Prepared by

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ENVIRONMENTAL IMPACT ASSESSMENT STUDY FOR SAI O TRUNK SEWER SEWAGE PUMPING STATION

APPENDIX 9.1
HAZARD TO LIFE ASSESSMENT OF TOWN GAS INSTALLATIONS

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1.0 Introduction

1.1 Background

A new sewage pumping station, the Sai O Trunk Sewer Sewage Pumping Station (hereafter referred to as the "Project") is proposed at the north of Sai O near Nai Chung, with a capacity of about 20,600m^3 per day for coping with the sewerage needs of both existing and future developments. The Project is part of Public Works Programme Item 4125DS – Tolo Harbour Sewerage of Unsewered Areas, Stage II, which originates from the findings of the Study "Review of North District and Tolo Harbour Sewerage Master Plan" completed in 2002. The location of the proposed sewage pumping station is shown in **Figure 1**.

The Project consists of Designated Project (DP) under Item F3, Part I, Schedule 2 of the Environmental Impact Assessment Ordinance (EIAO). An application for an Environmental Impact Assessment (EIA) Study Brief under section 5(1)(a) of the EIAO was made to Environmental Protection Department (EPD) and the EIA Study Brief No. ESB-281 /2014 issued under the EIAO. According to the Study Brief, a Hazard to Life Assessment is required to address the potential risks associated with two high pressure (HP) town gas pipelines running across the proposed development site and Sai O Offtake and Pigging Station.

1.2 This Document

This document aims to present the Hazard to Life Assessment of the HP town gas pipelines and the Sai O Offtake and Pigging Station (using a Quantitative Risk Assessment (QRA) approach).

A draft QRA report was previously prepared and submitted for the concerned Sai O SPS in 2017 as well as 2019. Since then the site boundary of the concerned Sai O SPS has changed slightly. So, the current report acts as an update to the previous submitted report based on the latest proposed SPS.

1.3 Report Scope and Objectives

The scope of the hazard assessment includes two underground HP town gas pipelines along Nin Ming Road and Sai Sha Road; and the Sai O Offtake and Pigging Station that are adjacent to the Project Site.

The hazard assessment aims to achieve the objectives as set out in Section 3.4.5 of the EIA Study Brief:

"3.4.5 Hazard to Life

3.4.5.1 The Applicant shall follow the criteria for evaluating hazard to life as stated in Annex 4 of the TM.

3.4.5.2 … The hazard to life assessment for construction and operation phases of the Project shall follow the detailed technical requirements given in Appendix G."

Appendix G of the EIA Study Brief:

"1. The Applicant shall investigate methods to eliminate and/or minimize risks from town gas/chlorine. The Applicant shall carry out hazard assessment to evaluate potential hazard to life during construction and operation stages of the Project. The hazard assessment shall include but not limited to the following:

(i) Identify hazardous scenarios associated with town gas/chlorine, and then determine a set of relevant scenarios to be included in a Quantitative Risk Assessment (QRA);

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

(iii) Compare individual and societal risks with the criteria for evaluating hazard to life stipulated in Annex 4 of the TM; and

(iv) Identify and assess practicable and cost-effective risk mitigation measures.

2. The methodology to be used in the hazard assessment should be consistent with previous studies having similar issues."

1.4 Study Approach

The overall approach to the QRA is represented in **Figure 2**. It follows the Risk Guidelines stipulated in Annex 4 of the EIAO-TM[1] and the approved Environmental Impact Assessment (EIA) report "East Rail Extensions – Tai Wai to Ma On Shan" [2].

The major phases in the QRA are:

i. **Hazard Identification**: Identify hazard scenarios associated with the transmission of town gas, and then determine a set of relevant scenarios to be included in a QRA.

ii. **Frequency Assessment**: Assess the likelihood of occurrence of the identified hazard scenarios.

iii. **Consequence Assessment**: Assess the consequences and impact to the surrounding population.

iv. **Risk Summation and Assessment**: Evaluate the risk level, in terms of individual risk and societal risk. The risk is compared with the criteria stipulated in Annex 4 of the Environmental Impact Assessment Ordinance – Technical Memorandum (EIAO-TM)[1] to determine their acceptability.

v. **Identification of Mitigation Measures**: Identify and assess practicable and cost-effective risk mitigation measures. The risk of mitigated cases is then reassessed to determine the level of risk reduction.

In addition, the guideline developed by the Institution of Gas Engineers and Managers (IGEM) for the risk assessment of high pressure natural gas pipelines, IGEM/TD/2 [3], is also taken as reference as applicable, in view of the facts that: (i) the design of the concerned pipelines follows the standard of the IGEM, IGEM/TD/1 [4], and (ii) the dispersive and flammable properties of natural gas are comparable to those of town gas.

To obtain the site-specific societal risk, the study should cover the maximum distance over which the worst case event could affect the population in the vicinity. As the IGEM societal risk criterion is expressed on a per-mile (i.e. 1.6 km) basis, the highest risk 1.6 km section of pipeline should be selected for pipe interaction length, in which interaction length is defined as the length of the pipeline through the community such that there is no or very little population within the maximum hazard range beyond this distance. Otherwise, for pipe interaction length less than 1.6 km, the risk values (F) are factorized by a value equal to 1.6 km divided by the pipe interaction length.

1.5 Risk Acceptance Criteria

As stipulated in Annex 4 of the EIAO-TM [1], the risk guidelines comprise two measures shown as follows:

i. Individual Risk: a measure of the frequency at which an individual at a specified distance from the hazardous installations is expected to sustain a specified level of harm from the realization of hazardous incident(s). The maximum level of off-site individual risk causing fatality of a person located 24 hours a day outside the facility of concern should not exceed 1×10^{-5} / year, i.e. 1 in 100,000 per year.

ii. Societal Risk: a measure of the relationship between the frequency of an incident and the number of fatalities that will result. It is typically expressed graphically by an F-N curve showing the cumulative frequency (F) of incidents causing N or more fatalities. The societal risk criteria are presented graphically as in **Figure 3**. There are three regions as described below:

- **Acceptable** where the risk is so low that no action is necessary;
- **Unacceptable** where the risk is so high that they should be reduced regardless of the cost or else the hazardous activity should not be proceeded; and
- **ALARP** where the risk associated with the hazardous activities should be reduced to a level of "As Low As Reasonably Practicable", in which the mitigation measures should be prioritized on the basis of practicality and implementation cost versus the risk reduction achieved.

1.6 Cases to be considered

The years of construction and operation of the Project are anticipated to be around 2022 and 2024, respectively, based on current project program. The operation phase assessment year is taken as 2025 to tally with the population data obtained, which is considered to be conservative. Three cases are considered in this study to demonstrate the changes in risk level caused by the proposed development:

- Case 1 - Base case without the proposed development (2025) - to assess the risk by considering the surrounding population in 2025 without the proposed sewage pumping station;
- Case 2 - Construction case (2022) – to assess the risk due to the presence of construction workers within the site and the surrounding population in 2022 with the construction of the proposed sewage pumping station;
- Case 3 - Operation case with the proposed development (2025) - to assess the increase of risk due to the presence of the proposed sewage pumping station and the surrounding population in 2025;

1.7 Description of Proposed Sewage Pumping Station

The proposed sewage pumping station is situated at the north of Sai O near Nai Chung, with a capacity of about 20,600m^3 per day. No Dangerous Goods will be stored in the pumping station.

