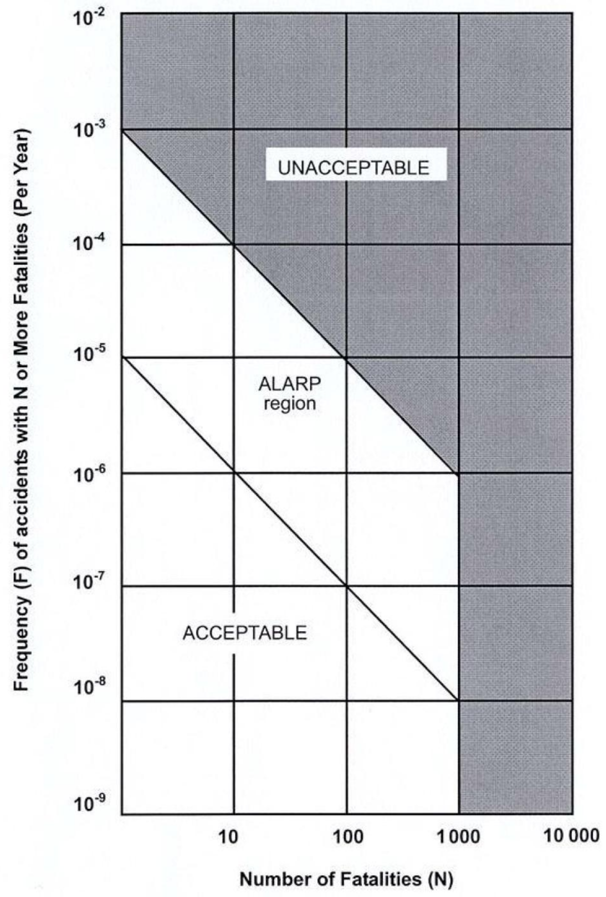


Figure 1.3 Societal Risk Guidelines for Acceptable Risk Levels

1.2.3 Institution of Gas Engineers and Managers (IGEM) Risk Guidelines

1.2.3.1 Criteria for individual risk levels and societal risk levels for gas pipelines recommended by the IGEM have also been considered in this study.

1.2.3.2 The criteria for individual risk levels have been determined by HSE based on historic risk of death. The framework for the tolerability of individual risk is shown in **Figure 1.4**. The framework specifies ranges of risk values which define the limits of “broadly acceptable”, “tolerable if ALARP”, and “intolerable”. Individual risk level less than $1×10^{-6}$/year is considered broadly acceptable for general public.

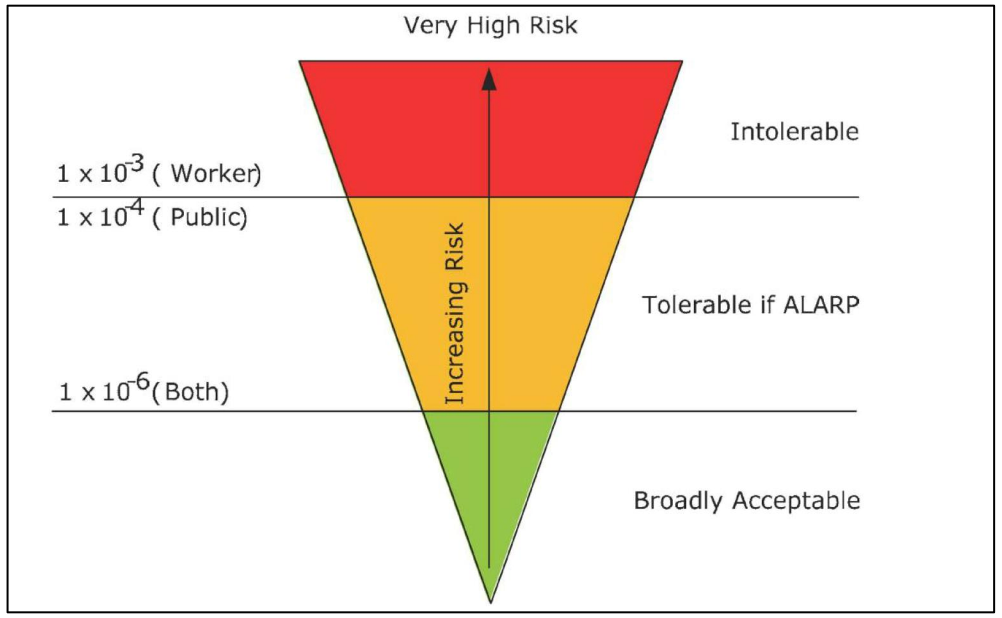


Figure 1.4 Framework for the Tolerability of Individual Risk in IGEM

1.2.3.3 For societal risk, the IGEM/TD/1 criterion envelope relates to a 1.6km length of pipelines and is shown in **Figure 1.5**. If the societal risk exceeds the "negligible or acceptable" risk limits, mitigation measures should be required to reduce risks to acceptable.

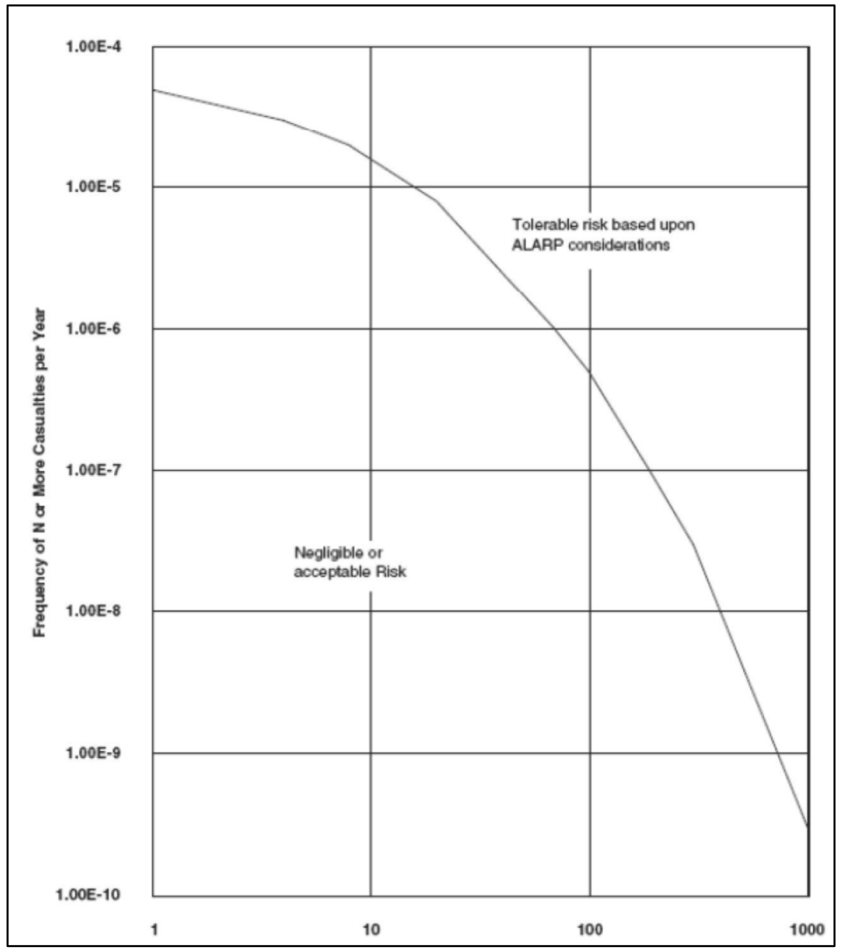


Figure 1.5 IGEM F-N Criterion Envelope

1.3 Study Approach

1.3.1.1 The QRA consists of the following 6 main tasks:

(a) **Data / Information Collection and Update:** Collect relevant data / information which is necessary for the hazard assessment.

(b) **Hazard Identification:** Identify hazardous scenarios associated with the HP underground town gas transmission pipelines.

(c) **Frequency Estimation:** Estimate the frequencies of each hazardous event leading to fatalities with full justification by reviewing historical accident data and previous similar projects.

(d) **Consequence Analysis:** Analyse the consequences of the identified hazardous scenarios.

(e) **Risk Integration and Evaluation:** Evaluate the risks associated with the identified hazardous scenarios. The evaluated risks will be compared with the HKRG to determine their acceptability. Where necessary, risk mitigation measures will be identified and assessed to comply with the "as low as reasonable practicable" (ALARP) principle used in the HKRG.

(f) **Identification of Mitigation Measures:** Review the recommended risk mitigation measures from previous studies, practicable and cost-effective risk mitigation measures will be identified and assessed as necessary. Risk outcomes of the mitigated case will then be reassessed to determine the level of risk reduction.

2 DESCRIPTION OF SURROUNDINGS

2.1 Surrounding Population

2.1.1 Introduction

2.1.1.1 Societal risk is a measure of the consequence magnitude and the frequency of the hazardous events. In order to establish the impact of any release (the number of people likely to be affected) in the future, it is necessary to have a good knowledge of the surrounding population levels. It includes residential population, government and institutional population and transport population. The main population groups in the vicinity of the 1.9km section of the proposed transport route of explosives interfacing with the HP underground town gas transmission pipeline are shown in **Figure 2.1**.

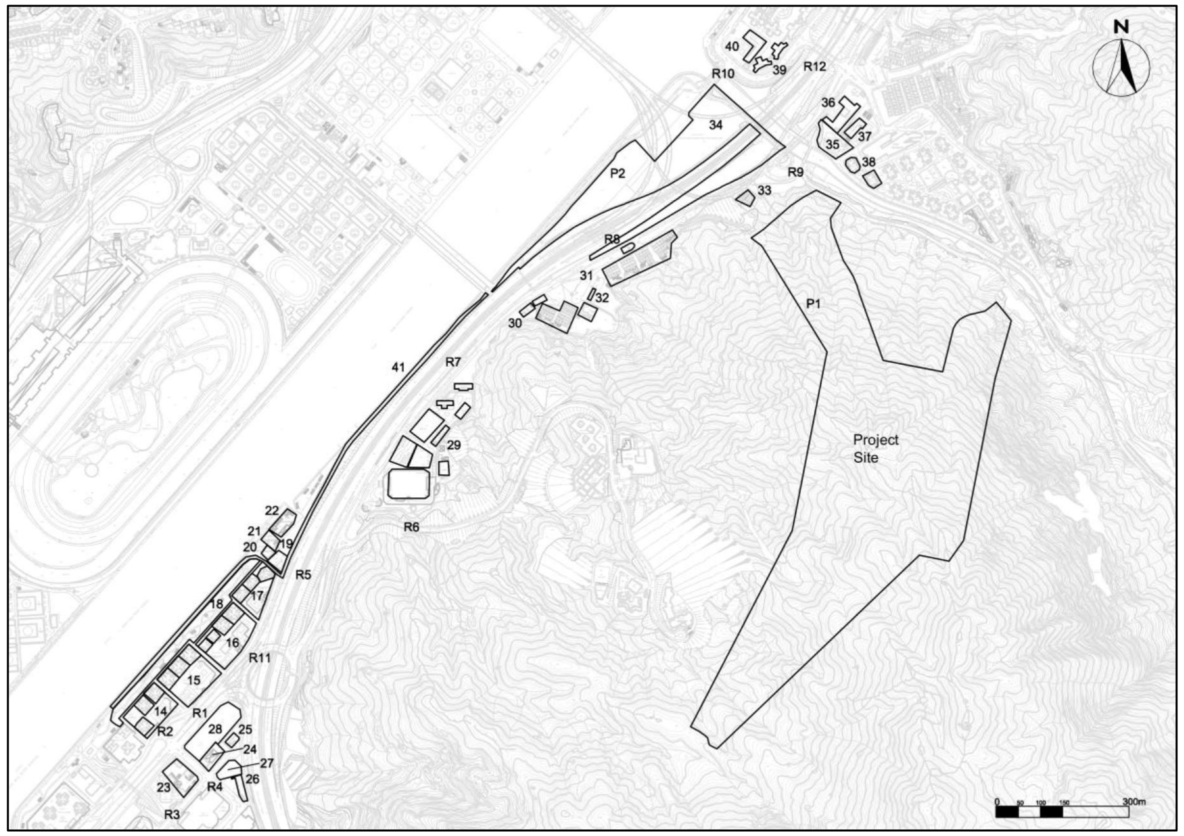


Figure 2.1 Population Groups

2.1.2 Land and Building Population

2.1.2.1 Construction of the Project is tentatively scheduled to substantially commence in 2017 for completion in 2027, and the peak cavern construction year is Year 2022. Assessment years for construction stage and operational stage of the Project would thus be Year 2022 and Year 2027 respectively. The populations in each area are listed in **Table 2.1**.

2.1.2.2 Population estimations are based on site surveys, Centamap, and data from the enhanced 2011-based Territorial Population and Employment Data Matrix (TPEDM) provided by the Planning Department. Planning Department, Lands Department, Civil Engineering and Development Department, and Home Affairs Department have been consulted on the population assumptions.

Table 2.1 Land and Building Population Data

Population ID	Description	Population in Construction Stage (Year 2022) [Note 1][Note 2]	Population in Operational Stage (Year 2027) [Note 1][Note 2]
14	Garden Vista	1662	1615
14a	Block D	562	545
14b	Block E	562	545
14c	Block F	432	419
14d	Car park under podium of Block D, Block E & Block F	30	30
14e	Podium of Block D, Block E & Block F	76	76
15	Pictorial Garden (Stage 1)	1958	1904
15a	Abbey Court	605	587
15b	Belleve Court	605	587
15c	Capilano Court	605	587
15d	Car park under podium	40	40
15e	Podium	103	103
16	Pictorial Garden (Stage 2)	1831	1779
16a	Delite Court	281	272
16b	Elegant Court	281	272
16c	Forum Court	562	545
16d	Galaxy Court	562	545
16e	Car park under podium	40	40
16f	Podium	105	105
17	Pictorial Garden (Stage 3)	1212	1176
17a	Hillview Court	373	361
17b	Iris Court	373	361
17c	Juniper Court	373	361
17d	Car park under podium	30	30
17e	Podium	63	63
18	On King Street Park	100	100
19	Open Car Park (near Jockey Club Shek Mun Rowing Centre)	10	10
20	Jockey Club Shek Mun Rowing Centre	50	50
21	Hong Kong China Dragon Boat Association Shatin Shek Mun Training Centre	50	50
22	Hong Kong Canoe Union Shatin Training Centre	50	50
23	Site Offices (DSD / LandsD)	60	60
24	Petrol Station	10	10
25	Shek Mun Fresh Water Booster Pumping Station	0	0

Population ID	Description	Population in Construction Stage (Year 2022) [Note 1][Note 2]	Population in Operational Stage (Year 2027) [Note 1][Note 2]
26	On Sum Street Substation	0	0
27	Sha Tin Community Green Station	60	60
28	Open Car Park (near Pumping House on Ping Street)	20	20
29	Shatin Hospital	1296	1292
29a	Shatin Hospital	975	975
29b	Open Car Park	10	10
29c	Transport Terminus	30	30
29d	Football Field	22	22
29e	Basketball Court	16	16
29f	Jockey Club Centre for Positive Ageing	25	25
29g	A Kung Kok Government Quarters Block B	104	102
29h	A Kung Kok Government Quarters Block C	104	102
29i	Tennis Court	10	10
30	A Kung Kok Sewage Pumping Station	10	10
31	Ah Kung Kok Fishermen's Village	1061	1045
31a	Ah Kung Kok Fishermen’s Village (a)	374	368
31b	Ah Kung Kok Fishermen’s Village (b)	639	629
31c	Basketball Court	16	16
31d	Football Field	22	22
31e	A Kung Kok Sitting-out Area	10	10
32	Hong Kong Mountaineering Union	0	0
33	Evangelical Lutheran Church of Hong Kong Shatin Youth Centre Recreational Camp and Training Centre	0	0
34	Custom and Excise Department Shatin Vehicle Detention Centre [Note 4]	0	800
35	A Kung Kok Street Garden	10	10
36	Ma On Shan Tsung Tsin Secondary School	1406	1406
37	Kowloon City Baptist Church Hay Nien Primary School	1124	1124

Population ID	Description	Population in Construction Stage (Year 2022) [Note 1][Note 2]	Population in Operational Stage (Year 2027) [Note 1][Note 2]
38	Chevalier Garden	1136	1120
38a	Chevalier Garden Block 6	568	560
38b	Chevalier Garden Block 5	568	560
39	Kam Tai Court	1436	1414
39a	Kam Ying House Block H	718	707
39b	Kam Tin House Block J	718	707
40	S.K.H. Ma On Shan Holy Spirit Primary School	1318	1318
41	Shing Mun River Promenade	36	36
P1	Proposed Project Site [Note 3]	500	300
P2	Proposed Project Site Office and Works Area	500	0

Note 1: Populations for residential are estimated based on domestic household size in enhanced 2011-based TPEDM.
Note 2: School populations estimated based on the school information from the Education Bureau.
Note 3: It is assumed that there will be a maximum of 500 construction workers in construction stage and a maximum of 300 staff and visitors in operational stage in the project site.
Note 4: The centre will be changed to site office during cavern construction stage. The land use after completion of construction works is not known at the moment. In view that with the constraint imposed by Tate's Cairn Highway, it is unlikely to have high density population there. Therefore it is assumed that it will be an educational institution.