The Project Site is located on Nin Ming Road surrounding by Hong Kong Baptist Theological Seminary, a planned development and Sai O Offtake and Pigging Station. Currently, there are two underground HP town gas pipelines running across the Project Site.

The location of the Project Site and its vicinity is shown in **Figure 1**.

1.8 Description of Gas Facilities

1.8.1 Underground HP Town Gas Pipelines

A 600mm diameter pipeline running along Nin Ming Road transmits high pressure town gas (at 35 bar) from the production plant in Tai Po to Sai O Offtake and Pigging Station. Another pipeline of 750mm diameter is buried along Sai Sha Road, which is connecting from Sai O Offtake and Pigging Station to Tseng Lan Shue Offtake and Pigging Station. The existing alignment of the underground HP town gas pipelines as well as the location of Sai O Offtake and Pigging Station are shown in **Figure 4**. The two underground HP town gas pipelines are designed in accordance with the standard of IGEM, IGEM/TD/1 [4]. They have a nominal wall thickness of 12.7 mm and are buried at a minimum depth of 1.1m.

The two underground HP town gas pipelines are undergoing a planned pipe diversion under Sai Sha Road project works in the vicinity of the Project Site. The pipe diversion works are anticipated to be completed in 2020 / 2021. Information of diverted pipe has been obtained from HKCG. Since the construction and operation of the proposed Sewage Pumping Station will commence after the completion of the relevant pipe diversion works, only the modified alignment (as shown in **Figure 5**) is considered in this EIA to reflect the actual circumstances.

1.8.2 Sai O Offtake and Pigging Station

The Sai O Offtake and Pigging Station consists of one pressure reduction unit with two streams, one in operation and one on standby. It regulates the pressure of town gas from high pressure (35 barg) to medium pressure (2.4 barg) for supplying to Ma On Shan and Sai Kung area. The Sai O Offtake and Pigging Station also consists of a pigging station to carry out the internal inspection for the HP town gas pipe network. The size of pipework and number of critical equipment in the Sai O Offtake and Pigging Station as confirmed with HKCG are summarized in **Annex A**.

1.8.3 Maintenance and Safety Management

It is understood that HKCG conducts regular inspection and preventive maintenance for gas offtake stations in Hong Kong. HKCG also has comprehensive operating procedures and safety guidelines to safeguard its employees and the public.

HKCG always commits to achieve high standards of gas safety and there has not been any incident recorded from all offtake and pigging stations since the operation started in early 80’s (i.e. more than 30 years).

Details of HKCG’s maintenance and safety system are given in **Annex A**.

1.9 Properties of Town Gas

Town gas is colourless and buoyant under ambient conditions. Odorant is added to make it smell distinctive for easy detection of gas leakage. The main components of town gas are hydrogen and methane which are flammable. It also contains carbon dioxide and a small amount of carbon monoxide which are toxic and asphyxiating **Table 1** lists its composition and physical properties.

Table 1 Gas Composition and its Physical Properties

Component	Percentage (%)	Physical Properties	Values
Hydrogen (H_2)	46.3-51.8	Calorific Value (MJ/m^3)	17.27
Methane (CH_4)	28.2-30.7	Specific Gravity	0.52
Carbon Dioxide (CO_2)	16.3-19.9	Wobbe Index (MJ/Nm^3)	24
Carbon Monoxide (CO)	1-3.1	Weaver Flame Speed (Dimensionless)	35
Nitrogen & Oxygen (N_2 & O_2)	0-3.3	Lower Flammable Limit (LFL) (%)	5.5
Total	**100**		

1.10 Meteorological Information

Meteorological conditions affect the consequences of a gas release, in particular wind directions, speeds and stabilities which influence the direction and degree of turbulence of a gas dispersion. Meteorological data from the Sha Tin Weather Station (Year 2014 to 2018) was collected from the Hong Kong Observatory and adopted in the consequence modelling to compute the effects of various gas dispersions, fires and explosions. The data are rationalized into a set of weather classes in accordance with the Netherlands Organisation for Applied Scientific Research (TNO) Purple Book [5]. The meteorological data can be expressed in the combinations of wind speeds and Pasquill stability classes. Pasquill classes (A to F) represent the atmospheric turbulence, in which class A being the most turbulent class while class F being the least turbulent class.

The six most dominant sets of wind speed-stability class combination for both day-time and night-time are listed in **Table 2** and **Table 3** respectively. The average ambient temperature adopted in the analysis is 23°C and relative humidity is 78%.

Table 2 Day Time Wind Direction Frequency at Sha Tin Weather Station (Year 2014 to 2018)

Direction	WEATHER CLASS						Total
	3.0B	1.5D	4.0D	7.5D	3.0E	1.5F	
0 – 30	5.34	1.63	0.63	0.01	0.72	1.84	10.16
30 – 60	16.04	2.67	1.69	0.09	1.18	2.39	24.07
60 – 90	7.09	1.83	0.88	0.02	0.61	2.37	12.80
90 – 120	8.62	1.53	1.06	0.01	0.64	1.83	13.68
120 – 150	6.47	1.19	0.98	0.05	0.43	0.96	10.08
150 – 180	1.96	0.52	0.24	0.03	0.10	0.40	3.24
180 – 210	2.22	0.61	0.18	0.00	0.11	0.55	3.68
210 – 240	10.57	0.90	2.26	0.30	0.46	0.72	15.21
240 – 270	2.18	0.34	0.60	0.04	0.12	0.40	3.68
270 – 300	0.40	0.15	0.01	0.00	0.02	0.25	0.81
300 – 330	0.13	0.08	0.00	0.00	0.01	0.12	0.33
330 – 360	0.96	0.36	0.17	0.00	0.13	0.63	2.25
All	61.98	11.80	8.69	0.53	4.53	12.46	100.00

Table 3 Night Time Wind Direction Frequency at Sha Tin Weather Station (Year 2014 to 2018)

Direction	WEATHER CLASS						Total
	3.5B	1.5D	4.0D	7.5D	3.0E	1.5F	
0 – 30	0.00	0.50	0.88	0.01	2.05	8.02	11.45
30 – 60	0.00	0.33	2.43	0.07	3.81	9.83	16.48
60 – 90	0.00	0.19	1.25	0.03	2.18	11.81	15.46
90 – 120	0.00	0.24	1.17	0.00	3.02	9.79	14.22
120 – 150	0.00	0.07	0.62	0.03	1.33	5.51	7.56
150 – 180	0.00	0.02	0.42	0.07	0.51	4.98	6.01
180 – 210	0.00	0.03	0.87	0.02	0.78	3.75	5.45
210 – 240	0.00	0.05	3.00	0.05	2.91	4.19	10.20
240 – 270	0.00	0.03	1.37	0.00	1.16	2.43	4.99
270 – 300	0.00	0.01	0.01	0.00	0.03	1.69	1.73
300 – 330	0.00	0.03	0.02	0.00	0.01	1.42	1.48
330 – 360	0.00	0.14	0.18	0.00	0.51	4.13	4.96
All	0.00	1.65	12.22	0.28	18.28	67.57	100.00

2.0 Population Adopted for the Assessment

Population data to be considered include population in the vicinity of the offtake and pigging station and along the underground HP town gas pipelines which may be affected by the hazardous scenarios of the HP town gas installations.