2.1.3 Road & Train Population

2.1.3.1 Traffic data is based on the latest Annual Traffic Census (ATC) [12] and Based District Traffic Model (BDTM) developed by the Transport Department. Speed limits on Tate’s Cairn Highway ad Ma On Shan Road are assumed to be 80km/hr and 70km/hr respectively, and the speed limit on other roads is assumed to be 50km/hr. The road population is predicted based on the following equation:

*Population Density (persons/km) = No. of person/vehicle * No. of vehicles/hr / Speed*

2.1.3.2 The occupancies for each vehicle type and vehicle mix are taken as the average at the 4 core stations which are considered representative of the road traffic in the study area. Details please refer to Section 4.2.3 of **Appendix 7.01**. The average occupancy is estimated to be 4.34 persons/vehicle.

2.1.3.3 The Ma On Shan Line runs along the Tate’s Cairn Highway and Ma On Shan Road, and is in parallel to the HP underground town gas transmission pipelines. The maximum carrying capacity of Ma On Shan Line is currently 30,500 people per hour per direction with the use of 4 train compartments per train [3]. With the commissioning of the section between Tai Wan and Hung Hom stations of SCL in 2018, the number of train compartments of Ma On Shan Line will be increased to 8 [3]. It is assumed that the maximum carrying capacity will then be increased to 61,000 per hour per direction. The maximum train population density is calculated by the following formula:

Population Density (persons/km) = Passenger per hour / Train Speed

2.1.3.4 Maximum speed of the Ma On Shan Line is 110km/hr, assuming that the train is operating with average speed of around 80km/hr, the population density is calculated to be 1,525 persons/km.

Table 2.2 Road and Train Population to be Considered in Year 2022

Population ID	Description	Travel Speed (km/hr)	Occupancy (persons per vehicle)	No. of Vehicle at peak hour (veh/hr)	Population Density (persons/km)
R1	Tai Chung Kiu Road	50	4.34	2,917	253
R2	On King Street	50	4.34	583	51
R3	On Ping Street	50	4.34	729	63
R4	On Sum Street	50	4.34	729	63
R5	Tate's Cairn Highway	80	4.34	8,677	470
R6	A Kung Kok Shan Road	50	4.34	111	10
R7	A Kung Kok Street	50	4.34	966	84
R8	Ma On Shan Road	70	4.34	2,173	135
R9	Mui Tsz Lam Road	50	4.34	97	8
R10	Hang Tai Road	50	4.34	435	38
R11	Shek Mun Interchange	50	4.34	1,742	151
R12	MTR - Ma On Shan Line	80	--	122,000*	1,525

Note: * This figure presents the total number of passengers travelled on the Ma On Shan Line per hour in both directions. It is calculated based on maximum carrying capacity of Ma On Shan Line and assumed that passenger flow reaches the maximum carrying capacity for both directions as conservative approach.

Table 2.3 Road and Train Population to be Considered in Year 2027

Population ID	Description	Travel Speed (km/hr)	Occupancy (persons per vehicle)	No. of Vehicle at peak hour (veh/hr)	Population Density (persons/km)
R1	Tai Chung Kiu Road	50	4.34	3,066	266
R2	On King Street	50	4.34	613	53
R3	On Ping Street	50	4.34	767	67
R4	On Sum Street	50	4.34	767	67
R5	Tate's Cairn Highway	80	4.34	9,492	515
R6	A Kung Kok Shan Road	50	4.34	111	10
R7	A Kung Kok Street	50	4.34	583	51
R8	Ma On Shan Road	70	4.34	2,284	142
R9	Mui Tsz Lam Road	50	4.34	58	5
R10	Hang Tai Road	50	4.34	457	40
R11	Shek Mun Interchange	50	4.34	1,586	138
R12	MTR - Ma On Shan Line	80	--	122,000*	1,525

Note: * This figure presents the total number of passengers travelled on the Ma On Shan Line per hour in both directions. It is calculated based on maximum carrying capacity of Ma On Shan Line and assumed that passenger flow reaches the maximum carrying capacity for both directions as conservative approach.

2.1.4 Time Modes

2.1.4.1 To be consistent with the hazard assessment for the storage, transport and use of explosives methodology, 3 day categories (Weekdays, Saturdays and Sundays) with 4 time periods (AM Peak, Daytime, PM Peak and Night) for population have been considered in this study. A total of 6 time modes are being considered and are summarised in **Table 2.4**.

Table 2.4 Definitions of Time Modes

Time Mode	Definition	Proportion of Time
Night	All days 8:00pm to 7:00am	0.4583
AM Peak	All days 7:00am to 9:00am	0.0833
PM Peak	All days 6:00pm to 8:00pm	0.0833
Weekday Daytime	Weekdays 9:00am to 6:00pm	0.2679
Saturday Daytime	Saturdays 9:00am to 6:00pm	0.0536
Sunday Daytime	Sundays 9:00am to 6:00pm	0.0536

2.2 Meteorology

2.2.1.1 Meteorological data is required for consequence modelling and risk calculation. Consequence modelling (dispersion modelling) requires wind speed and stability class to determine the degree of turbulent mixing potential whereas risk calculation requires wind-rose frequencies for each combination of wind speed and stability class.

2.2.1.2 Meteorological data is obtained from Sha Tin Weather Station (2014) where wind speed, stability class, weather class and wind direction are available. This data represents the weather conditions for the whole year in 2014 and has already taken into account of seasonal variations, and is therefore considered applicable for the assessment. **Table 2.5** shows the wind speed-stability frequencies.

Table 2.5 Stability Category-Wind Speed Frequencies at Sha Tin Station

Day-time							
Wind Speed (m/s)	A	B	C	D	E	F	Total (%)
0.0-1.9	10.60	7.74	0.00	9.25	0.00	14.47	42.06
2.0-3.9	8.66	19.07	8.20	8.66	4.88	0.89	50.36
4.0-5.9	0.00	3.57	1.95	1.67	0.05	0.00	7.24
6.0-7.9	0.00	0.00	0.09	0.25	0.00	0.00	0.34
Over 8.0	0.00	0.00	0.00	0.00	0.00	0.00	0.00
All (%)	19.26	30.38	10.24	19.83	4.93	15.36	100.00

Night-time							
Wind Speed (m/s)	A	B	C	D	E	F	Total (%)
0.0-1.9	0.0	0.0	0.0	0.8	0.0	70.1	70.91
2.0-3.9	0.0	0.0	0.0	6.9	15.5	3.2	25.59
4.0-5.9	0.0	0.0	0.0	2.8	0.4	0.0	3.23
6.0-7.9	0.0	0.0	0.0	0.3	0.0	0.0	0.25
Over 8.0	0.0	0.0	0.0	0.0	0.0	0.0	0.02
All (%)	0.00	0.00	0.00	10.80	15.91	73.29	100.00

2.2.1.3 According to **Table 2.5**, 6 combinations (2B, 1D, 3D, 6D, 2E and 1F) and 5 combinations (1D, 4D, 6D, 2E and 1F) of wind speed and stability class are chosen for daytime and night-time meteorological conditions respectively. These combinations are considered adequate to reflect the full range of observed variations in these quantities. It is not necessary and efficient to consider every combination observed. The principle is to group these combinations into representative weather classes which together cover all conditions observed.

2.2.1.4 Once the weather classes have been selected, frequencies for each wind direction for each weather class can then be determined. **Table 2.6** listed out separately these frequency distributions for the daytime and night-time meteorological conditions.

Table 2.6 Weather Class-Wind Direction Frequencies at Sha Tin Station

Daytime							
Direction	**2B**	**1D**	**3D**	**6D**	**2E**	**1F**	**Total (%)**
0 – 30	6.25	1.01	2.80	0.00	2.27	1.82	14.15
30 – 60	12.11	1.05	4.43	0.05	2.03	1.27	20.94
60 – 90	5.75	0.89	2.42	0.02	1.24	1.72	12.04
90 – 120	7.52	0.91	3.69	0.05	1.63	1.13	14.93
120 – 150	5.34	0.62	2.87	0.05	1.03	0.65	10.56
150 – 180	1.53	0.22	0.65	0.05	0.19	0.31	2.95
180 – 210	1.77	0.38	0.50	0.05	0.36	0.31	3.37
210 – 240	8.33	0.31	4.57	0.57	0.69	0.34	14.81
240 – 270	1.08	0.07	0.81	0.07	0.12	0.34	2.49
270 – 300	0.26	0.10	0.02	0.00	0.05	0.24	0.67
300 – 330	0.10	0.07	0.02	0.00	0.02	0.14	0.35
330 – 360	0.77	0.22	0.79	0.00	0.41	0.55	2.74
All (%)	50.81	5.85	23.57	0.91	10.04	8.82	100.00

Night-time						
Direction	**1D**	**4D**	**6D**	**2E**	**1F**	**Total (%)**
0 – 30	0.10	1.00	0.00	6.15	8.15	15.40
30 – 60	0.13	1.62	0.10	5.48	6.69	14.02
60 – 90	0.03	1.11	0.15	4.43	9.20	14.92
90 – 120	0.05	1.34	0.00	5.20	6.91	13.50
120 – 150	0.03	0.39	0.05	1.83	4.86	7.16
150 – 180	0.03	0.28	0.13	0.82	3.83	5.09
180 – 210	0.03	0.64	0.03	1.03	3.09	4.82
210 – 240	0.00	2.96	0.08	4.76	2.11	9.91
240 – 270	0.00	1.03	0.00	1.36	2.32	4.71
270 – 300	0.00	0.00	0.00	0.05	1.98	2.03
300 – 330	0.00	0.00	0.00	0.03	1.80	1.83
330 – 360	0.15	0.41	0.00	1.93	4.12	6.61
All (%)	0.55	10.78	0.54	33.07	55.06	100.00

3 HAZARD IDENTIFICATION AND ANALYSIS

3.1 Introduction

3.1.1.1 A hazard is an undesired event which may cause harm to people or to the environment or damage to property.

3.1.1.2 Potential hazards related to transmission of town gas are identified and discussed. The Hong Kong and China Gas Company Limited (HKCG) are consulted for operation information and parameters. This section outlined the hazards identification of the pipeline transport of gas including a review of historical accident database, Major Hazard Incident Data Services (MHIDAS).

3.1.1.3 The initiating events resulting in a release of town gas could occur due to various reasons, including spontaneous failure and leakage of pipeline. The main hazard from the HP Gas Pipeline is loss of containment leading to a gas leak, fire, explosion and toxicity. Town gas is flammable and explosive due to the presence of methane, hydrogen and carbon dioxide. It is also toxic due to presence of carbon dioxide and carbon monoxide.

3.2 Pipeline Design Parameters

3.2.1.1 The HP pipeline is constructed of steel with specification API X52. The nominal wall thickness for the pipe is 12.7mm and the maximum operating pressure is 35 bar. The pipeline is provided with internal epoxy coating, external fusion bonded epoxy coating, sacrificial anodes cathodic protection system, and a minimum earth cover of 1.1m. The leak detection system uses low pressure sensors at above ground installations (AGIs), the operator can initiate remote shutdown of valves at AGIs if needed. In addition of remote isolation at AGIs, manual isolation of intermediate sections in the HP network can also be achieved through manual ball valves located in underground chambers.

3.3 Behaviour of Town Gas Releases

3.3.1.1 Town gas, produced from naphtha and natural gas, is the final product of the gas works. It is a clean, safe and reliable gaseous fuel. With about half the density of air, it rises and will dissipate in the air if leakages occur. It has neither colour nor odour; therefore odouriser has been added to the gas such that it can easily be detected.

3.3.1.2 Town gas is a mixture of hydrogen, methane, carbon dioxide and carbon monoxide. It is both flammable and toxic while carbon monoxide, components of the town gas, is chemical asphyxiant. **Table 3.1** lists the composition and physical properties of town gas.

Table 3.1 Compositions and Properties of Town Gas

Composition	***% (By Volume)***	***Physical Properties***	***Values***
Hydrogen	48.1%	Calorific Value	17.27 MJ/m^3
Methane	29.4%	Specific Gravity	0.52
Carbon Dioxide	19.5%	Wobbe Index	24
Carbon Monoxide	3%	Weaver Flame Speed	35

3.3.1.3 Release in large quantity, if ignited immediately, will produce a fireball. Initially the gas concentration in the mixture will be above the Upper Flammability Limit (UFL). As burning occurs around the edges of the release, this will entrain more air into the mixture and more combustion will take place. The process accelerates until the mixture rises above the ground as a ball of fire.

3.3.1.4 If not ignited immediately, the gas will disperse and dilute. When the gas concentration is between lower Flammability Limit (LFL) and Upper Flammability Limit (UFL), presence of an ignition source in entire length of the gas cloud movement path may result in a flash fire. In case of continuous release, fire is flashed back to the release source and leads to a jet fire.

3.3.1.5 For continuous releases, immediate ignition will produce a long vigorous jet flame from the point of release.

3.3.1.6 For all sizes of release, town gas will have a toxic effect on nearby population sites if there is no source of ignition and allowed to disperse.

3.3.1.7 Possible hazardous scenarios associated with the operation of the HP underground town gas transmission pipelines are the loss of containment leading to a gas leak, fire explosion and toxicity.

3.4 Domino Effects

3.4.1.1 The transport route of explosives is in close vicinity of a section of the HP underground town gas transmission pipelines from the Sha Tin Hospital to Mui Tsz Lam Road. Separation distance between the transport route of explosives and the pipelines is around 50m. For the HP underground town gas transmission pipelines, a minimum earth cover of 1.1m is provided, with consideration of the separation distance from the transport route of explosives and the protection from the earth cover, it is presumed that probability of the failure of the transport of explosives triggering failure of HP underground town gas transmission pipelines is very unlikely and thus will not be further considered in the HA.

3.5 Hazard Analysis for the HP Gas Pipeline

3.5.1 General

3.5.1.1 The hazards from the pipeline transport of gas are well understood based on historical experience world-wide relating to pipeline transportation of oil and gas. From the incident review by HSE (1995) [6], some common causes of failure gas pipelines are identified below:

(a) External events;

(b) Pipe corrosion;

(c) Defective pipe and welds Vehicle impact;

(d) Equipment malfunction and improper operations; and

(e) Spontaneous & partial failure.

3.5.2 External Events

Earthquake

3.5.2.1 An earthquake has the potential to cause damage to HP underground town gas transmission pipelines. The damage could occur due to ground movement/ vibration, with spontaneous failure of pipelines possibly resulting. Though Hong Kong is not particularly prone to earthquake, the probability 1.0×10^{-5} per year of earthquake MMI VIII occurrence is adopted for conservative approach. The failure rate of pipeline due to earthquake is assumed to be 0.01 [4]. Failure due to earthquake is in the order of 10^{-7} which is considered 1 to 2 orders of magnitude lower than base failure rate and/or other causes.

Aircraft Crash

3.5.2.2 Aircrafts crashing into the HP underground town gas transmission pipelines due to airway accidents from arrival/departure flight paths are taken into account in this study. The method given in HSE (1997) [5] for the calculation of aircraft frequency is adopted. Further details are included in **Annex 2**. Since the calculated failure rates are much smaller than order of 10^{-9}, failure caused by aircraft crash is not further considered in the assessment.

Landslide

3.5.2.3 The 1.9km pipeline segment is not located close to hillside or slope and loss of containment due to landslide is not possible. Therefore, landslide is not further assessed and this factor is not added to the fault tree analysis separately.

Severe Environmental Event

3.5.2.4 Loss of containment due to severe environmental event such as typhoon or tsunami (large scale tidal wave) is considered to be insignificant as the installation of the HP underground town gas transmission pipelines is situated underground and away from seashore. Subsidence is usually slow in movement and such movement can be observed and remedial action can be taken in time. Besides, the pipeline was built for many years. Soil condition is rather stable. Failure caused by subsidence is not considered further in this assessment.

Lightning

3.5.2.5 The HP underground town gas transmission pipelines is buried at 1.1m underground along Tate's Cairn Highway. Besides, nearby buildings also provide shielding effect to prevent the pipeline being struck by lightning. With sufficient protection system, no further consideration is given for effect of lightning strike in this assessment.

Third Party Damage

3.5.2.6 Third party damage includes activities causing incidents such as work on other underground utilities, drilling for ground sampling, construction work on adjoining areas, etc. These excavation works are well controlled in Hong Kong, and there are guidelines issued by EMSD and also the gas company for construction in the vicinity of gas pipelines. Accurate alignment records of the HP underground town gas transmission pipelines will be provided by HKCG for works in the vicinity of the pipelines. Nevertheless, failures may still occur due to inadequate site control and supervision, and the failure rates adopted in Section 3.6 have already included this cause of gas pipeline failure.

External Fire

3.5.2.7 The HP underground town gas transmission pipelines is buried at 1.1m underneath the paved Tate's Cairn Highway. Loss of containment due to external fire is considered not possible. Therefore, external fire is not further assessed and this factor is not added to the fault tree analysis separately.

3.5.3 Pipeline Corrosion

3.5.3.1 HKCG put particular emphasis on the importance of close inspection and surveillance of its transmission and distribution system. An "intelligent pig" was brought into service to ensure the integrity of the strategic high pressure pipelines. It is effectively a magnetic flux pig, ran through the pipelines to record data on electronic devices. Anomalies such as internal or external corrosion, reduction in pipe wall thickness, dents, attachments etc. were reflected by the strength, change or orientation of magnetic flux signal as the pig ran through the pipeline. The data was sent to the On-line Inspection Centre of British Gas for detail analysis [9].