2.1 Study Area

To carry out a site-specific societal risk assessment, the maximum distance over which the worst case event could affect the surrounding population should be considered [1][3]. This is defined as the site-specific pipeline interaction distance plus the maximum hazard range, which is the impact radius for the most severe pipeline event.

The pipeline interaction distance is selected to be the section of a pipeline through the community such that there is very little population in the hazard range beyond this distance[3]. The total length of pipelines considered in this QRA is 1.6 km as shown in **Figure 5**.

According to the consequence modelling results summarized in **Table 21** to **Table 25**, the maximum impact distance of the worst case event is approximately 176 m, resulting from the vapour cloud explosion of the full bore rupture of a pipeline. A conservative hazard range of 200 m is adopted for the underground HP town gas pipelines in this study. Similarly, a study area of radius 200 m is adopted for offtake and pigging station.

The study area of the offtake and pigging station and underground HP town gas pipelines is illustrated in **Figure 6**.

2.2 Population Considered in This Study

2.2.1 The Proposed Sewage Pumping Station

As advised by DSD, the proposed sewage pumping station will be an unmanned station during operation. Regular maintenance is assumed to be conducted twice a year and about 8 staffs and contractors will be involved in maintenance. A conservative number of 30 people (including engineers and construction workers) is assumed during construction. It is assumed that the construction and regular maintenance works will be carried out in day time only.

2.2.2 Population in the Vicinity

The surrounding populations will be directly impacted by hazardous events arising from the loss of contaminant of town gas in the pipeline and the offtake and pigging station. According to the Outline Zoning Plan (OZP), areas within the study area are mainly Residential, Village, Government, Institution or Community (G/IC) and Green Belt. Major population groups include:

- Residents of the nearby residential buildings and village houses;
- Transient population including traffic population and pedestrians; and
- Visitors / users of other public facilities.

Population information within the study area is collected based on desktop studies. Reference has been made to to population data in a recent QRA study covering similar study area for the same underground HP town gas pipelines and Sai O Offtake and Pigging Station under planning application no. A/NE-SSH/125.

The A/NE-SSH/125 QRA Report [6] forecasted the future population near Nai Chung and Sai O in year 2025 with a positive population growth. The operational phase assessment year is taken as 2025 and the population data estimated in A/NE-SSH/125 QRA Report is adopted for year 2025 scenarios (i.e. Case 1 and Case 3) in this study, considering that it is conservative to take in account future population growth in a full extent.

To population group not considered in the A/NE-SSH/125 QRA Report and also the year 2022 scenario in Case 2 of this study, the population data is estimated following the methodology in the A/NE-SSH/125 QRA Report [6]. The following assumptions are adopted:

- Average household size of 3.0 and 3.1 in Town Planning Unit (TPU) 741 and TPU 757, respectively [7];
- Assumption of annual residential population growth of 0.53% between Year 2016 to Year 2021 and 1.53% between Year 2021 to Year 2026 as predicted from figures for Ma On Shan in 2016-based TPEDM[8].

The coverage and location of the population considered are illustrated in **Figure 6**. The population data is summarized in **Table 4**.

2.2.3 Transient Population

Transient population includes traffic population as well as pedestrians along the road sections. Traffic population can be calculated using the equation below:

$$\text{Traffic Population (ppl)} = \frac{\frac{\text{No. of ppl}}{\text{vehicle}} \times \frac{\text{No. of vehicle}}{\text{hr}}}{\text{Traffic Speed } (\text{km}/\text{hr})} \times \text{Road Section Length (km)}$$

The transient population adopted for this study is summarized in **Table 4** with the detailed calculations are provided in **Annex B**.

Table 4 Population Considered in this Study

ID	Population Name	Population Type in 2022	Population Type in 2025	Population in 2022	Population in 2025 without development	Population in 2025 with development	Indoor Ratio 2022	Indoor Ratio 2025	Remarks
01	Helping Hand Cheung Muk Tau Holiday Centre For Elderly	Holiday Centre	Holiday Centre	340	340	340	50%	50%	Assumption based on up-to-date information: 300 guests and 40 staffs in daytime, 150 guests and 40 staffs in night time. Ref: http://www.helpinghand.org.hk/article.php?pid=8&id=25&gid=8&lang=big5
02	The Outward Bound Alumni Assn of HK Activities Centre	Recreational	Recreational	100	100	100	0%	0%	According to Table 2 of A/NE-SSH/125 QRA Report
03	Helping Hand Father Sean Burke Care Home For Elderly	Elderly Home	Elderly Home	252	252	252	90%	90%	Assumption based on up-to-date information: Maximum of 212 people permitted under the License of Residential Care Home for the Elderly. Assume 40 staffs. Ref: http://www.helpinghand.org.hk/article.php?pid=9&gid=80&lang=big5
04	Proposed School	Construction	School	150	1050	1050	0%	80%	According to population data of A/NE-SSH/125 QRA Report. Assume it will be under construction in Year 2022 and 150 construction workers will be involved.
05	Recreational Area	Construction	Recreational		150	150	0%	0%	
06	Proposed Pumping Station	Construction	Pumping Station	30	0	8	0%	95%	Advised by DSD.
07	BBQ Site	BBQ	BBQ	100	100	100	0%	0%	According to Table 2 of A/NE-SSH/125 QRA Report
08	Villa Concerto	Residential	Residential	1718	1797	1797	90%	90%	According to Table 2 of A/NE-SSH/125 QRA Report, estimated from 540 units with average household size of 3.1 in TPU 757 and the residential population growth rates from 2016-based TPEDM.
09	Villa Rhapsody	Residential	Residential	1374	1438	1438	90%	90%	According to Table 2 of A/NE-SSH/125 QRA Report, estimated from 432 units with average household size of 3.1 in TPU 757 and the residential population growth rates from 2016-based TPEDM.
10	HK Baptist Theological Seminary	Seminary	Seminary	219	219	219	80%	80%	According to Table 2 of A/NE-SSH/125 QRA Report
11	Reprovided Car Park	Car Park	Car Park	40	40	40	0%	0%	According to Table 2 of A/NE-SSH/125 QRA Report
12	Reprovided Bus Terminus	PTI	PTI	50	50	50	0%	0%	According to Table 2 of A/NE-SSH/125 QRA Report
13	Sai O Village	Village	Village	1393	1458	1458	80%	80%	According to Table 2 of A/NE-SSH/125 QRA Report, estimated from 146 houses with 3 storeys per house and 1 unit per storey and average household size of 3.1 in TPU 757 and the residential population growth rates from 2016-based TPEDM.
14	Nai Chung (South)	Village	Village	372	389	389	80%	80%	According to Table 2 of A/NE-SSH/125 QRA Report, estimated from 39 houses with 3 storeys per house and 1 unit per storey and average household size of 3.1 in TPU 757 and the residential population growth rates from 2016-based TPEDM.
15	Nai Chung (North)	Village	Village	458	479	479	80%	80%	According to Table 2 of A/NE-SSH/125 QRA Report, estimated from 48 houses with 3 storeys per house and 1 unit per storey and average household size of 3.1 in TPU 757 and the residential population growth rates from 2016-based TPEDM.
16	Nai Chung Barbecue Site	BBQ	BBQ	106	106	106	0%	0%	According to Table 2 of A/NE-SSH/125 QRA Report
17	Future Golf Course	Rural	Golf	0	210	210	0%	0%	According to Table 2 of A/NE-SSH/125 QRA Report
18	Kwun Hang Village	Village	Village	601	629	629	80%	80%	According to Table 2 of A/NE-SSH/125 QRA Report, estimated from 63 houses with 3 storeys per house and 1 unit per storey and average household size of 3.1 in TPU 757 and the residential population growth rates from 2016-based TPEDM.
19	Football Court	Recreational	Recreational	30	30	30	0%	0%	According to Table 2 of A/NE-SSH/125 QRA Report

ID	Population Name	Population Type in 2022	Population Type in 2025	Population in 2022	Population in 2025 without development	Population in 2025 with development	Indoor Ratio 2022	Indoor Ratio 2025	Remarks
20	Li Po Chun United World College of Hong Kong	Boarding School	Boarding School	315	315	315	90%	90%	According to Table 2 of A/NE-SSH/125 QRA Report
21	Cheung Muk Tau and Symphony Villas	Village	Village	1221	1278	1278	80%	80%	According to Table 2 of A/NE-SSH/125 QRA Report, estimated from 128 houses with 3 storeys per house and 1 unit per storey and average household size of 3.1 in TPU 757 and the residential population growth rates from 2016-based TPEDM.
22	The Entrance	Residential	Residential	471	493	493	90%	90%	Residential development of 148 flats completed in 2020. Estimate from average household size of 3.1 in TPU 757 and the residential population growth rates in A/NE-SSH/120 QRA Report.
23	Road Widening Construction Workers	Construction	Vacant Space	50	0	0	0%	0%	Conservatively assume 50 construction workers for the Sai Sha Road Widening Project
24	Road Widening Construction Site Office	Site Office	Vacant Space	200	0	0	90%	0%	Conservatively assume 200 people for the Sai Sha Road Widening Project site office
R01	Nin Ming Road	Road	Road	22	25	25	0%	0%	Refer to Annex B
R02	Nin Wah Road Section 1	Road	Road	27	25	25	0%	0%	Refer to Annex B
R03	Nin Wah Road Section 2	Road	Road	12	13	13	0%	0%	Refer to Annex B
R04	Sai Sha Road Section 1	Road	Road	272	432	432	0%	0%	Refer to Annex B
R05	Nin Fung Road	Road	Road	28	27	27	0%	0%	Refer to Annex B
R06	Sai Sha Road Section 2 (Widened)	Road	Road	177	278	278	0%	0%	Refer to Annex B
R07	Lok Wo Sha Lane	Road	Road	23	22	22	0%	0%	Refer to Annex B

2.2.4 Temporal Change in Population

To reflect the temporal changes in population within a week, the corresponding population proportion of the time periods are assumed based on observation from site survey and with reference to the A/NE-SSH/125 QRA Report[6]. Day time is defined as 07:00 to 19:00 and night time from 19:00 to 07:00 next day. The temporal changes of different population category are provided in **Table 5**.

Table 5 Temporal Change of Population within a Week

Category	Time Period			
	Weekday Day	Weekday Night	Weekend Day	Weekend Night
BBQ (2)	30%	10%	100%	20%
Boarding School (1)	100%	100%	50%	100%
Car Park (2)	60%	45%	100%	60%
Elderly Home (2)	100%	100%	100%	100%
Holiday Centre (2)	100%	56%	100%	56%
Golf (2)	30%	10%	100%	20%
PTI (2)	100%	70%	100%	70%
Pumping Station (2)	100%	0%	50%	0%
Recreational (2)	50%	5%	100%	5%
Residential (2)	30%	100%	70%	100%
Road (2)	100%	45%	75%	65%
School (2)	100%	1%	50%	1%
Seminary (2)	100%	100%	100%	100%
Site Office(1)	100%	10%	100%	10%
Village (2)	35%	100%	80%	100%

Note:

(1) Conservative assumption from survey
(2) Reference to A/NE-SSH/125 QRA Report [6]

2.3 Indoor/Outdoor Fraction

Building structures can offer some protection from fires for the occupants inside. An indoor ratio of 90% is applied to the population in residential buildings, elderly home and club house while the remaining 10% of population is assumed to be outdoor, accounting for outdoor activities and walking pathways. Considering the outdoor activities in school, seminary and village, an indoor ratio of 80% is applied.

The population of Helping Hand Cheung Muk Tau Holiday Centre For Elderly (Site ID 01) is considered 50% indoor only as there are outdoor facilities such as swimming pool and lawn bowls.

Passengers in vehicles are also considered as 100% outdoors population although vehicles may provide certain protection.

2.4 Source of Ignition

Flammable gas cloud from an accidental release can be ignited and led to fire or explosion if there are ignition sources present in the close proximity or along the dispersion path of the cloud. If the gas cloud is diluted outside the flammable concentration range (i.e. below Lower Flammable Limit), or in the absent of ignition sources, no fire hazards will be expected. The energy level, timing, location and ignition effectiveness of ignition sources in the vicinity of the underground HP town gas pipelines and the Sai O Offtake and Pigging Station affect the extent of gas cloud dispersion and its potential impacts.

Two types of ignition sources are defined in the SAFETI model, including:

- *Population source* which are assigned implicitly to all population groups by SAFETI to account for human activities such as smoking, cooking and using electrical appliances.

- *Transportation route segments* which are defined for the moving vehicles on roads. The ignition probability of a transportation route segment is calculated form the traffic density, average vehicle speed, vehicle ignition efficiency and total length of the road. The vehicle ignition efficiency for moving vehicles is adopted to be 0.4 per 60 second [5]. Traffic flow and average vehicle speed are included in **Annex B**.

3.0 Hazard Identification

3.1 Overview

The hazards arising from offtake and pigging station and gas pipelines are mainly associated with the loss of containment events due to failure of equipment and piping, which can lead to release of significant amount of hazardous materials.

The following section presents the hazardous scenarios identified for this study. All potential major hazards associated with the offtake and pigging station and the underground HP town gas pipelines are identified based on review of assessment reports on similar facilities.