3.5.3.2 It is noted though that the HP underground town gas transmission pipelines under consideration in this study is approximately 10-30 years old. However, given that the wall thickness is 12.7mm, and that recent inspection found no significant loss of thickness due to corrosion, the high pressure system of HKCG in general is still in an excellent condition. It appears unnecessary to consider failure caused by ageing of pipeline.

3.5.4 Defective Pipe and Welds

3.5.4.1 HKCG have not experienced any loss of containment failure in their high pressure transmission network (35bar) due to material or construction defect since commencement of operation in 1983.

3.5.5 Equipment Malfunction and Improper Operations

3.5.5.1 From time to time, HKCG receives voluminous notifications from other utility companies or contractor regarding their construction work. HKCG replies expediently to each enquiry with clear marking of the existing pipeline alignment. For work which may jeopardise the safety of the gas system, engineers with closely liaise with the party concerned and a trench inspector will monitor the progress of the work. The trench inspector are well-trained and can provide valuable advice to the roadwork contractors on the safety precaution required to avoid damage of pipelines and proper site equipment maintenances work.

3.5.6 Spontaneous & Partial Failure

3.5.6.1 Offtake stations control and regulate pressures of gas inflow from high to intermediate/medium pressure network and are sensitive to interferences. In case of minor accident, interferences would disturb inflow of gas in the transmission system. In case of overpressure, pipeline would be overloaded and lead to full bore rupture follow by an instantaneous gas release. In cold partial failure, it results in continuous gas release to the atmosphere through a pipe crack or leak.

3.6 Frequency Estimation

3.6.1 General

3.6.1.1 Subsequent to the Hazard Identification and Analysis in previous section, the next step will be to estimate the likelihoods of various release scenarios. There are combinations of hazard initiating events, as identified in previous section, which would lead to release scenarios.

3.6.1.2 Fault Tree Analysis (FTA) permits the hazardous incident ("Significant Failure Events") frequency to be estimated from a logical model of the failure mechanisms of a system. The model is based on the combinations of failures of more basic components, safety systems and human errors.

3.6.1.3 FTA is the use of a combination of simple logic gates, "AND" and "OR" gates, to synthesize a failure model of the hazardous installation. The "Significant Failure Events" frequency is calculated from failure data of more simple events.

3.6.1.4 A basic assumption in FTA is that all failures in a system are binary in nature, a component or operator either performs successfully or fails completely. In addition, the system is assumed to be functioning if all sub-components are operating properly.

3.6.1.5 The stepwise procedure for undertaking FTA is presented below:

(a) Hazard identification and selection of the "Significant Failure Events"

(b) Construction of fault tree

(c) Quantitative evaluation of the fault tree

3.6.2 Gas Pipeline Failure Frequency

3.6.2.1 Failure rate for onshore pipeline hazards from the UK Onshore Pipeline Operators' Association (UKOPA) [1] will be adopted in this study. The UKOPA Database represents a source of pipeline fault data which is specific to UK pipelines and based on exposure of incident during over 810,000km pipeline operating years between 1952 and 2012. The data are contributed to by ten organisations, including Shell. It may be preferable to use local data to estimate failure frequencies; however, such data are not sufficient to provide statistically significant results.

3.6.2.2 The approach is to examine UKOPA databases and derive an appropriate failure frequency for the HKCG pipeline taking into account specific pipeline and environment features. The total failure rate for onshore gas transmission and distribution in the UK, derived based on data for the period 1992 to 2012 is 1.0×10^{-5} per km per year [1]. This failure rate will be adopted for the HP underground town gas transmission pipeline running along the Tate's Cairn Highway.

3.6.3 Hole Size Distribution

3.6.3.1 The hole size distribution is given in **Table 3.2**. In this study, possible releases from holes and ruptures are included. The distribution of the overall frequency into different failure sizes are selected based on UKOPA data. Although the probability of a full bore rupture is extremely low due to the design factor of 0.3 and wall thickness of 12.7mm, it is considered in this study for completeness. When modelling pipeline ruptures, the release rate from both sides of the ruptured pipeline was addressed. **Table 3.3** summarises the failure rates for all identified failure scenarios.

Table 3.2 Hole Size Distribution

Category	Hole Size (inch)	% Contribution
Rupture	Full bore	1
Puncture	4"	19
Hole	2"	30
Leak	1"	30
Leak	10mm	20

Table 3.3 Summary of Identified Failure Scenarios and Their Associated Failure Rates for the HP underground town gas transmission pipeline

Failure Scenarios	Failure Rates	Reference Source
Spontaneous Failure of HP Underground Town Gas Transmission Pipeline		
Full bore rupture	1.00×10^{-7} per km per year	Reference [1]
Partial Failure of HP Underground Town Gas Transmission Pipeline		
Leak (4" hole)	1.90×10^{-6} per km per year	Reference [1]
Leak (2" hole)	3.00×10^{-6} per km per year	Reference [1]
Leak (1" hole)	3.00×10^{-6} per km per year	Reference [1]
Leak (10mm)	2.00×10^{-6} per km per year	Reference [1]
Total Failure Rate	1.00×10^{-5} per km per year	
External Event		
Earthquake (MMI VIII)	1.00×10^{-5} per year	Reference [4]

4 FREQUENCY ANALYSIS

4.1 Introduction

4.1.1.1 Subsequent to the Hazard Identification and Analysis in previous section, the next step will be to estimate the likelihoods of various releases of town gas. There are combinations of hazard initiating events, as identified in previous section, which would lead to the releases.

4.1.1.2 Fault Tree Analysis (FTA) permits the hazardous incident ("Significant Failure Events") frequency to be estimated from a logical model of the failure mechanisms of a system. The model is based on the combinations of failures of more basic components, safety systems and human errors.

4.1.1.3 FTA is the use of a combination of simple logic gates, "AND" and "OR" gates, to synthesize a failure model of the hazardous installation. The "Significant Failure Events" frequency is calculated from failure data of more simple events.

4.1.1.4 A basic assumption in FTA is that all failures in a system are binary in nature, a component or operator either performs successfully or fails completely. In addition, the system is assumed to be functioning if all sub-components are operating properly.

4.1.1.5 The stepwise procedure for undertaking FTA is presented below:

(a) Hazard identification and selection of the "Significant Failure Events", where the "Significant Failure Events" are considered as significant release cases;

(b) Construction of fault tree; and

(c) Quantitative evaluation of the fault tree.

4.2 Frequency of Occurrence

4.2.1.1 Fault tree analysis was used to provide models for the calculation of failure rates or the probabilities of the hazardous scenarios as identifies in Section 3.

4.2.1.2 The estimated likelihoods of various releases of town gas at the HP Gas Pipeline are summarized in **Table 4.1**. Set of fault tree diagrams are attached in **Annex 3**.

Table 4.1 Estimated Occurrence Frequencies of Significant Town Gas Releases at the HP Underground Town Gas Transmission Pipelines

Release Case	Frequency of Occurrence/ Year
Spontaneous Failure of HP Gas Pipeline (Full Bore Rupture)	2.90E-07
Partial Failure of HP Gas Pipeline (4" Hole Leak)	3.71E-06
Partial Failure of HP Gas Pipeline (2" Hole Leak)	5.80E-06
Partial Failure of HP Gas Pipeline (1" Hole Leak)	5.80E-06
Partial Failure of HP Gas Pipeline (10mm Hole Leak)	3.90E-06

5 CONSEQUENCES AND IMPACT ANALYSIS

5.1 Introduction

5.1.1.1 Consequence and impact analysis is conducted to provide a quantitative estimate of the likelihood and number of deaths associated with the range of possible outcomes (i.e. fireball, jet fire, flash fire etc.) which are resulted from failure cases identified in previous sections for the HP Underground Town Gas Transmission Pipeline. In this study, Phast Risk 6.7, upgraded version of DNV SAFETI, is used.

5.2 Source Term

5.2.1.1 All the releases will be modeled assuming 7.8km pipeline section (which has an inventory of about 50 tonnes), i.e. the section between the offtake station at City One and the downstream Sai O pigging station.

5.3 Scenarios Following Gas Release

5.3.1.1 This section gives a brief description of the physical effects models used in the study to assess the effects zones for the following hazardous outcomes,

- Fireball;
- Jet fire;
- Flash fire;
- VCE;
- Unignited toxic release; and
- Safe dispersion

5.3.2 Fireball

5.3.2.1 The release rate following a rupture, if ignition was immediate, would be too high to give a stable flame, and the initial 'quasi instantaneous' release is characterised as a fireball. The fireball is limited to a maximum duration of 30s. The combustion would develop into a stable jet fire once the instantaneous release has been burnt and the release rate has become sufficiently steady for a flame to stabilise as stated by Bilo and Kinsman [10]. A release from a hole, if ignited, gives a stable flame close to the hole and produces a jet fire.

5.3.2.2 Adopting a conservative approach, the gas mixture for the fatality calculation is assumed 100% CO. The following probit equation for CO, from the built-in material database of Phast Risk, is applied to the risk model,

5.3.2.3 Due to the large size and intensity of a fireball, its effects are not significantly influenced by weather or wind direction. The thermal radiation from a fireball at given distances from the fireball centre are estimated using the Phast Risk's built-in fireball modelling suite in which TNO model and HSE model are adopted. The modelling suite is set such that it decides the most appropriate one in the effect modelling.

5.3.3 Jet Fire

5.3.3.1 A jet fire occurs following the ignition and combustion of a flammable fluid issuing continuously from a pipeline, which burns close to the release source. The jet fire which

follows the fire ball is assumed to be directed vertically upwards out of the crater. The jet fire shape is the frustum of a cone and the location and orientation of the frustum are dependent on a number of factors such as release rate and wind speed.

5.3.3.2 Combustion in a jet fire occurs in the form of a strong turbulent diffusion flame that is strongly influenced by the initial momentum of the release. The principal hazards from a jet fire are thermal radiation and the potential for knock-on effects. Jet fires also dissipate thermal radiation and causes casualty and damage to the population and property nearby.

5.3.4 Gas Dispersion and Flash Fire

5.3.4.1 As town gas is pressurized in the transmission network, it is heavier than air at the initial release stage. While the gas expands, it rises rapidly due to the buoyancy nature of the gas under atmospheric conditions. It will propagate and be diluted as a result of air entrainment with the influence of wind.

5.3.4.2 The principal hazard arising from a cloud of dispersing town gas is the delayed ignition of the flammable cloud that cause a flame to flash back to the release location and develop into a stable jet or crater fire. The potential for vapour cloud explosion is not considered significant for a buoyant gas plume and thus will not be further considered in this study.

5.3.4.3 Large scale experiments on the dispersion and ignition of flammable gas clouds show that ignition is unlikely when the average concentration is below the Lower Flammable Limit (LFL) or above the Upper Flammable Limit (UFL). The hazard distance is calculated by the Unified Dispersion Model (UDM) in the Phast Risk. It estimates the profile of a dispersing cloud in segments according to properties of propagating cloud. For simplicity of presenting the hazardous extent of the clouds, the cloud dispersion segment is described as a half/ full ellipse by the following parameters,

- Downwind distance to the LFL of the cloud - major semi-axis of the ellipse;
- Crosswind distance to the LFL of the cloud - minor semi-axis of the ellipse;
- Downwind displacement – downwind distance to centre of ellipse.

5.3.4.4 It is considered that there is no scope for escape within the LFL of a flammable cloud in a flash fire. Therefore, a fatality probability of 100% of persons present within the flammable cloud is assumed for flash fires.

5.4 Effect Modelling of the HP Gas Pipeline

5.4.1 Probit Equations

5.4.1.1 The estimation of the fatality/ injury caused by a physical effect such as thermal radiation or overpressure requires the use of probit equations, which describe the probability of fatality as a function of some physical effect. The probit equations take the following general form

$$Y = a + b \ln(V)$$

where Y is the probit;
a and b are constants determined from experiments; and
V is a measure of the physical effect such as thermal dose, peak overpressure etc.

5.4.1.2 The probit is an alternative way of expressing the probability of fatality and is derived from a statistical transformation of the probability of fatality. The relationship between fatality probabilities and probits is given in [7].

5.4.2 Probit Equations For Thermal Impact

5.4.2.1 Fatality rates due to exposure to thermal radiation from a fire were determined by the following probit function which is set as the default in the Phast Risk,

a = -36.38

b = 2.56

V = t x $I^{4/3}$

where I = thermal radiation intensity at the target (W/m^2); and
t = duration of exposure (s).

5.4.2.2 For jet fires, the exposure duration is estimated to be 20s, which is considered to be the time taken for people to take evasive action such as seeking refuge etc.

5.4.3 Probit Equations For Toxic Impact

5.4.3.1 As shown previously in **Table 3.1**, the composition of town gas contains by volume 19.5% CO_2 and 3% CO. Both gases have the potential to cause adverse health effects at population centres if allowed to disperse without ignition.

5.4.3.2 Carbon dioxide (CO_2) is not classified as a toxic or harmful gas, but is considered an asphyxiant gas. It is a potent stimulus to respiration and both a depressant and excitant of the central nervous system. Carbon dioxide content in fresh air varies around 0.037%. Concentrations of 20% to 30% can result in unconsciousness and convulsions within 1 minute of exposure [11].

5.4.3.3 Carbon monoxide (CO) is a highly toxic gas capable of causing harm at very low concentrations. It combines with haemoglobin in the blood, thus displacing oxygen. The IDLH (Immediately Dangerous to Life and Health) value for CO is 1200ppm (0.12%) [11], but concentrations at 0.0035% are enough to cause headache and dizziness.

5.4.3.4 While both gases are odourless, town gas has been odourised with THT. As such, populations under the exposure of town gas are warned olfactorily, allowing the affected individuals to react and escape exposure. It is expected that there is a significant interval between the start of the exposure and the onset of incapacitation which would prevent escape action. Therefore, escaping from the affected area is a practicable action and has a high success rate.

5.4.3.5 Since town gas is lighter than air, the release will disperse upwards under normal wind conditions until its concentration equilibrates with the surrounding air, where it is then free to move in any direction. Assuming no immediate ignition has occurred, the surrounding population of the HP underground town gas transmission pipelines is unlikely to be fully exposed to the emerging gas cloud. As the gas cloud continues to disperse, its CO_2 and CO concentration will begin to dilute, significantly reducing its toxicity over time.

5.4.3.6 Adopting a conservative approach, the gas mixture for the fatality calculation is assumed 100% CO. The following probit equation for CO, from the built-in material database of Phast Risk, is applied to the risk model,

$$Pr = -7.21 + \ ln(Ct)$$

where C is gas concentration in ppm and t is the exposure time in minute.

5.4.3.7 Toxic effect is not considered for rail traffic since the gas is likely to be ignited by the train motion. Even if the gas cloud is not ignited, the duration of exposure for a passenger in a

moving train provided with mechanical ventilation is limited and therefore it is considered unlikely to have any significant effects.

5.5 Ignition Probability

5.5.1 General

5.5.1.1 In order to calculate the risk from flammable materials, information on ignition sources present in the study area needs to be identified. Such data is included in the risk model for each type of ignition source (i.e. point sources, line sources and area sources). The risk calculation program (MPACT) built into Phast Risk then predicts the probability of a flammable cloud being ignited as the cloud moves downwind over ignition sources.

5.5.1.2 In general, the probability of immediate or delayed ignitions depends on the scale of release, the presence and location of ignition sources, and the weather conditions.

5.5.1.3 For town gas release analysis, ignition probabilities for pipelines were taken from the Cox, Lees and Ang model [8], which is summarized in **Table 5.1**. To be conservative, the probability of immediately ignition is taken as 100% of the listed probability. These ignition probabilities are applied to event trees as shown in **Annex 4**, which are entered in Phast Risk.

Table 5.1 Ignition Probabilities from Cox, Lees and Ang Model

Leak Size	Ignition Probability (Gas Release)
Minor (<< 1kg/s)	0.01
Major (1-50 kg/s)	0.07
Massive (>50kg/s)	0.3

5.5.2 Point Sources

5.5.2.1 No major point source is identified in vicinity of the HP underground town gas transmission pipelines.

5.5.3 Line Sources

5.5.3.1 Roads are defined as line sources in Phast Risk. The following assumptions are applied to estimate the presence factor of the line source and the ignition probability:

(a) Probability of ignition for a vehicle is taken as 0.4 in 60 seconds.

(b) Traffic density is based on the projected traffic flow as shown **Table 5.2** and **Table 5.3**.

5.5.3.2 In addition, the Ma On Shan Line is also defined as line sources in Phast Risk. The following assumptions are applied to estimate the presence factor of the line source and the ignition probability:

(a) Probability of ignition is taken as 0.75 in 60 seconds.

(b) Presence factor of the ignition source is assumed to be 1.