3.2 Hazardous Scenarios Identified

3.2.1 External Causes

Natural Hazards

Natural hazards such as earthquake, storm, typhoon, subsidence and storm surge may cause potential damage to the town gas installations. This section will discuss the credibility of these natural hazards to loss of containment incident with respect to Hong Kong's geographical location.

Earthquake – Hong Kong is not located within the seismic belt. According to the Hong Kong Observatory, earthquakes occurring in the circum-Pacific seismic belt which passes through Taiwan and Philippines are too far away to affect Hong Kong significantly. Although there has not been any reported case of destructive earthquake tremor in Hong Kong, loss of containment incident due to earthquake is still considered credible to cause rupture of aboveground pipeworks.

Subsidence/ Landslides - Excessive subsidence may lead to failure of the structure and ultimately loss of containment scenario. Subsidence is usually slow in movement and such movement can be observed and remedial action can be taken in time. Considering that pipeline failures due to landslide have been reported by the European Gas Pipeline Incident Data Group (EGIG), it is reviewed in frequency assessment of the underground HP town gas pipelines (refer **Section 4.3**).

Lightning - Lightning sparks could ignite the combustible gas in air. The Sai O Offtake and Pigging Station is equipped with lightning protection system that can effectively protect the equipment from lightning, hence lightning strike causing a release of town gas is deemed remote. In regards of the underground HP town gas pipelines, lightning is considered by EGIG, and thus, is further studied (refer **Section 4.3**).

Other Severe Environmental Events - Super typhoons had been observed in recent years, but no major loss of containment incident had been reported in all offtake and pigging stations in Hong Kong. The Sai O Offtake and Pigging Station is designed to withstand wind load for local typhoon. There is also no record showing any incidence of destruction of offtake and pigging station in Hong Kong due to storm surge. Therefore, the chance of loss of containment due to severe environmental event such as typhoon and storm surge is considered very remote.

Vehicle Crash

Vehicle crashing onto aboveground pipe or equipment may lead to loss of containment event. The Sai O Offtake and Pigging Station is located at the end Nin Ming Road. It is surrounded by concrete fence wall. Vehicle crashing into the station and causing damage to the pipework / equipment is deemed remote, and thus not further considered.

External Fire

External fire means the occurrence of a fire event which leads to the failure of pipelines or equipment. Potential external fire includes vehicle fire and smoking / flames inside the offtake and pigging station. The Sai O Offtake and Pigging Station is surrounded by concrete fence wall, which keeps the vehicle on fire outside at a safe distance. Moreover, stringent procedures are implemented to prohibit smoking or naked flames to be used on-site. The present of external fire inside the Sai O Offtake and Pigging Station is deemed remote. In addition, external fire from aboveground is considered not possible to damage underground pipes. Hence, external fire causing loss of containment is not further assessed.

Dropped Objects

Dropped objects from the residential building into Sai O Offtake and Pigging Station could be a concern. Falling objects such as cigarette stubs and balls may influence the facilities inside the station. The nearest existing building to the Sai O Offtake and Pigging Station is the HK Baptist Theological Seminary, which is at least 35 m away. Therefore, dropping objects is deemed a remote scenario and is not considered in this study.

Major Leakage of Underground Water Mains

Major leakage of underground water mains could be another concern to underground HP town gas pipeline. In case if the water ejects towards the gas main, it carries the surrounding soil and sand and impacts on the surface of the pipes. Moreover, washing out the backfill material may also lead to settlement. Both scenarios may result in damage on pipe wall and loss of containment.

Operational Error

Historical data revealed that human error is a significant contributor to equipment failure. Even though operators at the Sai O Offtake and Pigging Station are well-trained to minimise the chance of human error, human error leading to leakage or loss of containment is still considered credible.

Third Party Damage

Third party damage on gas pipeworks includes the damage to pipes due to drilling, hammering, excavation works, etc. In fact, the potential of third party damage to the gas piping depends on the pipe design and also the surrounding environment. Pipe wall thickness, buried depth, concrete cover and design factor have influence on whether third party damage would result in pipe damage.

In Hong Kong, excavation/ trenching works are well controlled. As per EMSD's Code of Practice on "Avoidance of Damage to Gas Pipes, 2nd ed", utility mapping must be conducted to identify any underground utility within the site before any construction work commences. This could minimize the risk of damaging any existing underground utility. In addition, HKCG has issued a "Requirements for Construction Works Adjacent to Existing Gas Offtake Station and in the Vicinity of Gas Main", which the Contractor should strictly follow. Clearance distances from offtake and pigging stations and gas pipelines, as well as safety precautions during the construction works are indicated in the requirements.

Nevertheless, generic loss of containment incident due to third party damage is still a credible scenario and is considered in this study.

3.2.2 Internal Causes

Corrosion

Corrosion is one of the main contributors for pipeline failure. External corrosion of a buried pipe could occur due to the contact of stray DC electric earth current or coating damage and direct contact with contaminated ground. Protective coating and cathodic protection system are adopted to avoid external corrosion. Internal corrosion occurs due to the presence of moisture and contaminants in the gas. The underground pipelines carry dry town gas which is not expected to have any moisture and it is coated with epoxy internally to avoid corrosion. Nevertheless, loss of containment incident due to corrosion is still a credible scenario.

Material Defect

Material defect of pipelines including welding failure and mechanical strength failure, etc., could occur for various reasons. HKCG adopted non-destructive testing (NDT) by X-ray for each butt weld and magnetic particle inspection (MPI)/ ultrasonic test for fillet welds of the underground pipelines according to IGEM/TD/1[4]. Historical data showed that material failure leading to loss of containment is credible and such scenario is included in this QRA.

3.2.3 Operation and Maintenance

In Sai O Offtake and Pigging Station, two pig traps of diameter of 600mm and 750mm are installed for pigging operations. Under normal operation, the pig traps are isolated from the active pipework so the risk associated with it should be limited. According to HKCG's information, pigging is normally carried out once in every ten years. Historical data showed that pig trap failure leading to loss of containment is credible and such scenario is included in this assessment.

4.0 Frequency Assessment

4.1 Overview

Frequency analysis involves estimation of failure frequencies resulting in a release of hazardous materials. This section examines the failure frequencies of the Sai O Offtake and Pigging Station and the underground HP town gas pipelines that result in loss of containment. The analysis is based on the application of historical data, with modifications to reflect the local factors, such as good safety practice, anchorage protection, pipeline integrity, etc.

4.2 Sai O Offtake and Gas Pigging Station

4.2.1 Process Equipment

The Sai O Offtake and Pigging Station consists of valves, flanges and instrument connections. A failure rate of 8.8×10^{-5} per year for miscellaneous valves is quoted by Lees [9], based on US nuclear operation experience during 1968-1972 and some non-nuclear references. Taylor [10] gives a number of failure rates for different types of valves, which are 8.8×10^{-4} per year for large valve valves (4”, 8”) and 8.8×10^{-5} per year for small valves (2”). Cox, Lee and Ang [11] give the rates of 1.0×10^{-3} per year for minor failures and 1.0×10^{-4} per year for major failures, respectively. With reference to these databases, failure rates of 8.8×10^{-4} per year and 1.0×10^{-3} per year are adopted respectively for valves and flanges, considering the large diameters of the flow control valves and flanges in the Sai O Offtake and Pigging Station. Failure of filter and gas meter can be estimated from their components, which typically consist of 2 small flanges for each.

In light of the actual situation in Hong Kong that:

i. There have not been any failures from flanges, valves or instrument connections at the HKCG offtake and pigging stations; and

ii. HKCG performs weekly patrols to check the integrity of the valves, flanges and instrument connections and remedial action will be taken in case of any signs of damage.

A reduction factor of 0.1 is applied to the failure rates adopted from historical data to reflect the realistic situation in Hong Kong. **Table 7** tabulates the failure rates of different pieces of equipment in the Sai O Offtake and Pigging Station.

In regards of pig trap, when it is filled up with town gas, it can be considered as an aboveground pipe. Failure of pig trap has been included in the failure of aboveground pipes in **Section 4.2.2**.

HKCG conducts pigging operation once in every ten years. Such operation may cause additional risk to the pig trap. To ensure correct and safe sequence of pigging operations and to minimize of the risk of operation error, HKCG adopts a high standard and stringent control procedure to each pigging operation on transmission system. Mechanical interlocks will also be used on the pig trap to prevent the door being opened before the pig trap has been free from pressurized gas. Nevertheless, pigging operation is considered creditable to pig trap failure when the pig trap is filled with town gas and damaged by the pipe inspection gauge (PIG) manoeuvring inside. Hence, the chance of pig trap failure due to pigging operation is deemed significant only at the time when launching or receiving the PIG. In consideration of the length of the pig trap and the speed of the PIG, the critical period for the PIG moving inside the pig trap can be only a few seconds. As a conservative approach, it is taken as 15 minutes.

The diameter of the pig traps are 600mm and 750 mm, i.e., 24 and 30 inches. Under normal operation, the pig traps are isolated from the active pipework so the risk associated with it should be limited. There is no specific failure rate for pig traps for towngas. For the purpose of current study only, to be conservative, the historical release frequencies for pig launchers / receivers reported in the Hydrocarbon Release (HCR) Database [12], as shown in **Table 6**, the failure rate of pig traps is taken as 8.0×10^{-3} per receiver-year. Taking account of the frequency of pigging operation and the critical period for PIG manoeuvring inside the pig traps, the likelihood of pig trap failure due to pigging operation is estimated as 2.28×10^{-8} per year per pig trap. Such failure is assumed resulting in rupture of the pig trap.

Table 7 summarises the failure rates of different critical equipment in the offtake and pigging station.

Table 6 Gas Release Frequency of Pig Launchers/ Receivers

Diameter (inch)	Failure Rate (per equipment year)
> 16	8.00×10^{-3}
$12 < D \leq 16$	8.00×10^{-3}
$8 < D \leq 12$	N/A

Table 7 Failure Rates of Process Equipment in the Offtake and Pigging Station

Process Equipment	Failure Rate (per equipment year)	Quantity (1)	Failure Rate (per year)	Modified Failure Rate (per year)
Valve (2)	8.80×10^{-4}	44	3.87×10^{-2}	3.87×10^{-3}
Flange (2)(3)	1.00×10^{-3}	80	8.00×10^{-2}	8.00×10^{-3}
Pig Trap (4) (due to pigging operation)	2.28×10^{-8}	2	4.57×10^{-8}	4.57×10^{-8}

Notes:

(1) Quantity according to ***Annex A****.*
(2) Failure rate adopted from database [9][10][11].
(3) Quantity includes flanges derived from gas meter and filter.
(4) Under normal operation, the pig traps are isolated from the active pipework. Failure rate derived from Offshore Hydrocarbon Releases Statistics [12] is adopted for the purpose of current study only. Assume resulting in full bore rupture of pig trap.

4.2.2 Aboveground Pipes

Based on previous approved reports of similar issues [14], the aboveground pipework failure rate within offtake and pigging stations is about 2.7×10^{-5} per km-year. The length of aboveground pipeline in the Sai O Offtake and Pigging Station is 137m. The spontaneous failure rate of aboveground pipework is calculated as 3.7×10^{-6} per year.

In addition, as mentioned in **Section 3.2.1**, severe earthquakes may also cause various degrees of damage to pipe works and the loss of containment incidents. Comparing to other regions, the probability of earthquake occurrence at Modified Mercalli Intensity Scale VII and higher in Hong Kong is low, and is estimated to be 1.0×10^{-5} per year [15]. The failure probability of a pipeline in an earthquake is assumed to be 0.01 [16]. Therefore, the failure rate of a pipeline due to an earthquake is estimated to be 1.0×10^{-7} per year and it is assumed that an earthquake always leads to rupture of the above ground pipe.

The total failure rate of the aboveground pipes in the offtake and pigging station is 3.8×10^{-6} per year.

4.3 Underground HP Town Gas Pipeline

4.3.1 EGIG Historical Failure Data

EGIG is an industry group of 15 major gas transmission system operators in Europe, which owns an extensive database of pipeline incident data since 1970.

The failure frequency over the reporting period of 1970 – 2016 is 3.10×10^{-4} per km year [17]. A steady reduction of the failure frequency over the last two decades is observed, showing improved safety performance. The recent failure frequency during 2007 – 2016 is significantly lower with only 1.50×10^{-4} per km year.

The breakdown of the accident frequencies by causes for all types of gas pipelines is shown in **Table 8** below. External interference remains the dominant cause for gas leakage.

Table 8 Incident Causes for Onshore Pipeline Gas Leakage

Causes	Distribution of Incidents	
	Period 1970-2016	Period 2007-2016
External interference	46.5%	28.7%
Corrosion (Internal and external)	16.8%	24.7%
Construction defect/ Material failure	16.5%	18.0%
Ground movement	8.4%	20.7%
Hot tap made by error	4.5%	2.0%
Other and unknown	7.4%	6.0%
Total	100%	100%

4.3.2 Analysis of Modification Factors

External Interference

The major contributor of external interference in Hong Kong is third party damage, such as the inadvertent damages during excavation. The degree of damage depends on surrounding environment, wall thickness, buried depth and protection from concrete cover.

The concerned underground HP town gas pipelines are of sizes 600mm (nominal diameter 24 inch) and 750 mm (nominal diameter 30 inch) and the nominal wall thickness is 12.7 mm. The HP town gas pipes are buried at a minimum depth of 1.1 m (modified new pipes at a minimum of 1.2 m) with concrete cover, giving significant protection to the pipeline against external interference.

In addition, the following practices are required while carrying out underground works to reduce the probability of third party damage to HP town gas pipes:

- Contractor should carry out utility survey and trial trench inspection for any underground works before construction work commences.
- Much of the gas pipeline is laid under carriageway in which excavation is under stringent control. The HKCG's "Requirements for Construction Works in the Vicinity of Gas Main" and the Electrical and Mechanical Services Department (EMSD)'s Code of Practice on "Avoidance of Damage to Gas Pipes" should be strictly followed for any underground excavation works to be done nearby the HKCG's gas pipeline.