Table 5.2 Summary of Road Ignition Source for Construction Stage (Year 2022)

Line Source	Peak Traffic Flow (veh/hr)	Daytime Traffic Flow (veh/hr)	Night-time Traffic Flow (veh/hr)	Traffic Speed (km/hr)
Tai Chung Kiu Road	2,917	2,179	937	50
On King Street	583	436	187	50
On Ping Street	729	545	234	50
On Sum Street	729	545	234	50
Tate's Cairn Highway	8,677	6,481	2,787	80
A Kung Kok Shan Road	111	83	36	50
A Kung Kok Street	966	722	310	50
Ma On Shan Road	2,173	1,623	698	70
Mui Tsz Lam Road	97	72	31	50
Hang Tai Road	435	325	140	50
Shek Mun Interchange	1,742	1,301	559	50

Table 5.3 Summary of Road Ignition Source for Operational Stage (Year 2027)

Line Source	Peak Traffic Flow (veh/hr)	Daytime Traffic Flow (veh/hr)	Night-time Traffic Flow (veh/hr)	Traffic Speed (km/hr)
Tai Chung Kiu Road	3,066	2,290	985	50
On King Street	613	458	197	50
On Ping Street	767	573	246	50
On Sum Street	767	573	246	50
Tate's Cairn Highway	9,492	7,090	3,049	80
A Kung Kok Shan Road	111	83	36	50
A Kung Kok Street	583	435	187	50
Ma On Shan Road	2,284	1,706	734	70
Mui Tsz Lam Road	58	44	19	50
Hang Tai Road	457	341	147	50
Shek Mun Interchange	1,586	1,185	510	50

5.5.4 Area Source

5.5.4.1 Phast Risk considers residential population as an ignition source (such as cooking, smoking, heating appliances etc.). The ignition probability is derived from population densities in the concerned area by the software.

5.5.5 Population Input

5.5.5.1 With reference to previous practice with SAFETI in Hong Kong, population at locations listed in **Table 2.1**, **Table 2.2**, **Table 2.3** and **Annex 1** are applied to the risk model. Shielding factors are applied in fireball events according to recommendations in [2]. Shielding factors are determined by considering the location of a building and the fireball size. For a building shielded by other buildings and not in the direct line of sight of the fireball or with a blank wall facing towards the fireball, population in the building is considered protected. For buildings in the direct line of the fireball, population in units directly in front is affected.

6 RISK EVALUATION

6.1 Introduction

6.1.1.1 In this section, the risks arising from the HP underground town gas transmission pipeline are evaluated in terms of both individual and societal risks separately.

6.1.1.2 Individual risk is a measure of the risk to a chosen individual at a particular location. As such, this is evaluated by summing the contributions to that risk across a spectrum of incidents which could occur at a particular location.

6.1.1.3 Societal risk is a measure of the overall impact of an activity upon the surrounding community. As such, the likelihoods and consequences of the range of incidents postulated for that particular activity are combined to create a cumulative picture of the spectrum of the possible consequences and their frequencies. This is usually presented as a fN curve and the acceptability of the results can be judged against the societal risk criterion under the risk guidelines.

6.2 Individual Risk

6.2.1.1 The associated individual risk levels are shown in **Figure 6.1**. The risk level is based on 100% occupancy with no allowance made for shelter or escape, which can be referred from the user manual of Phast Risk.

6.2.1.2 The Hong Kong Risk Guidelines' criterion for individual risk is that no person off-site shall be subject to an additional risk of 1×10^{-5}/year; while the tolerability of individual risk in the IGEM Risk Guidelines is less than 1×10^{-6}/year for general public.

6.2.1.3 The maximum individual risk is less than 1×10^{-7} per year. On this basis, it would appear that the level of individual risk associated with the HP underground town gas transmission pipeline should be acceptable since it meets both the Hong Kong Risk Guidelines and the IGEM Risk Guidelines.

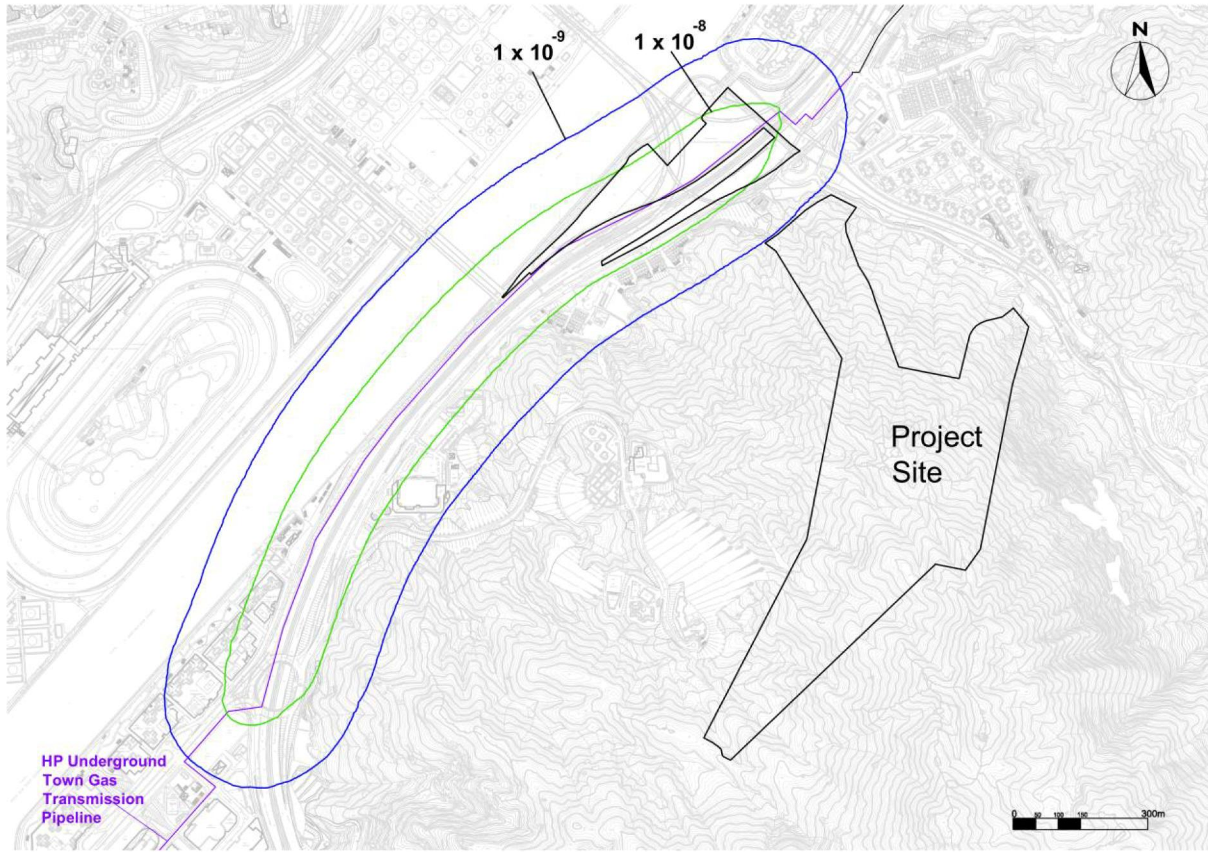


Figure 6.1 Individual Risk Contours for the HP Underground Town Gas Transmission Pipeline

6.3 Societal Risk

6.3.1 Societal Risk for the HP Gas Pipeline According to Hong Kong Risk Guidelines

6.3.1.1 The societal risks are evaluated for the range of incidents with the potential for fatalities in the vicinity and are shown in **Table 6.1** and **Table 6.2**. The societal risk is more complex than that for individual risk but, in essence, comprises three regions:

(a) "Unacceptable" - a region within which the risks may be regarded as unacceptable;

(b) "Acceptable" - a region within which the risks may be regarded as acceptable; and

(c) "ALARP" - a region between the two in which measures should be taken to demonstrate the risks as "as low as reasonably practicable" (ALARP). In other words, consideration is given not only to the level of risk but also the cost and practicality of reducing it.

6.3.1.2 Numerically, the upper bound of the ALARP region (and hence the borderline of "unacceptability") can be summarised as:

(a) 1 chance in 1,000 per year of an incident resulting in 1 or more fatalities;

(b) 1 chance in 10,000 per year of an incident resulting in 10 or more fatalities;

(c) 1 chance in 100,000 per year of an incident resulting in 100 or more fatalities; and

(d) not more than 1,000 fatalities at a frequency of greater than 1 chance in a billion (1,000,000,000) per year.

6.3.1.3 As shown in **Figure 6.2** and **Figure 6.3**, majority of the societal risks associated with the operation of the HP underground town gas transmission pipeline for both construction and operational stages fall in the "Acceptable" region, with number of fatality between 200 and 300 fall in the lower "ALARP" region.

6.3.1.4 Compared to the "without Project" scenarios for both construction and operational stages, it is found that the ALARP is due to the background population instead of the population induced by the Project. Data points for the Construction Stage Scenario and Operational Stage Scenario are tabulated in **Table 6.1** and **Table 6.2** respectively.

Table 6.1 Societal Risk Data for Construction Stage Scenario

No. Fatalities	Frequency (/year)	No. Fatalities	Frequency/ year	No. Fatalities	Frequency/ year
1	1.91E-06	15	1.41E-07	120	5.60E-08
2	3.90E-07	20	1.31E-07	150	5.23E-08
3	3.21E-07	25	1.21E-07	200	5.12E-08
4	2.96E-07	30	1.11E-08	250	5.00E-08
5	2.71E-07	40	9.49E-08	300	4.67E-08
6	2.44E-07	50	8.93E-08	400	2.96E-08
8	1.98E-07	60	8.63E-08	500	8.36E-09
10	1.68E-07	80	7.58E-08	600	3.87E-09
12	1.55E-07	100	6.51E-08		

Table 6.2 Societal Risk Data for Operational Stage Scenario

No. Fatalities	Frequency (/year)	No. Fatalities	Frequency/ year	No. Fatalities	Frequency/ year
1	1.82E-06	15	1.42E-07	120	5.37E-08
2	3.93E-07	20	1.32E-07	150	5.22E-08
3	3.17E-07	25	1.22E-07	200	5.07E-08
4	2.93E-07	30	1.12E-07	250	4.97E-08
5	2.69E-07	40	9.56E-08	300	4.53E-08
6	2.49E-07	50	8.75E-08	400	2.58E-08
8	2.06E-07	60	8.34E-08	500	7.18E-09
10	1.70E-07	80	7.48E-08	600	1.55E-09
12	1.57E-07	100	6.24E-08		

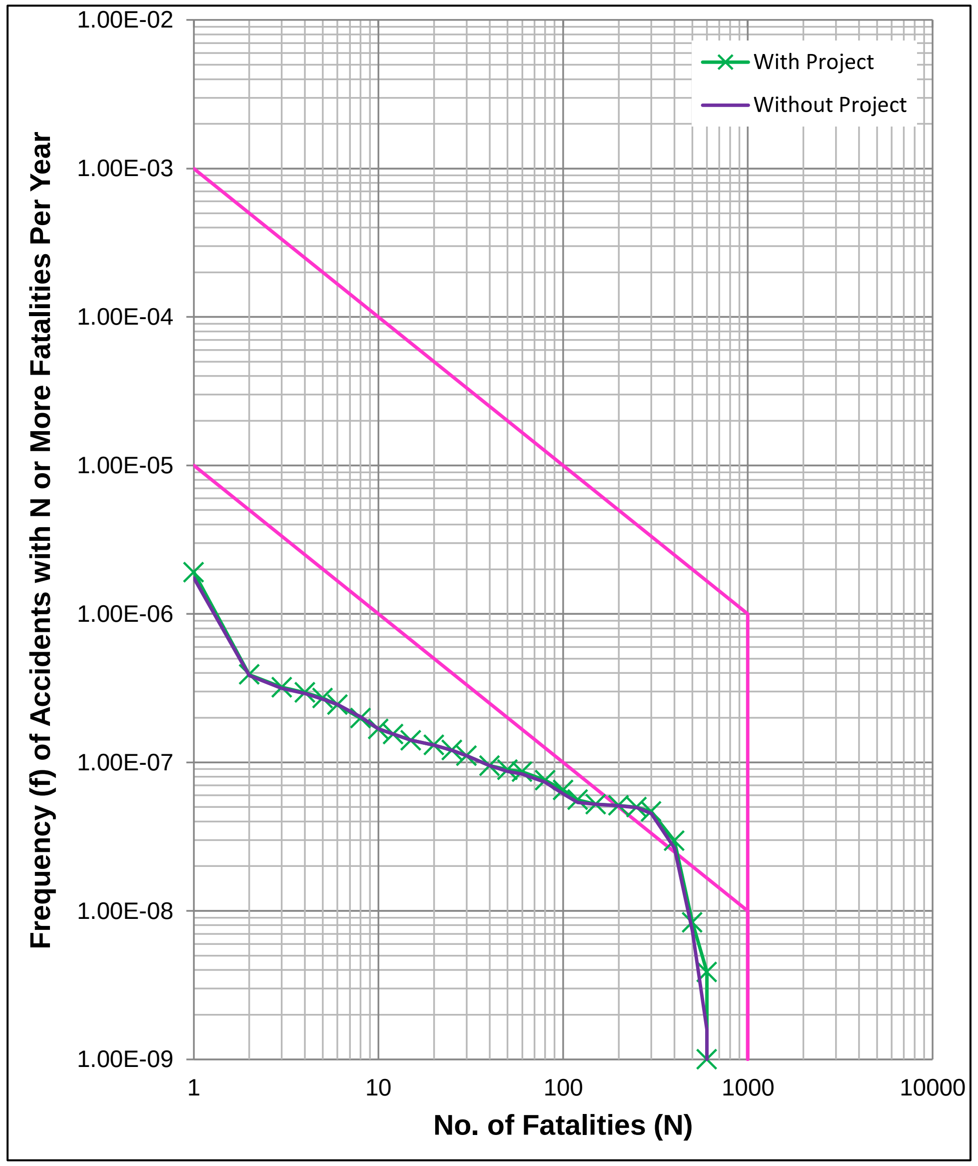


Figure 6.2 Societal Risk Curve for Construction Stage

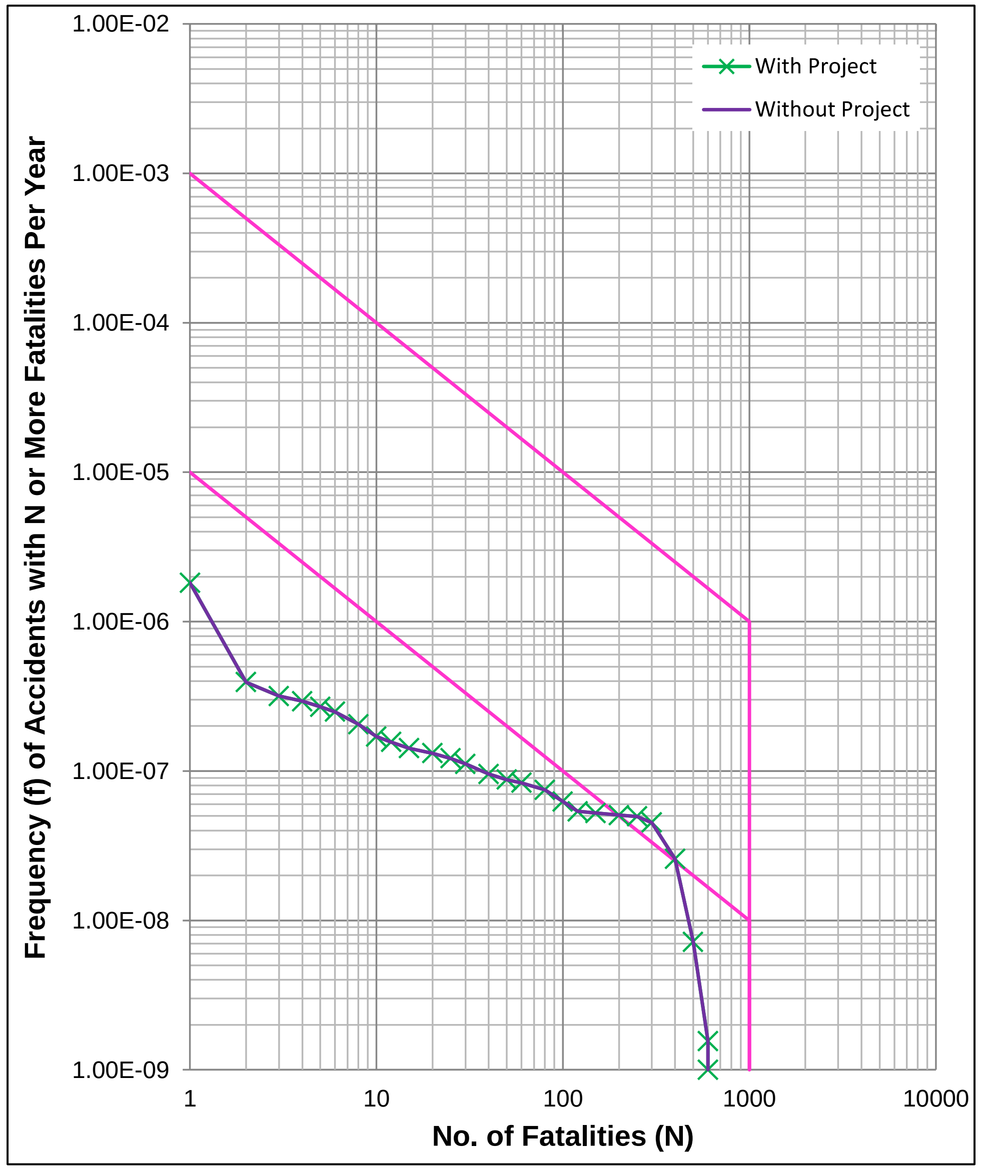


Figure 6.3 Societal Risk Curve For Operational Stage

6.3.2 Societal Risk for the HP Gas Pipeline According to IGEM Risk Guidelines

6.3.2.1 The societal risks are evaluated for the range of incidents with the potential for fatalities in the vicinity and are shown in **Figure 6.4** and **Figure 6.5** for construction stage and operational stage respectively. The societal risk criterion envelope of IGEM comprises two regions:

(a) "Negligible or Acceptable" - a region within which the risks may be regarded as acceptable; and

(b) "Tolerable Risk based upon ALARP Considerations" - a region in which measures should be taken to demonstrate the risks as "as low as reasonably practicable" (ALARP). In other words, consideration is given not only to the level of risk but also the cost and practicality of reducing it.

6.3.2.2 As a conservative approach, the entire pipeline section of 1.9km instead of scaling to 1.6km pipeline length is considered in the risk assessment. The fN curves are shown in **Figure 6.4** and **Figure 6.5** along with the criteria for comparison with the IGEM risk guidelines. As shown in the figures, the societal risks associated with the operation of the HP underground town gas transmission pipeline for both Construction Stage Scenario and Operational Stage Scenario fall in the "Tolerable Risk based upon ALARP Considerations" region. Compared to the "without Project" scenarios for both construction and operational stages, it is found that the tolerable risk is mainly due to the background population instead of the population induced by the Project.

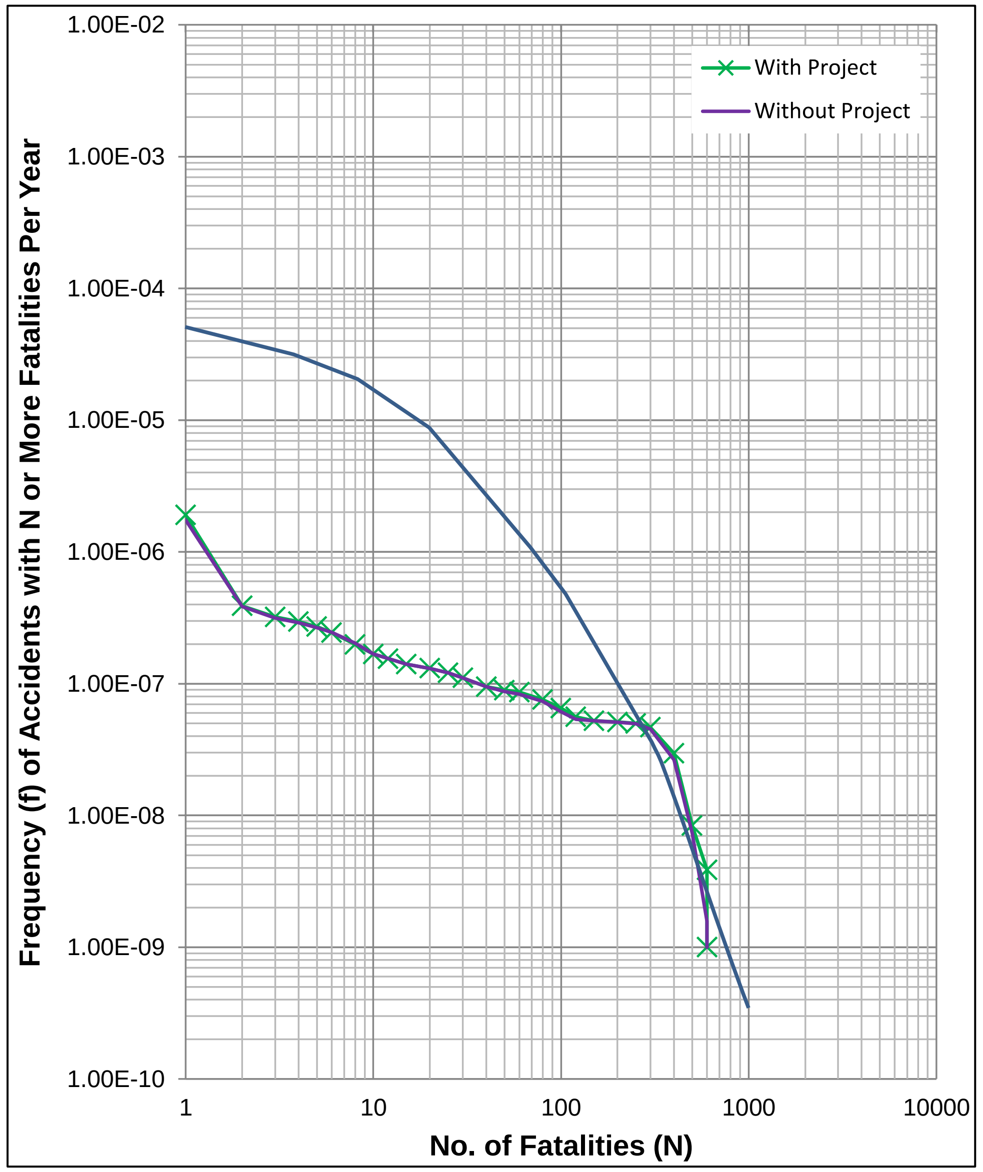


Figure 6.4 Societal Risk Curve With IGEM F-N Criterion Envelope For Construction Stage

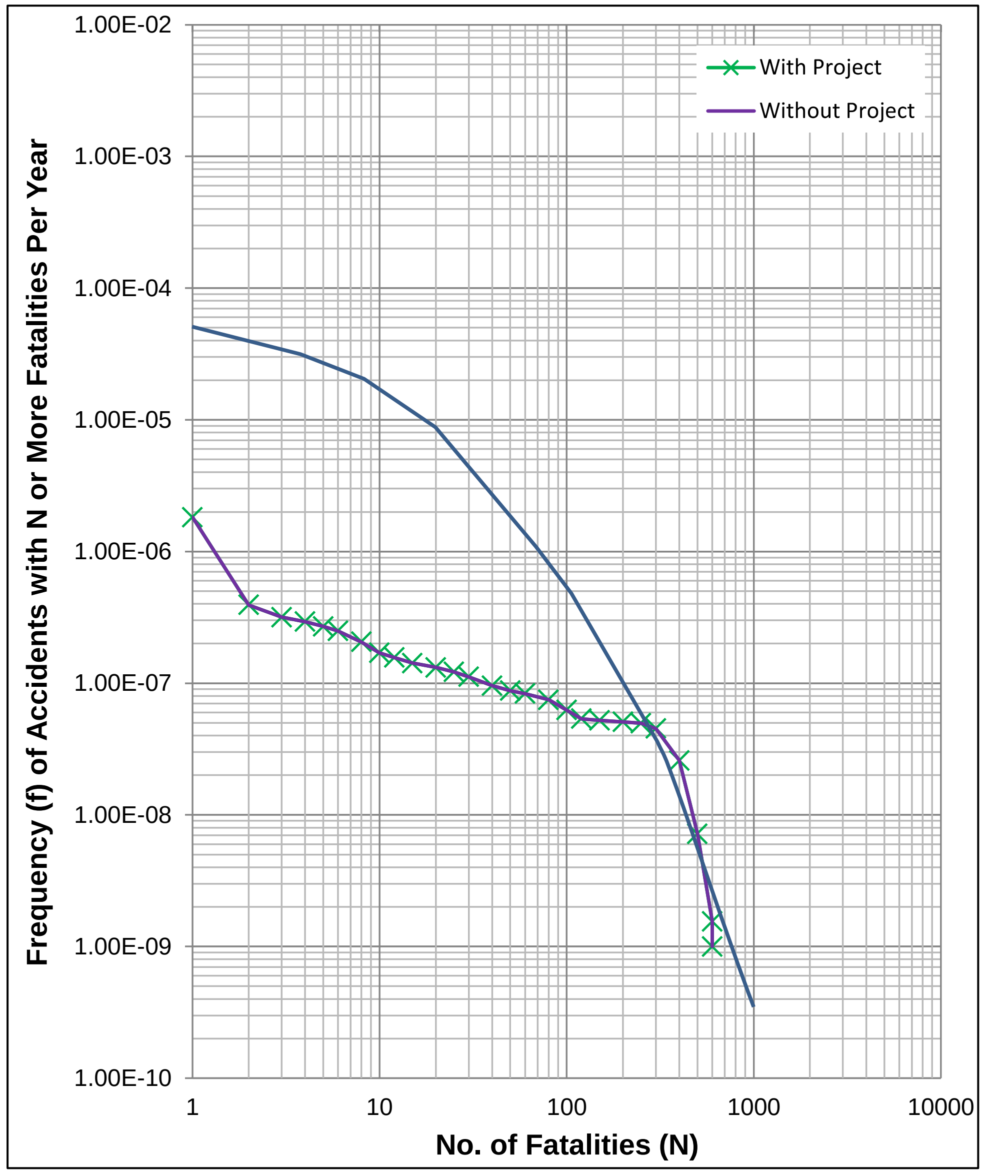


Figure 6.5 Societal Risk Curve With IGEM F-N Criterion Envelope For Operational Stage

6.3.3 Potential Loss of Life (PLL)

6.3.3.1 The total PLL for construction stage and operational stage are found to be 2.95×10^{-5} per year and 2.84×10^{-5} per year respectively. Fireball events from town gas release contribute to most of the proportion (~85%) of the overall PLL.

7 CONCLUSIONS AND RECOMMENDATIONS

7.1.1.1 A Hazard to Life Assessment of the risks associated with operation of the HP underground town gas transmission pipeline has been conducted for both construction and operational stages of the Project.

7.1.1.2 The individual risk complies with both the Hong Kong Risk Guidelines and the IGEM Risk Guidelines.

7.1.1.3 The societal risk expressed in the form of FN curves lies in the lower "ALARP" region of the Hong Kong Risk Guidelines for both construction stage and operational stage scenarios. Compared to the "without Project" scenarios for both construction and operational stages, it is found that the ALARP is due to the background population instead of the population induced by the Project.

7.1.1.4 It is recommended that adequate emergency response / evacuation plans for the project works areas and the future sewage treatment works staff are established and emergency training / drills for all relevant personnel conducted at regular intervals.

8 REFERENCES

[1] RA McConnell & Dr J V Haswell (2012). UKOPA Pipeline Product Loss Incidents and Faults Report (1962-2012).

[2] Reeves, A.B., Minah, F.CC. and Chow, V.H.K. (1997). "Quantitative Risk Assessment Methodology for LPG Installations", Conference on Risk & Safety Management in the Gas Industry, EMSD & HKIE, Hong Kong

[3] Legislative Council Panel on Transport Subcommittee on Matters Relating to Railways – Capacity and Loading of MTR Trains CB(1)980/13-14(03).

[4] Ling Chan & Partners Limited (2001). Environmental Impact Assessment for Proposed Headquarters and Bus Maintenance Depot in Chai Wan (BDEIA).

[5] Health and Safety Executives (1997). The Calculation of Aircraft Crash Risk in the UK. J P Byrne.

[6] Health & Safety Executive, UK (1995). Risk from Hazards Pipelines in the United Kingdom, Arthur D Little, HSE Contract Research Report No. 82/1994, HMSO

[7] TNO, Guideline for Quantitative Risk Assessment (Purple Book), CPR 18E, 2005

[8] Lee's Loss Prevention of the Process Industries: Hazard Identification, Assessment and Control, 3rd edition, 2005

[9] ERM (1998) Proposed High Pressure Steel Gas Pipeline from Tai Po Tsai to Tseung Kwan O (ETPE), HKCG.

[10] Bilo and Kinsman PR (1997). MISHAP - HSE's pipeline risk assessment methodology. Pipes and Pipelines International.

[11] Nick H. Proctor, James P. Hughes and Michael L. Fischman (1988), Chemical Hazards of the Workplace

[12] Transport Department (June 2014). The Annual Traffic Census 2013.