Giving consideration to the above preventive measures, a reduction factor of 0.1 are applied to the failure frequencies of underground gas pipeline due to external interference to account for the pipeline design and the safe practices.

Construction Defect/ Material Failure

There is a decreasing trend in incidents due to welding, mechanical strength and material failure against year of construction. Majority of incidents were caused by pipelines that were built before 1973. The HKCG adopts NDT by X-ray for each butt weld and magnetic particle inspection / ultrasonic test for fillet welds of the underground pipeline in accordance with IGEM/TD/1 [4]. With the stringent design and the preventive inspection measures adopted by the HKCG, a reduction factor of 0.1 is adopted.

Corrosion (Internal and External)

Similar to "Construction Material Defect / Material Failure", there is a decreasing trend in incidents due to corrosion against year of construction. No leak case due to corrosion has been reported for pipeline which was constructed after 2003. In addition, internal corrosion is very unlikely since town gas is dry and free from corrosive gases. External corrosion of the pipeline is prevented by protective coating and cathodic protection. Hence, a reduction factor of 0.5 is adopted for all pipelines with nominal wall thickness of 12.7mm.

Ground Movement

Ground movement can be caused by a number of causes, e.g. subsidence, landslides or flooding. Pipes of smaller diameter are more susceptible to ground movement. The major cause of the ground movement failures was due to landslide. Considering the pipeline is not constructed in a hilly region, landslides are unlikely. The pipeline is buried with a cover of at least 1.1 m deep and with safety measure as described in "External Interference" section above. A reduction factor of 0.1 is assumed to reflect the actual situation.

Hot Tap Made by Error

"Hot tap made by error" means that a connection has been made by error to a live gas transmission pipeline. Hot tap practice is not adopted by HKCG for gas transmission pipelines and thus is irrelevant to this study.

Other and Unknown

Other and unknown include failure caused by design error, lightning and maintenance error. The HKCG has extensive experience in designing and operating the underground gas pipes. It also applies stringent in-house procedures to monitor operation and maintenance of the gas pipes. The HP town gas pipeline is buried under the ground with a minimum concrete cover of 1.1m, lightning striking the pipeline is unlikely. A reduction factor of 0.1 is therefore assumed.

4.3.3 Adopted Failure Frequencies of the Underground HP Town Gas Pipeline

A direct application of the EGIG database is not appropriate to the situation of the concerned pipework. Reduction factors have been adopted to modify the failure rate to reflect the actual condition. The breakdown of failure rates with reduction factors is listed in **Table 9.**

Table 9 Breakdown of EGIG Incidents with Reduction Factors

Causes	Failure Rate (1) (per km year)	Reduction Factor	Modified Failure Rate (per km year)	
			O.D. 600mm	O.D. 750mm
External event for Pipe Diameter (23-29")	2.70×10^{-5}	0.1	2.70×10^{-6}	-
External event for Pipe Diameter (29-35")	1.00×10^{-5}		-	1.00×10^{-6}
Corrosion (thickness 10-15mm)	1.50×10^{-6}	0.5	7.50×10^{-7}	7.50×10^{-7}
Construction defect/ material failure (Year of construction 1984-2016)	2.45×10^{-5}	0.1	2.45×10^{-6}	2.45×10^{-6}
Ground movement (23-29")	1.81×10^{-5}	0.1	1.81×10^{-6}	-
Ground movement (29-35")	8.50×10^{-6}		-	8.50×10^{-7}

Causes	Failure Rate (1) (per km year)	Reduction Factor	Modified Failure Rate (per km year)	
			O.D. 600mm	O.D. 750mm
Hot tap made by error (23-29”)	0	0	0	-
Hot tap made by error (29-35”)	0		-	0
Other and unknown	6.60×10^{-6}	0.1	6.60×10^{-7}	6.60×10^{-7}
Total			$\mathbf{8.37\times10^{-6}}$	$\mathbf{5.71\times10^{-6}}$

Note:
(1) Based on 10th EGIG Report [17]

The modified failure rates from the EGIG database for pipeline are 8.37×10^{-6} per km year for pipe of size 600mm and 5.71×10^{-6} per km year for pipe of size 750 mm. The modified failure rate for underground HP town gas pipeline is taken as 1.0×10^{-5} per km year, conservatively.

As mentioned in **Section 1.8.1**, the existing underground HP town gas pipelines will be modified in 2020 where few sections of existing pipelines will be replaced. The new pipelines will also be designed as per IGEM/TD/1[4], with the same nominal thickness and material as that of the existing pipeline and having a minimum cover of 1.2m. As a conservatively approach, the failure frequency of the new underground HP town gas pipelines is assumed to be identical to that of the existing ones, hence 1.0×10^{-5} per km year.

4.4 Hole Size Distribution

The failure of pipes and equipment may be resulted in gas leakage from various hole sizes. In case of leakage from the process equipment, only small leaks are expected because equipment failures are likely to be detected before resulting in failures. With reference to the HKCG quantitative risk assessment report for town gas facilities in Hong Kong [14], the hole size distributions of process equipment and aboveground/ underground pipes are assumed as listed in **Table 10** and **Table 11**.

The HP town gas pipeworks have a design factor of 0.3 or better and has a nominal thickness of 12.7 mm, which makes full bore rupture extremely unlikely. Nevertheless, it is considered in this study in this study by allocating a probability of 1%.

Table 10 Hole Size Distribution of Process Equipment

Hole Size Category	Hole Size	Probability (%)
Flange	10 mm	90
	25 mm	9
	50 mm	1
Valves	10 mm	100
Pig Trap	Full Bore	100

Table 11 Hole Size Distribution of Aboveground and Underground Pipeline

Hole Size Category	Hole Size	Probability (%)
Full Bore Rupture	Full Bore	1
Puncture	100 mm	19
Hole	50 mm	30
Leak	25 mm	30
Pin Hole	10 mm	20

4.5 Summary of Hazardous Failure Frequencies

The failure scenarios considered in this study is summarized in **Table 12**. The corresponding failure frequencies in various sizes of release are tabulated in **Table 13**.