Annex 1

ID	Description	Land Use	OZP reference	Population		Indoor Ratio	% occupancy						Population in Yr 2022						Population in Yr 2027					
				Maximum Population (Yr 2022)	Maximum Population (Yr 2027)		Night	AM Peak	PM Peak	Weekday Daytime	Saturday Daytime	Sunday daytime	Night	AM Peak	PM Peak	Weekday Daytime	Saturday Daytime	Sunday daytime	Night	AM Peak	PM Peak	Weekday Daytime	Saturday Daytime	Sunday daytime
14	Garden Vista	R(B)	S/ST/31	1624	1577								0	0	0	0	0	0	0	0	0	0	0	0
14a	Block D	R(B)	S/ST/31	562	545	0.95	100%	50%	50%	20%	50%	80%	562	281	281	112	281	450	545	273	273	109	273	436
14b	Block E	R(B)	S/ST/31	562	545	0.95	100%	50%	50%	20%	50%	80%	562	281	281	112	281	450	545	273	273	109	273	436
14c	Block F	R(B)	S/ST/31	432	419	0.95	100%	50%	50%	20%	50%	80%	432	216	216	86	216	346	419	210	210	84	210	335
14d	Car park under podium of Block D, Block E & Block F	R(B)	S/ST/31	30	30	0.95	10%	100%	100%	70%	70%	70%	3	30	30	21	21	21	3	30	30	21	21	21
14e	Podium of Block D, Block E & Block F	R(B)	S/ST/31	38	38	0	10%	100%	100%	70%	70%	70%	4	38	38	27	27	27	4	38	38	27	27	27
15	Pictorial Garden (Stage 1)	R(B)	S/ST/31	1924	1870								0	0	0	0	0	0	0	0	0	0	0	0
15a	Abbey Court	R(B)	S/ST/31	605	587	0.95	100%	50%	50%	20%	50%	80%	605	303	303	121	303	484	587	294	294	117	294	470
15b	Belleve Court	R(B)	S/ST/31	605	587	0.95	100%	50%	50%	20%	50%	80%	605	303	303	121	303	484	587	294	294	117	294	470
15c	Capilano Court	R(B)	S/ST/31	605	587	0.95	100%	50%	50%	20%	50%	80%	605	303	303	121	303	484	587	294	294	117	294	470
15d	Car park under podium	R(B)	S/ST/31	40	40	0.95	10%	100%	100%	70%	70%	70%	4	40	40	28	28	28	4	40	40	28	28	28
15e	Podium	R(B)	S/ST/31	69	69	0	10%	100%	100%	70%	70%	70%	7	69	69	48	48	48	7	69	69	48	48	48
16	Pictorial Garden (Stage 2)	R(B)	S/ST/31	1796	1744								0	0	0	0	0	0	0	0	0	0	0	0
16a	Delite Court	R(B)	S/ST/31	281	272	0.95	100%	50%	50%	20%	50%	80%	281	141	141	56	141	225	272	136	136	54	136	218
16b	Elegant Court	R(B)	S/ST/31	281	272	0.95	100%	50%	50%	20%	50%	80%	281	141	141	56	141	225	272	136	136	54	136	218
16c	Forum Court	R(B)	S/ST/31	562	545	0.95	100%	50%	50%	20%	50%	80%	562	281	281	112	281	450	545	273	273	109	273	436
16d	Galaxy Court	R(B)	S/ST/31	562	545	0.95	100%	50%	50%	20%	50%	80%	562	281	281	112	281	450	545	273	273	109	273	436
16e	Car park under podium	R(B)	S/ST/31	40	40	0.95	10%	100%	100%	70%	70%	70%	4	40	40	28	28	28	4	40	40	28	28	28
16f	Podium	R(B)	S/ST/31	70	70	0	10%	100%	100%	70%	70%	70%	7	70	70	49	49	49	7	70	70	49	49	49
17	Pictorial Garden (Stage 3)	R(B)	S/ST/31	1180	1144								0	0	0	0	0	0	0	0	0	0	0	0
17a	Hillview Court	R(B)	S/ST/31	373	361	0.95	100%	50%	50%	20%	50%	80%	373	187	187	75	187	298	361	181	181	72	181	289
17b	Iris Court	R(B)	S/ST/31	373	361	0.95	100%	50%	50%	20%	50%	80%	373	187	187	75	187	298	361	181	181	72	181	289
17c	Juniper Court	R(B)	S/ST/31	373	361	0.95	100%	50%	50%	20%	50%	80%	373	187	187	75	187	298	361	181	181	72	181	289
17d	Car park under podium	R(B)	S/ST/31	30	30	0.95	10%	100%	100%	70%	70%	70%	3	30	30	21	21	21	3	30	30	21	21	21
17e	Podium	R(B)	S/ST/31	31	31	0	10%	100%	100%	70%	70%	70%	3	31	31	22	22	22	3	31	31	22	22	22
18	On King Street Park	O	S/ST/31	100	100	0	0%	10%	10%	70%	85%	100%	0	10	10	70	85	100	0	10	10	70	85	100
19	Open Car Park (near Jockey Club Shek Mun Rowing Centre)	G/IC	S/ST/31	10	10	0	10%	100%	100%	70%	70%	70%	1	10	10	7	7	7	1	10	10	7	7	7
20	Jockey Club Shek Mun Rowing Centre	G/IC	S/ST/31	50	50	0	0%	10%	10%	70%	85%	100%	0	5	5	35	43	50	0	5	5	35	43	50
21	Hong Kong China Dragon Boat Association Shatin Shek Mun Training Centre	G/IC	S/ST/31	50	50	0	0%	10%	10%	70%	85%	100%	0	5	5	35	43	50	0	5	5	35	43	50
22	Hong Kong Canoe Union Shatin Training Centre	G/IC	S/ST/31	50	50	0	0%	10%	10%	70%	85%	100%	0	5	5	35	43	50	0	5	5	35	43	50
23	Site Offices (DSD / LandsD)	O	S/ST/31	60	60	0.95	10%	10%	10%	100%	55%	10%	6	6	6	60	33	6	6	6	6	60	33	6
24	Petrol Station	G/IC	S/ST/31	10	10	0	100%	100%	100%	100%	100%	100%	10	10	10	10	10	10	10	10	10	10	10	10
25	Shek Mun Fresh Water Booster Pumping Station	G/IC	S/ST/31	0	0	0.95	100%	100%	100%	100%	100%	100%	0	0	0	0	0	0	0	0	0	0	0	0
26	On Sum Street Substation	G/IC	S/ST/31	0	0	0.95	100%	100%	100%	100%	100%	100%	0	0	0	0	0	0	0	0	0	0	0	0
27	Sha Tin Community Green Station	G/IC	S/ST/31	60	60	0	10%	10%	10%	100%	100%	100%	6	6	6	60	60	60	6	6	6	60	60	60
28	Open Car Park (near Pumping House on On Ping Street)	G/IC	S/ST/31	20	20	0	0%	100%	100%	70%	45%	20%	0	20	20	14	9	4	0	20	20	14	9	4
29	Shatin Hospital	G/IC	S/ST/31	1296	1292								0	0	0	0	0	0	0	0	0	0	0	0
29a	Shatin Hospital	G/IC	S/ST/31	975	975	0.95	80%	80%	80%	100%	90%	80%	780	780	780	975	878	780	780	780	780	975	878	780
29b	Open Car Park	G/IC	S/ST/31	10	10	0	10%	100%	100%	70%	70%	70%	1	10	10	7	7	7	1	10	10	7	7	7
29c	Transport Terminus	G/IC	S/ST/31	30	30	0	10%	100%	100%	70%	60%	50%	3	30	30	21	18	15	3	30	30	21	18	15
29d	Football Field	G/IC	S/ST/31	22	22	0	0%	10%	10%	70%	85%	100%	0	2	2	15	19	22	0	2	2	15	19	22
29e	Basketball Court	GB	S/ST/31	16	16	0	0%	10%	10%	70%	85%	100%	0	2	2	11	14	16	0	2	2	11	14	16
29f	Jockey Club Centre for Positive Ageing	GB	S/ST/31	25	25	0.95	80%	80%	80%	100%	90%	80%	20	20	20	25	23	20	20	20	20	25	23	20
29g	A Kung Kok Government Quarters Block B	G/IC	S/ST/31	104	102	0.95	100%	50%	50%	20%	50%	80%	104	52	52	21	52	83	102	51	51	20	51	82
29h	A Kung Kok Government Quarters Block C	GB	S/ST/31	104	102	0.95	100%	50%	50%	20%	50%	80%	104	52	52	21	52	83	102	51	51	20	51	82
29i	Tennis Court	GB	S/ST/31	10	10	0	0%	10%	10%	70%	85%	100%	0	1	1	7	9	10	0	1	1	7	9	10
30	A Kung Kok Sewage Pumping Station	GB	S/ST/31	10	10	0	10%	10%	10%	100%	55%	10%	1	1	1	10	6	1	1	1	1	10	6	1
31	Ah Kung Kok Fishermen's Village			1061	1045								0	0	0	0	0	0	0	0	0	0	0	0
31a	Ah Kung Kok Fishermen's Village (a)	V	S/ST/31	374	368	0.95	100%	50%	50%	20%	50%	80%	374	187	187	75	187	299	368	184	184	74	184	294
31b	Ah Kung Kok Fishermen's Village (b)	V	S/ST/31	639	629	0.95	100%	50%	50%	20%	50%	80%	639	320	320	128	320	511	629	315	315	126	315	503
31c	Basketball Court	V	S/ST/31	16	16	0	0%	10%	10%	70%	85%	100%	0	2	2	11	14	16	0	2	2	11	14	16
31d	Football Field	V	S/ST/31	22	22	0	0%	10%	10%	70%	85%	100%	0	2	2	15	19	22	0	2	2	15	19	22
31e	A Kung Kok Sitting-out Area	V	S/ST/31	10	10	0	0%	10%	10%	70%	85%	100%	0	1	1	7	9	10	0	1	1	7	9	10
32	Hong Kong Mountaineering Union	V	S/ST/31	0	0	0.95	0%	10%	10%	70%	85%	100%	0	0	0	0	0	0	0	0	0	0	0	0
33	Evangelical Lutheran Church of Hong Kong Shatin Youth Centre Recreational Camp and Training Centre	GB	S/ST/31	0	0	0.95	0%	10%	10%	70%	85%	100%	0	0	0	0	0	0	0	0	0	0	0	0
34	Custom and Excise Department Shatin Vehicle Detention Centre	G/IC	S/ST/31	0	800	0	0%	10%	10%	100%	55%	10%	0	0	0	0	0	0	0	80	80	800	440	80
35	A Kung Kok Street Garden	O	S/MOS/21	10	10	0	0%	10%	10%	70%	85%	100%	0	1	1	7	9	10	0	1	1	7	9	10
36	Ma On Shan Tsung Tsin Secondary School	G/IC	S/MOS/21	1406	1406	0.95	0%	10%	10%	100%	55%	10%	0	141	141	1406	773	141	0	141	141	1406	773	141
37	Kowloon City Baptist Church Hay Nien Primary School	G/IC	S/MOS/21	1124	1124	0.95	0%	10%	10%	100%	55%	10%	0	112	112	1124	618	112	0	112	112	1124	618	112
38	Chevalier Garden	R(A)1	S/MOS/21	1136	1120								0	0	0	0	0	0	0	0	0	0	0	0
38a	Chevalier Garden Block 6	R(A)1	S/MOS/21	568	560	0.95	100%	50%	50%	20%	50%	80%	568	284	284	114	284	454	560	280	280	112	280	448
38b	Chevalier Garden Block 5	R(A)1	S/MOS/21	568	560	0.95	100%	50%	50%	20%	50%	80%	568	284	284	114	284	454	560	280	280	112	280	448
39	Kam Tai Court	R(A)	S/MOS/21	1436	1414								0	0	0	0	0	0	0	0	0	0	0	0
39a	Kam Ying House Block H	R(A)	S/MOS/21	718	707	0.95	100%	50%	50%	20%	50%	80%	718	359	359	144	359	574	707	354	354	141	354	566
39b	Kam Tin House Block J	R(A)	S/MOS/21	718	707	0.95	100%	50%	50%	20%	50%	80%	718	359	359	144	359	574	707	354	354	141	354	566
40	S.K.H. Ma On Shan Holy Spirit Primary School	G/IC	S/MOS/21	1318	1318	0.95	0%	10%	10%	100%	55%	10%	0	132	132	1318	725	132	0	132	132	1318	725	132
41	Shing Mun River Promenade	G/IC	S/ST/31	36	36	0	0%	10%	10%	70%	85%	100%	0	4	4	25	31	36	0	4	4	25	31	36
P1	Proposed Project Site	GB	S/ST/31	500	300	0.95	100%	100%	100%	100%	100%	100%	500	500	500	500	500	500	300	300	300	300	300	300
P2	Proposed Project Site Office and Works Area	G/IC	S/ST/31	500	0	0.5	100%	100%	100%	100%	100%	100%	500	500	500	500	500	500	0	0	0	0	0	0

ID	Description		Population in Yr 2022_FB							Population in Yr 2027_FB						Remarks
		Shielding	Night	AM Peak	PM Peak	Weekday Daytime	Saturday Daytime	Sunday daytime	Shielding	Night	AM Peak	PM Peak	Weekday Daytime	Saturday Daytime	Sunday daytime	
14	Garden Vista	0.0	0	0	0	0	0	0	0.0	0	0	0	0	0	0	= sum of 14a-14e
14a	Block D	0.5	281	141	141	56	141	225	0.5	273	136	136	55	136	218	Total 138 flats. Population estimated by adopting the household size projected from TPEDM in PDZ 386 from 2.91 (in yr 2015) to 2.70 (in yr 2022) and 2.62 (in yr 2027)
14b	Block E	0.5	281	141	141	56	141	225	0.5	273	136	136	55	136	218	Total 138 flats. Population estimated by adopting the household size projected from TPEDM in PDZ 386 from 2.91 (in yr 2015) to 2.70 (in yr 2022) and 2.62 (in yr 2027)
14c	Block F	0.5	216	108	108	43	108	173	0.5	210	105	105	42	105	168	Total 138 flats. Population estimated by adopting the household size projected from TPEDM in PDZ 386 from 2.91 (in yr 2015) to 2.70 (in yr 2022) and 2.62 (in yr 2027)
14d	Car park under podium of Block D, Block E & Block F	0.0	3	30	30	21	21	21	0.0	3	30	30	21	21	21	By site survey on 12 July 2015
14e	Podium of Block D, Block E & Block F	0.0	4	38	38	27	27	27	0.0	4	38	38	27	27	27	Assumed 0.01 ppl/area
15	Pictorial Garden (Stage 1)	0.0	0	0	0	0	0	0	0.0	0	0	0	0	0	0	= sum of 15a- 15e
15a	Abbey Court	0.5	303	151	151	61	151	242	0.5	294	147	147	59	147	235	Total 138 flats. Population estimated by adopting the household size projected from TPEDM in PDZ 386 from 2.91 (in yr 2015) to 2.70 (in yr 2022) and 2.62 (in yr 2027)
15b	Belleve Court	0.5	303	151	151	61	151	242	0.5	294	147	147	59	147	235	Total 138 flats. Population estimated by adopting the household size projected from TPEDM in PDZ 386 from 2.91 (in yr 2015) to 2.70 (in yr 2022) and 2.62 (in yr 2027)
15c	Capilano Court	0.5	303	151	151	61	151	242	0.5	294	147	147	59	147	235	Total 138 flats. Population estimated by adopting the household size projected from TPEDM in PDZ 386 from 2.91 (in yr 2015) to 2.70 (in yr 2022) and 2.62 (in yr 2027)
15d	Car park under podium	0.0	4	40	40	28	28	28	0.0	4	40	40	28	28	28	By site survey on 12 July 2015
15e	Podium	0.0	7	69	69	48	48	48	0.0	7	69	69	48	48	48	Assumed 0.01 ppl/area
16	Pictorial Garden (Stage 2)	0.0	0	0	0	0	0	0	0.0	0	0	0	0	0	0	= sum of 16a-16f
16a	Delite Court	0.5	141	70	70	28	70	112	0.5	136	68	68	27	68	109	Total 138 flats. Population estimated by adopting the household size projected from TPEDM in PDZ 386 from 2.91 (in yr 2015) to 2.70 (in yr 2022) and 2.62 (in yr 2027)
16b	Elegant Court	0.5	141	70	70	28	70	112	0.5	136	68	68	27	68	109	Total 138 flats. Population estimated by adopting the household size projected from TPEDM in PDZ 386 from 2.91 (in yr 2015) to 2.70 (in yr 2022) and 2.62 (in yr 2027)
16c	Forum Court	0.5	281	141	141	56	141	225	0.5	273	136	136	55	136	218	Total 138 flats. Population estimated by adopting the household size projected from TPEDM in PDZ 386 from 2.91 (in yr 2015) to 2.70 (in yr 2022) and 2.62 (in yr 2027)
16d	Galaxy Court	0.5	281	141	141	56	141	225	0.5	273	136	136	55	136	218	Total 138 flats. Population estimated by adopting the household size projected from TPEDM in PDZ 386 from 2.91 (in yr 2015) to 2.70 (in yr 2022) and 2.62 (in yr 2027)
16e	Car park under podium	0.0	4	40	40	28	28	28	0.0	4	40	40	28	28	28	By site survey on 12 July 2015
16f	Podium	0.0	7	70	70	49	49	49	0.0	7	70	70	49	49	49	Assumed 0.01 ppl/area
17	Pictorial Garden (Stage 3)	0.0	0	0	0	0	0	0	0.0	0	0	0	0	0	0	=sum of 17a - 17e
17a	Hillview Court	0.5	187	93	93	37	93	149	0.5	181	90	90	36	90	144	Total 138 flats. Population estimated by adopting the household size projected from TPEDM in PDZ 386 from 2.91 (in yr 2015) to 2.70 (in yr 2022) and 2.62 (in yr 2027)
17b	Iris Court	0.5	187	93	93	37	93	149	0.5	181	90	90	36	90	144	Total 138 flats. Population estimated by adopting the household size projected from TPEDM in PDZ 386 from 2.91 (in yr 2015) to 2.70 (in yr 2022) and 2.62 (in yr 2027)
17c	Juniper Court	0.5	187	93	93	37	93	149	0.5	181	90	90	36	90	144	Total 138 flats. Population estimated by adopting the household size projected from TPEDM in PDZ 386 from 2.91 (in yr 2015) to 2.70 (in yr 2022) and 2.62 (in yr 2027)
17d	Car park under podium	0.0	3	30	30	21	21	21	0.0	3	30	30	21	21	21	By site survey on 12 July 2015
17e	Podium	0.0	3	31	31	22	22	22	0.0	3	31	31	22	22	22	Assumed 0.01 ppl/area
18	On King Street Park	1.0	0	0	0	0	0	0	1.0	0	0	0	0	0	0	By site survey on 12 July 2015
19	Open Car Park (near Jockey Club Shek Mun Rowing Centre)	0.0	1	10	10	7	7	7	0.0	1	10	10	7	7	7	By site survey on 12 July 2015
20	Jockey Club Shek Mun Rowing Centre	0.5	0	3	3	18	21	25	0.5	0	3	3	18	21	25	By site survey on 12 July 2015
21	Hong Kong China Dragon Boat Association Shatin Shek Mun Training Centre	0.5	0	3	3	18	21	25	0.5	0	3	3	18	21	25	By site survey on 12 July 2015
22	Hong Kong Canoe Union Shatin Training Centre	0.5	0	3	3	18	21	25	0.5	0	3	3	18	21	25	By site survey on 12 July 2015
23	Site Offices (DSD / LandsD)	0.0	6	6	6	60	33	6	0.0	6	6	6	60	33	6	By site survey on 12 July 2015
24	Petrol Station	0.0	10	10	10	10	10	10	0.0	10	10	10	10	10	10	By site survey on 12 July 2015
25	Shek Mun Fresh Water Booster Pumping Station	0.0	0	0	0	0	0	0	0.0	0	0	0	0	0	0	By site survey on 12 July 2015
26	On Sum Street Substation	0.0	0	0	0	0	0	0	0.0	0	0	0	0	0	0	By site survey on 12 July 2015
27	Sha Tin Community Green Station	0.0	6	6	6	60	60	60	0.0	6	6	6	60	60	60	By site survey on 12 July 2015
28	Open Car Park (near Pumping House on On Ping Street)	0.0	0	20	20	14	9	4	0.0	0	20	20	14	9	4	By site survey on 12 July 2015
29	Shatin Hospital	0.0	0	0	0	0	0	0	0.0	0	0	0	0	0	0	=sum of 29a-29i
29a	Shatin Hospital	0.5	390	390	390	488	439	390	0.5	390	390	390	488	439	390	Total 650 beds, assume the ratio between staff and patient is 1:2
29b	Open Car Park	0.0	1	10	10	7	7	7	0.0	1	10	10	7	7	7	By site survey on 12 July 2015
29c	Transport Terminus	0.0	3	30	30	21	18	15	0.0	3	30	30	21	18	15	By site survey on 12 July 2015
29d	Football Field	0.0	0	2	2	15	19	22	0.0	0	2	2	15	19	22	By site survey on 12 July 2015
29e	Basketball Court	0.0	0	2	2	11	14	16	0.0	0	2	2	11	14	16	By site survey on 12 July 2015
29f	Jockey Club Centre for Positive Ageing	0.5	10	10	10	13	11	10	0.5	10	10	10	13	11	10	Total 17 beds and 8 staff http://www.jccpa.org.hk/tc/environment/environment/index.php
29g	A Kung Kok Government Quarters Block B	0.5	52	26	26	10	26	42	0.5	51	26	26	10	26	41	Total 20 flats. Population estimated by adopting the household size projected from TPEDM in PDZ 215 from 5.33 (in yr 2015) to 5.19 (in yr 2022) and 5.11 (in yr 2027)
29h	A Kung Kok Government Quarters Block C	0.5	52	26	26	10	26	42	0.5	51	26	26	10	26	41	Total 20 flats. Population estimated by adopting the household size projected from TPEDM in PDZ 215 from 5.33 (in yr 2015) to 5.19 (in yr 2022) and 5.11 (in yr 2027)
29i	Tennis Court	0.0	0	1	1	7	9	10	0.0	0	1	1	7	9	10	By site survey on 12 July 2015
30	A Kung Kok Sewage Pumping Station	0.0	1	1	1	10	6	1	0.0	1	1	1	10	6	1	Assumed 10 workers for the major improvement work
31	Ah Hung Kok Fishmen's Village	0.0	0	0	0	0	0	0	0.0	0	0	0	0	0	0	=sum of 31a - 31e
31a	Ah Kung Kok Fishermen Village (a)	0.5	187	94	94	37	94	150	0.5	184	92	92	37	92	147	Total 72 flats. Population estimated by adopting the household size projected from TPEDM in PDZ 215 from 5.33 (in yr 2015) to 5.19 (in yr 2022) and 5.11 (in yr 2027)
31b	Ah Kung Kok Fishermen Village (b)	0.5	320	160	160	64	160	256	0.5	315	157	157	63	157	252	Total 132 flats. Population estimated by adopting the household size projected from TPEDM in PDZ 215 from 5.33 (in yr 2015) to 5.19 (in yr 2022) and 5.11 (in yr 2027)
31c	Basketball Court	0.0	0	2	2	11	14	16	0.0	0	2	2	11	14	16	By site survey on 12 July 2015
31d	Football Field	0.0	0	2	2	15	19	22	0.0	0	2	2	15	19	22	By site survey on 12 July 2015
31e	A Kung Kok Sitting-out Area	0.0	0	1	1	7	9	10	0.0	0	1	1	7	9	10	By site survey on 12 July 2015
32	Hong Kong Mountaineering Union	0.0	0	0	0	0	0	0	0.0	0	0	0	0	0	0	By site survey on 12 July 2015
33	Evangelical Lutheran Church of Hong Kong Shatin Youth Centre Recreational Camp and Training Centre	0.5	0	0	0	0	0	0	0.5	0	0	0	0	0	0	To be demolished due to cavern construction work
34	Custom and Excise Department Shatin Vehicle Detention Centre	0.0	0	0	0	0	0	0	0.0	0	80	80	800	440	80	Change to site office during cavern construction stage. The land use after completion of construction works is not known at the moment. In view that with the constraint imposed by Tate's Cairn Highway, it is unlikely to have high density population there. Therefore it is assumed that it will be an educational institution.
35	A Kung Kok Street Garden	0.0	0	1	1	7	9	10	0.0	0	1	1	7	9	10	By site survey on 12 July 2015
36	Ma On Shan Tsung Tsin Secondary School	0.5	0	70	70	703	387	70	0.5	0	70	70	703	387	70	Population estimated by information from Education Bureau http://applications.edb.gov.hk/schoolsearch/permittedaccommodation.aspx?langno=2&scrn=190772000133
37	Kowloon City Baptist Church Hay Nien Primary School	0.5	0	56	56	562	309	56	0.5	0	56	56	562	309	56	Population estimated by information from Education Bureau http://applications.edb.gov.hk/schoolsearch/permittedaccommodation.aspx?langno=2&scrn=114987000123
38	Chevalier Garden	0.0	0	0	0	0	0	0	0.0	0	0	0	0	0	0	=sum of 38a - 38b
38a	Chevalier Garden Block 6	0.5	284	142	142	57	142	227	0.5	280	140	140	56	140	224	Total 190 flats. Population estimated by adopting the household size projected from TPEDM in PDZ 216 from 3.06 (in yr 2015) to 2.99 (in yr 2022) and 2.95 (in yr 2027)
38b	Chevalier Garden Block 5	0.5	284	142	142	57	142	227	0.5	280	140	140	56	140	224	Total 190 flats. Population estimated by adopting the household size projected from TPEDM in PDZ 216 from 3.06 (in yr 2015) to 2.99 (in yr 2022) and 2.95 (in yr 2027)
39	Kam Tai Court	0.0	0	0	0	0	0	0	0.0	0	0	0	0	0	0	=sum of 39a - 39b
39a	Kam Ying House Block H	0.5	359	180	180	72	180	287	0.5	354	177	177	71	177	283	Total 240 flats. Population estimated by adopting the household size projected from TPEDM in PDZ 216 from 3.06 (in yr 2015) to 2.99 (in yr 2022) and 2.95 (in yr 2027)
39b	Kam Tin House Block J	0.5	359	180	180	72	180	287	0.5	354	177	177	71	177	283	Total 240 flats. Population estimated by adopting the household size projected from TPEDM in PDZ 216 from 3.06 (in yr 2015) to 2.99 (in yr 2022) and 2.95 (in yr 2027)
40	S.K.H. Ma On Shan Holy Spirit Primary School	0.5	0	66	66	659	362	66	0.5	0	66	66	659	362	66	Population estimated by information from Education Bureau http://applications.edb.gov.hk/schoolsearch/permittedaccommodation.aspx?langno=2&scrn=535729000123
41	Shing Mun River Promenade	0.0	0	4	4	25	31	36	0.0	0	4	4	25	31	36	Area: 10865 ; density : 0.0030 (for cycle track) ; density: 0.0039 (for pedestrians)
P1	Project Site	0.0	500	500	500	500	500	500	0.0	300	300	300	300	300	300	Assume 500 construction workers in construction stage and 300 staff in operation stage
P2	Project Site Office	0.0	500	500	500	500	500	500	0.0	0	0	0	0	0	0	Change to site office during cavern construction stage. The land use after completion of construction works is not known at the moment. In view that with the constraint imposed by Tate's Cairn Highway, it is unlikely to have high density population there. Therefore it is assumed that it will be an educational institution.

ANNEX 2 Calculation of Aircraft Crash Frequency

The model considers specific factors such as target area of the proposed magazine site and its longitudinal (x) and perpendicular (y) distances from the runway threshold for landing and take-off movement. The aircraft crash frequency per unit ground area (per km^2) is calculated as:

$$g(x,y) = NRF(x,y) \tag{1}$$

Where N is the number of runway movements per year; R is the probability of an accident per movement (landing or takeoff). F(x,y) gives the spatial distribution of crashes and is given by:

For aircraft landing, for x > -3.275km,

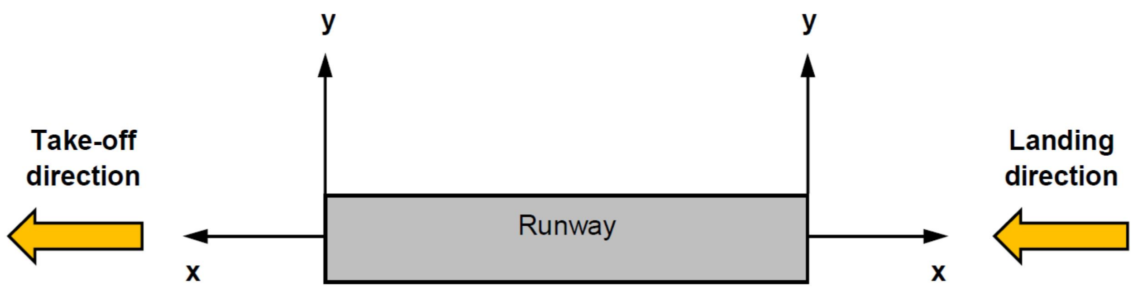
$$F_L(x,y) = \frac{(x+3.275)}{3.24} e^{\frac{-(x+3.275)}{1.8}} \left[\frac{56.25}{\sqrt{2\pi}} e^{-0.5(125y)^2} + 0.625 e^{-\frac{|y|}{0.4}} + 0.005 e^{-\frac{|y|}{5}} \right] \tag{2}$$

For aircraft takeoff, for x > -0.6km,

$$F_T(x,y) = \frac{(x+0.6)}{1.44} e^{\frac{-(x+0.65)}{1.2}} \left[\frac{46.25}{\sqrt{2\pi}} e^{-0.5(125y)^2} + 0.9635 e^{-4.1|y|} + 0.08 e^{-|y|} \right] \tag{3}$$

Equations (2) and (3) are valid only for the specified range of x values. If x lies outside this range, the impact probability is zero. This case applies for 07L and o7R runways for arrival flight path and 25L and 25R runways for departure flight path.

Distances between the proposed magazine and the runways are measured and transformed into longitudinal (x) and perpendicular (y) distances in the Aircraft Crash Coordinate System according to the following figure.



The probability of an accident per movement R is interpreted from NTSB data for fatal accidents in the U.S. involving scheduled airline flights during the period 1986-2005. The 10-year moving average suggested a downward trend with recent years showing a rate of about 2×10^{-7} per flight. There are only 13.5% of accidents associated with the approach to landing, 15.8% associated with take-off and 4.2% are related to the climb phase of the flight [6]. Thus it is assumed that the accident frequency for the approach to landings is taken as 2.7×10^{-8} per flight and for take-off is 4.0×10^{-8} per flight.

The number of runway movements of aircraft N is provided by yearly statistics of the Hong Kong International Airport in 2005-2014. Number of movements at year 2022 and year 2027 are estimated by linear regression respectively for landing and take-off cases. The movement number adopted in the

calculation has been divided by 4 to take into account that only a quarter of landing or take-off use a specific runway.

The aircraft crash frequency is finally obtained by multiplying g(x,y) to target area which is estimated to be 1.2×10^{-3} km^2 for the magazine.

The calculations are presented in **Table 1** and the total crash frequency per year in both construction stage (Yr 2022) ad operational stage (Yr 2027) are summarised in **Table 2**.

Table 1 Calculation for Aircraft Crash Frequency

Year	Runway	x (km)	y (km)	F(x,y)	N (per year)	R (per flight)	Crash frequency (per unit area)	Target area (km^2)	Crash Frequency (per year)
2022	25R Landing	30.6	9.1	5.7E-11	69422	2.7E-08	1.1E-13	1.14E-03	1.2E-16
2022	25L Landing	30.2	10.7	5.1E-11	69422	2.7E-08	9.5E-14	1.14E-03	1.1E-16
2022	07L Take-off	30.6	9.1	9.5E-16	69407	4.0E-08	2.6E-18	1.14E-03	3.0E-21
2022	07R Take-off	30.2	10.7	2.6E-16	69407	4.0E-08	7.3E-19	1.14E-03	8.4E-22
2027	25R Landing	30.6	9.1	5.7E-11	86442	2.7E-08	1.3E-13	1.14E-03	1.5E-16
2027	25L Landing	30.2	10.7	5.1E-11	86442	2.7E-08	1.2E-13	1.14E-03	1.4E-16
2027	07L Take-off	30.6	9.1	9.5E-16	86421	4.0E-08	3.3E-18	1.14E-03	3.7E-21
2027	07R Take-off	30.2	10.7	2.6E-16	86421	4.0E-08	9.1E-19	1.14E-03	1.0E-21

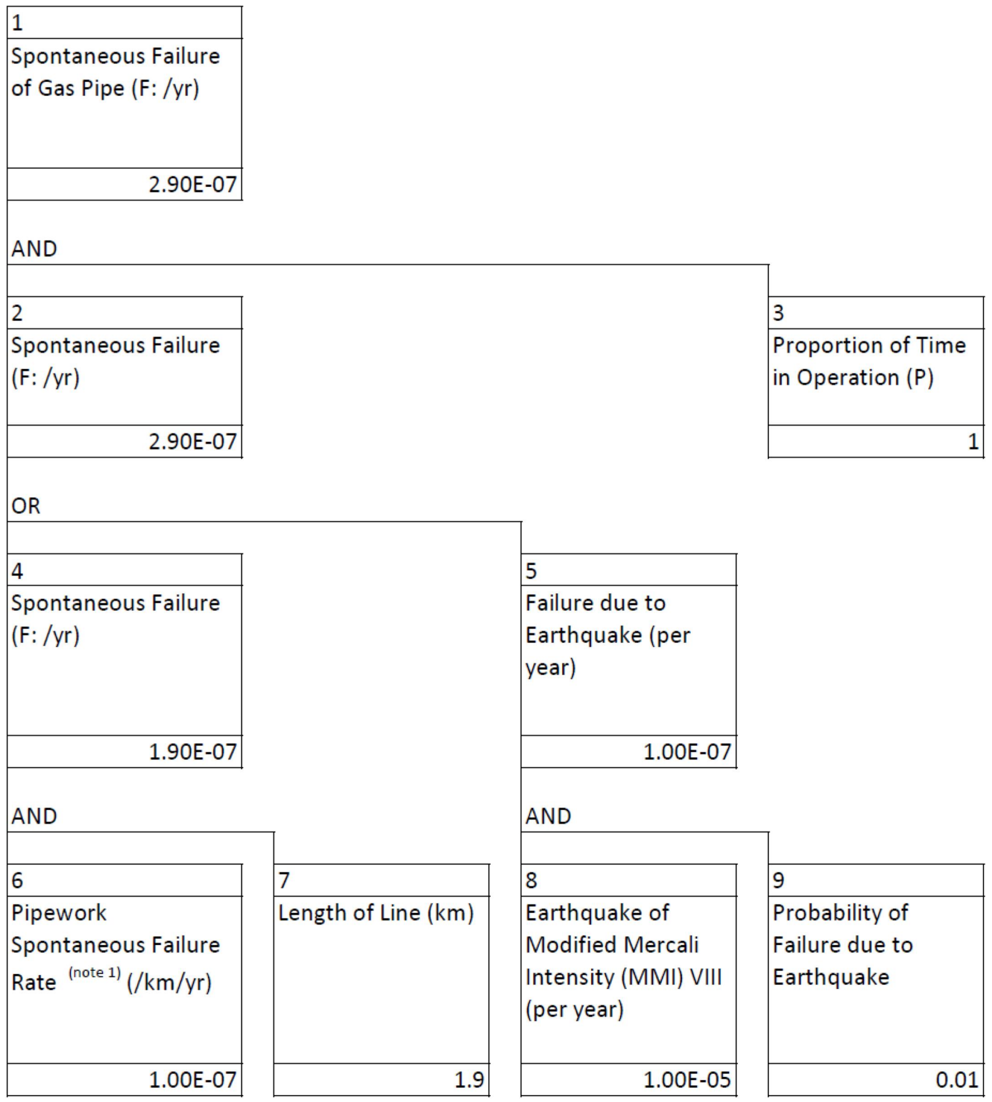
Table 2 Total Aircraft Crash Frequency

Year 2022	Total Crash Frequency (per year)
Landing	2.3E-16
Take-off	3.8E-21
Total	2.3E-16

Annex 3

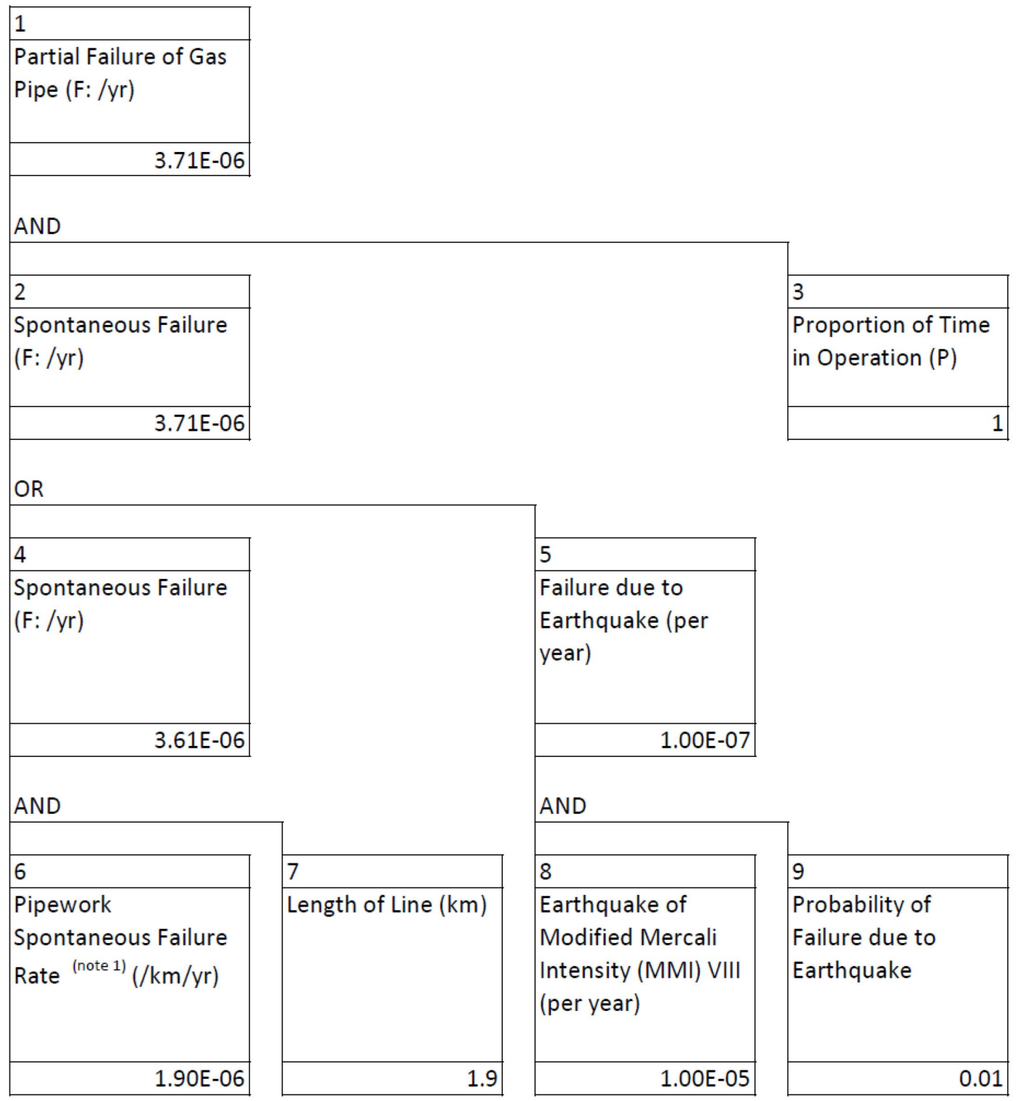
Fault Tree for the High Pressure (HP) Gas Pipeline

F1 Rupture of 600mm HP Gas Pipeline



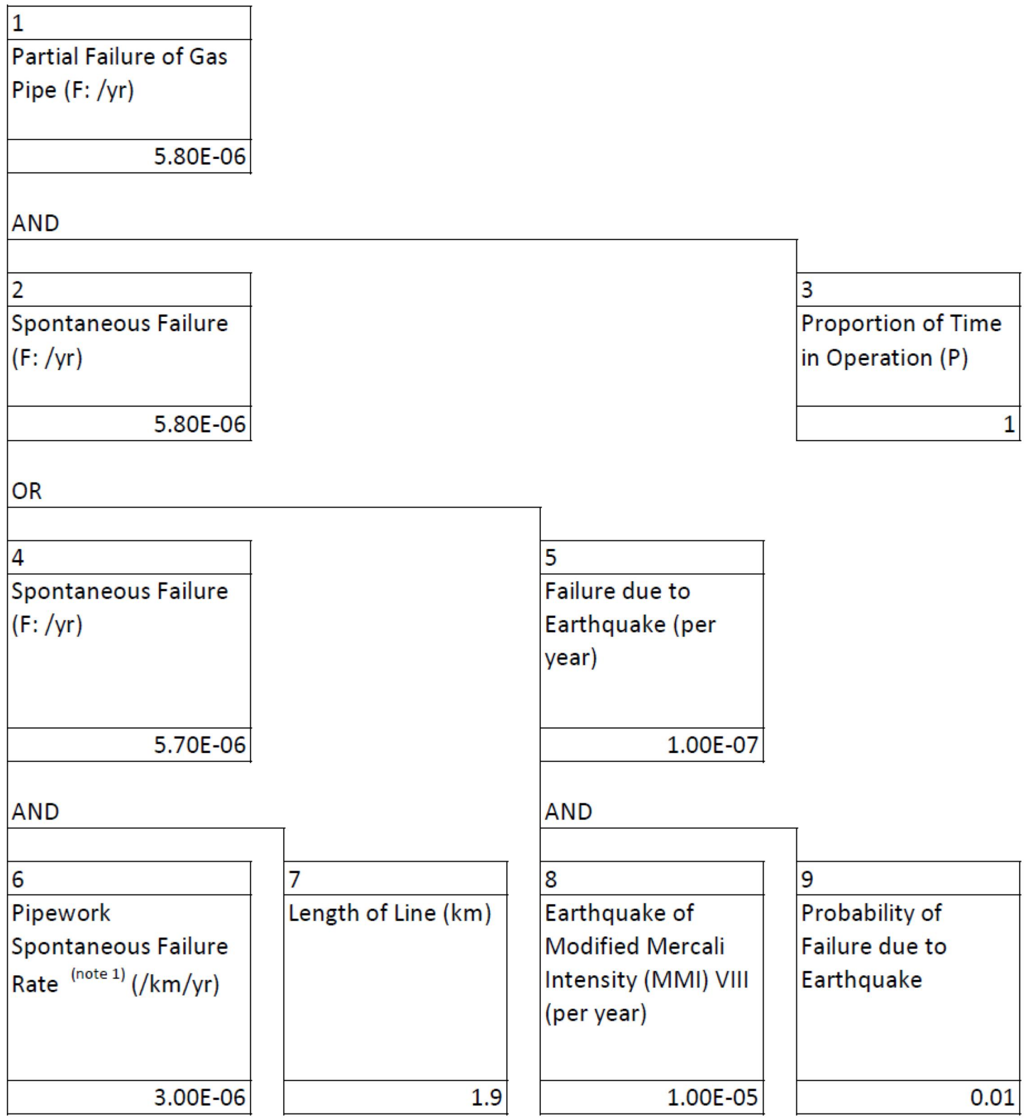
Note 1: UK Onshore Pipeline Operators' Association (UKOPA) Pipeline Fault Data
Note 2: Distribution of failure modes refers to aircraft strike rates in HSE Land Use and Planning 2012

F2 4" Leak of 600mm HP Gas Pipeline



Note 1: UK Onshore Pipeline Operators' Association (UKOPA) Pipeline Fault Data
Note 2: Distribution of failure modes refers to aircraft strike rates in HSE Land Use and Planning 2012

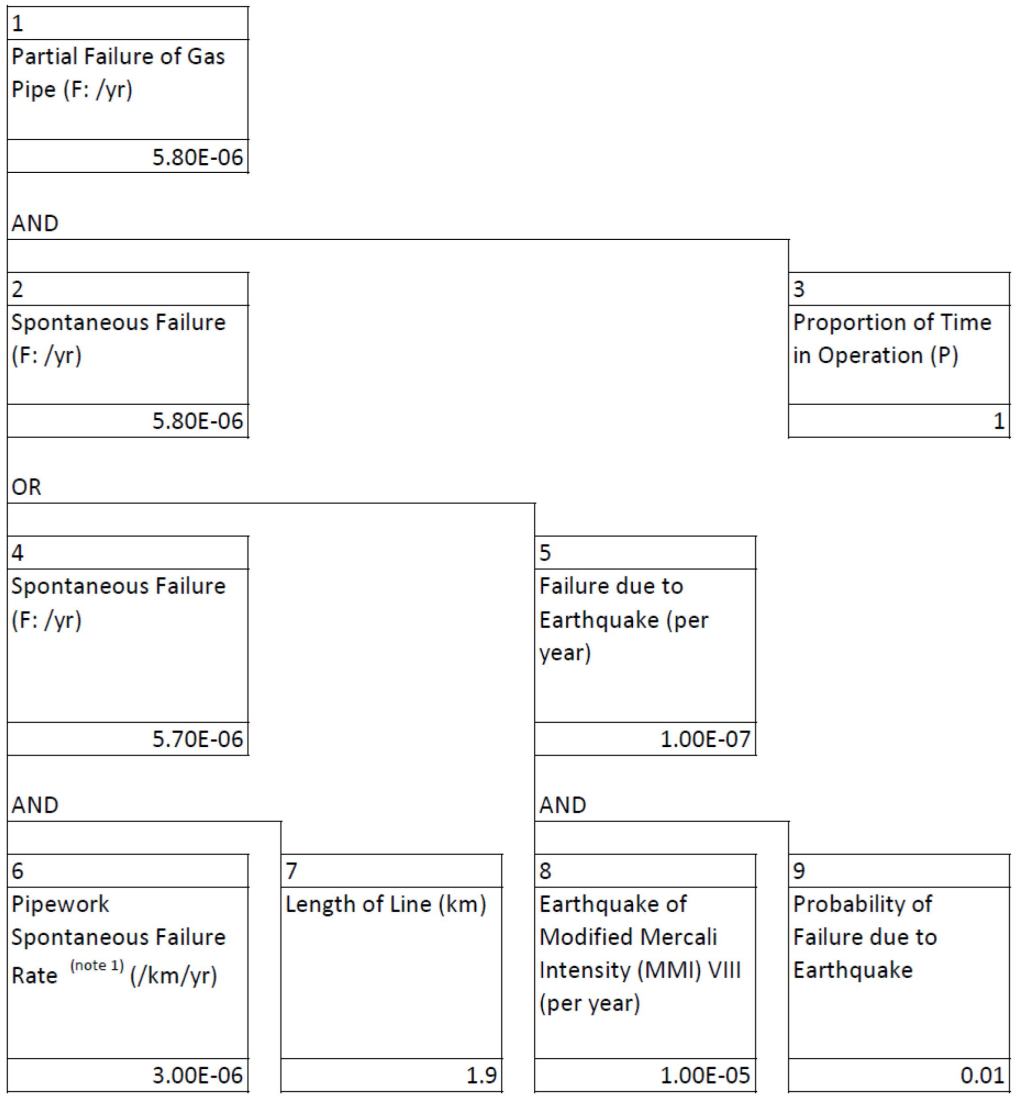
F3 2" Leak of 600mm HP Gas Pipeline



Note 1: UK Onshore Pipeline Operators' Association (UKOPA) Pipeline Fault Data
Note 2: Distribution of failure modes refers to aircraft strike rates in HSE Land Use and Planning 2012

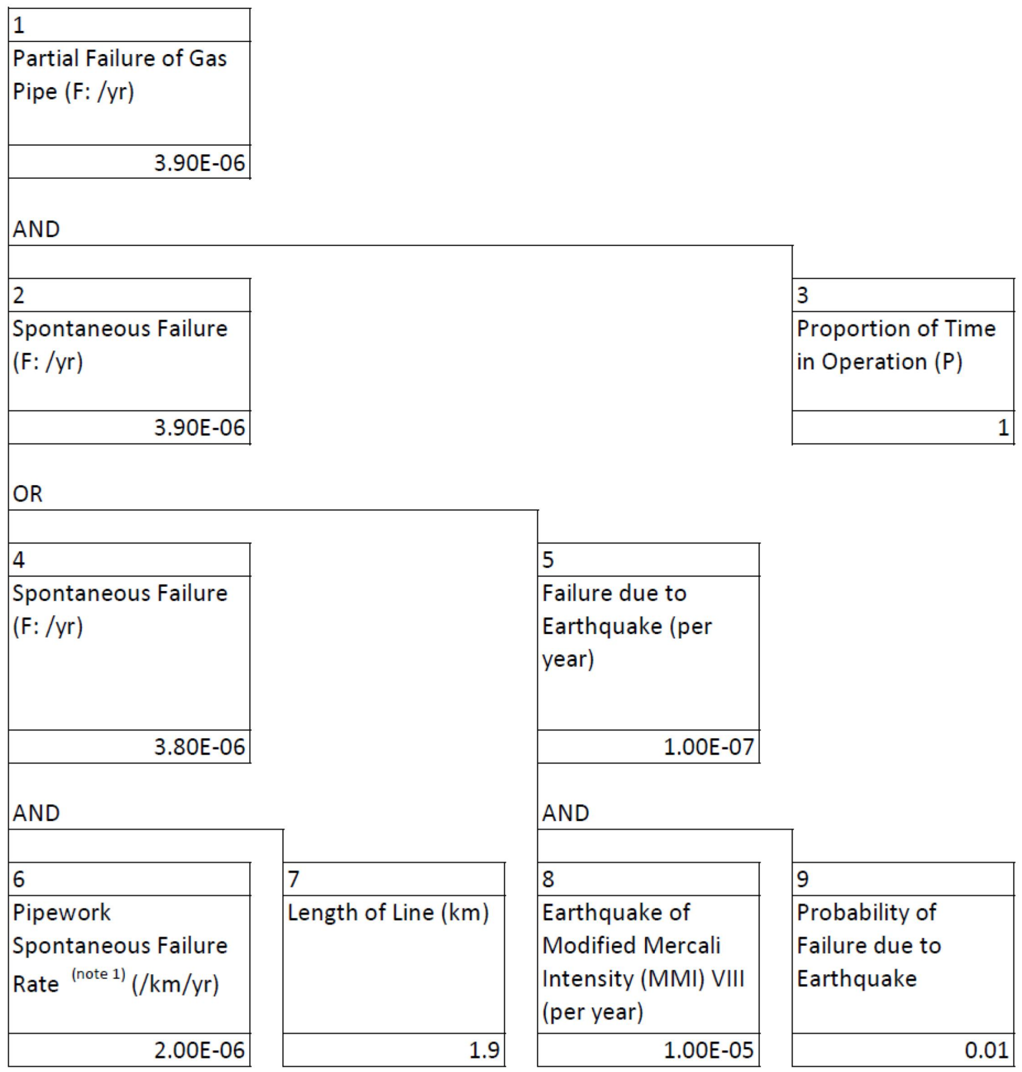
Sha Tin Cavern Sewage Treatment Works
EIA Report
Appendix 7.03

F4 1" Leak of 600mm HP Gas Pipeline



Note 1: UK Onshore Pipeline Operators' Association (UKOPA) Pipeline Fault Data
Note 2: Distribution of failure modes refers to aircraft strike rates in HSE Land Use and Planning 2012

F5 10mm Leak of 600mm HP Gas Pipeline



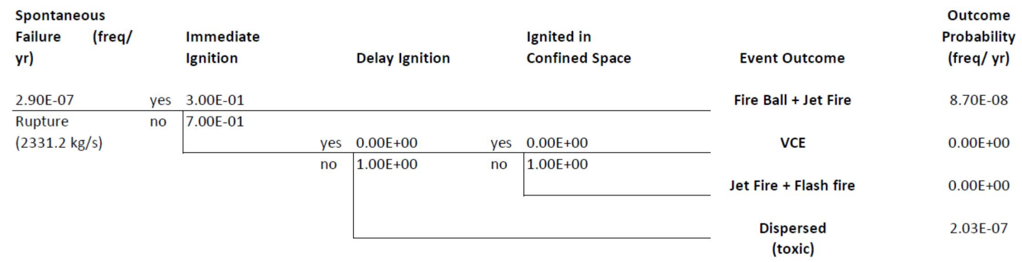
Note 1: UK Onshore Pipeline Operators' Association (UKOPA) Pipeline Fault Data

Note 2: Distribution of failure modes refers to aircraft strike rates in HSE Land Use and Planning 2012

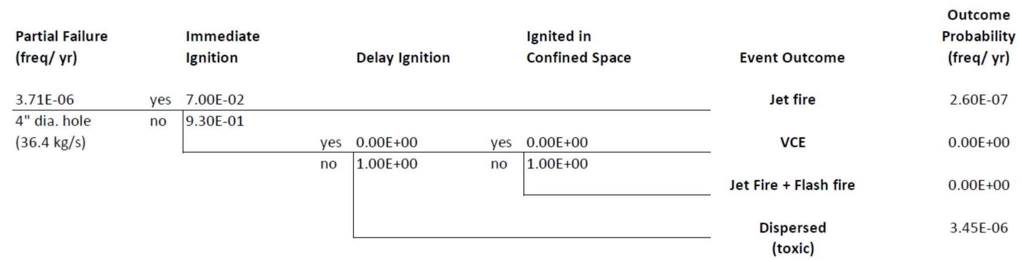
Annex 4

Event Tree for the High Pressure (HP) Gas Pipeline

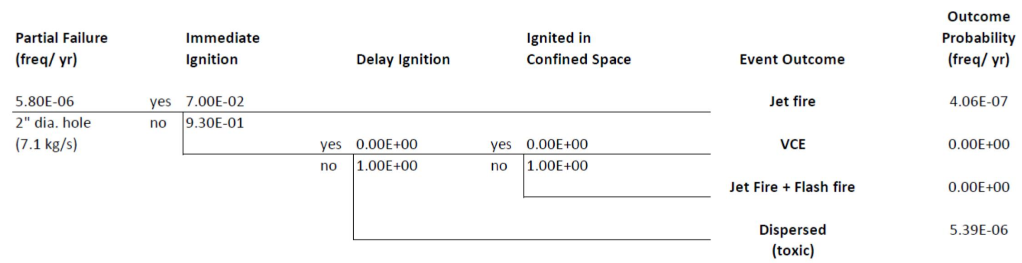
E1 Full bore rupture of gas pipe



E2 4" pipe leak of gas pipe



E3 2" pipe leak of gas pipe



Reference: Cox, Lees and Ang, 1990
Ignition probability for gas leakage size <1kg/s = 0.01
Ignition probability for gas leakage size 1-50kg/s = 0.07
Ignition probability for gas leakage size >50kg/s = 0.3
Probability of immediate ignition assumed 100%

E4 **1" pipe leak of gas pipe**

Spontaneous Failure (freq/ yr)		Immediate Ignition		Delay Ignition		Ignited in Confined Space	Event Outcome	Outcome Probability (freq/ yr)
5.80E-06	yes	7.00E-02					Jet fire	4.06E-07
1" dia. hole	no	9.30E-01						
2.90E-07			yes	0.00E+00	yes	0.00E+00	VCE	0.00E+00
			no	1.00E+00	no	1.00E+00		
							Jet Fire + Flash fire	0.00E+00
							Dispersed (toxic)	5.39E-06

E5 **10mm pipe leak of gas pipe**

Partial Failure (freq/ yr)		Immediate Ignition		Delay Ignition		Ignited in Confined Space	Event Outcome	Outcome Probability (freq/ yr)
3.90E-06	yes	1.00E-02					Jet fire	3.90E-08
10mm dia. hole	no	9.90E-01						
(0.1 kg/s)			yes	0.00E+00	yes	0.00E+00	VCE	0.00E+00
			no	1.00E+00	no	1.00E+00		
							Jet Fire + Flash fire	0.00E+00
							Dispersed (toxic)	3.86E-06

Reference: Cox, Lees and Ang, 1990
Ignition probability for gas leakage size <1kg/s = 0.01
Ignition probability for gas leakage size 1-50kg/s = 0.07
Ignition probability for gas leakage size >50kg/s = 0.3
Probability of immediate ignition assumed 100%