Table 12 Failure Scenarios Considered in This Study

Facility	Scenarios
Sai O Offtake and Pigging Station	**Aboveground Pipeline** - Partial failure: 10mm leak, 25mm leak, 50mm leak, 100mm leak (with 25% as horizontal release, 25% as inclined release at 45° and 50% as vertical release respectively) - Catastrophic rupture: Full bore rupture
Sai O Offtake and Pigging Station	**Process Equipment** - Valves and flanges failure: 10mm leak, 25mm leak, 50mm leak (with 25% as horizontal release, 25% as inclined release at 45° and 50% as vertical release respectively) - Pig trap Catastrophic rupture: Full bore rupture
Underground HP Town Gas Pipelines (600mm and 750mm)	- Partial failure: 10mm leak, 25mm leak, 50mm leak, 100mm leak (with 50% modelled as vertical release and 50% modelled as inclined release of 45°) - Catastrophic rupture: Full bore rupture (vertical release)

Table 13 Failure Frequency Adopted for Each Failure Mode

Scenario Name	Description	Size of Release	Frequency (per year or per km year)
Sai O Offtake and Pigging Station - Aboveground Pipes			
AG-10mm	Offtake and Pigging Station aboveground pipes (50% vertical release, 25% horizontal release and 25% inclined release)	10 mm	7.40×10^{-7}
AG-25mm		25 mm	1.11×10^{-6}
AG-50mm		50 mm	1.11×10^{-6}
AG-100mm		100 mm	7.03×10^{-7}

Scenario Name	Description	Size of Release	Frequency (per year or per km year)
AG-FB	Offtake and Pigging Station aboveground pipes (Full Bore Rupture)	Full Bore	1.37×10^{-7}
Sai O Offtake and Pigging Station - Process Equipment			
EQ-10mm	Offtake and Pigging Station valves and flanges (50% vertical release, 25% horizontal release and 25% inclined release)	10 mm	1.11×10^{-2}
EQ-25mm		25 mm	7.20×10^{-4}
EQ-50mm		50 mm	8.00×10^{-5}
EQ-FB	Offtake and Pigging Station pig trap (Full Bore Rupture)	Full Bore	4.57×10^{-8}
Underground HP Town Gas Pipeline			
UG-10mm	Underground HP Town Gas Pipeline (50% vertical release and 50% inclined release)	10 mm (pin hole)	2.00×10^{-6}
UG-25mm		25 mm	3.00×10^{-6}
UG-50mm		50 mm	3.00×10^{-6}
UG-100mm		100 mm (puncture)	1.90×10^{-6}
UG-FB	Underground HP Town Gas Pipeline (Full Bore Rupture)	Full Bore	1.00×10^{-7}

4.6 Event Outcome Frequencies

4.6.1 Orientation of Release

Consequence of a pipeline failure varies by the orientation of the release. Failure can occur at top, bottom, or side of a pipe. Pressured gas releasing at the top of a pipe will result in an unobstructed vertical jet release; whereas releasing from side of a pipe can result in an inclined or horizontal release. Releasing at bottom of the pipe will lead to a diffused jet due to loss of gas momentum by impinging with the surrounding.

In this study, partial failures for all pipe and process equipment are assumed to have a probability of 50% for vertical jet releasing from top and the remaining probability for gas releasing from side. In case of aboveground pipe and process equipment, release from the side can be either horizontal or inclined release having an equal chance of 25%. As for underground pipe, gas releasing from the side is considered as inclined release only. The angle of inclined release is assumed be at 45 degrees.

Catastrophic rupture of all pipes and process equipment is assumed to be top release only to account for completely unobstructed jet release.

4.6.2 Ignition Probability

Pressurized town gas release from pipeline disperses and may subsequently be ignited if the gas concentration is within the flammability limits. Estimation of ignition probabilities made by Cox, Lees and Ang are listed in **Table 14** below [11].

Table 14 Ignition Probability from Cox, Lees and Ang

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

As a conservative approach, the ignition probabilities quoted by Cox, Lees and Ang are taken as the probabilities for immediate ignition of vertical or inclined release. Higher ignition probabilities are adopted for immediate ignition of horizontal release and delayed ignition of all release, in consideration of the presence of ignition sources in the neighbouring area such as high-dense residential area and road traffic. The ignition probabilities adopted in this study are summarized in **Table 15** and **Table 16** below.

Table 15 Ignition Probabilities for Land Pipeline (Underground)

Leak Size	Initial Release Rate (kg/s)	Ignition Probability (Vertical/ Inclined Release)	
		Immediate	Delayed
Very Small Leak (10mm)	0.4	0.01	0.1
Small Leak (25mm)	2.6	0.07	0.1
Medium Leak (50mm)	10.4	0.1	0.1
Large Leak (100mm)	41.5	0.2	0.2
Full Bore Rupture	>100	0.5	0.5

Table 16 Ignition Probabilities for Land Pipeline (Aboveground) and Process Equipment in Offtake and Pigging Station

Leak Size	Initial Release Rate (kg/s)	Ignition Probability (Vertical/ Inclined Release)		Ignition Probability (Horizontal Release)	
		Immediate	Delayed	Immediate	Delayed
Very Small Leak (10mm)	0.4	0.01	0.1	0.05	0.15
Small Leak (25mm)	2.6	0.07	0.1	0.1	0.15
Medium Leak (50mm)	10.4	0.1	0.1	0.15	0.15
Large Leak (100mm)	41.5	0.2	0.2	0.25	0.25
Full Bore Rupture	>100	0.5	0.5	N/A	N/A

Vapour cloud explosion (VCE) may be possible if massive town gas is released and ignited. The probabilities of explosion, adopted from Cox, Lees and Ang [11], are 0.12 and 0.3 for large leaks (100 mm) and full bore rupture respectively.

4.6.3 Event Tree Analysis

Event tree model is used to estimate the frequency of various gas leak outcomes which includes jet fire, flash fire, fireball, VCE and no ignition. It also shows different consequences of vertical and horizontal leak scenarios of the cases for immediate ignition and delayed ignition.

The detailed event tree analysis is included in **Annex C**.

5.0 Consequence Analysis

The consequence assessment estimates impact of each outcome in the area of concern. The consequence assessment consists of two major parts, namely:

(1) **Source term modelling** to determine the release rate, released duration and released quantity; and

(2) **Physical effects modelling** to determine the effects zones of gas dispersions, fires and explosions, based on the outputs of source term modelling.

5.1 Source Term Modelling

Town gas is modelled as a mixture of hydrogen, methane, carbon dioxide and carbon monoxide. For pipelines connecting to a gas distribution network, release duration is determined by respond time for isolation.

5.1.1 Release Quantity and Duration

Discharge rates are calculated from leak hole sizes and operating conditions of the pipeline, which are assumed to be fixed for smaller leaks as the amount of gas leaked per unit time is small comparing to the overall amount available for release. The releases are modelled by assuming a section of 8.0km of HP town gas pipeline of diameter 600mm and a section of 19.1km of HP town gas pipeline of diameter 750mm, which can be isolated by automatic isolation valves. The closing time of the isolation valve are approximate 5 minutes as per HKCG's information (**Annex A**). The discharge rate is estimated based on the normal operation conditions a flow velocity of 20m/s with the release inventory calculated from the length of pipeline and the amount release before the time of isolation.

Transient nature of release is assumed for the case of full bore rupture. The release rate is expected to be very high in the first few seconds, followed by a rapid drop to a constant level. The initial release rate and quantity which is discharged to the release point in an event of fireball following the rupture of HP town gas pipeline are estimated from the empirical correlations developed by Bell and modified by Wilson [18][19]:

$$Q_0 = C_d A_p \psi \sqrt{\rho_0 P_0 \gamma (\frac{2}{\gamma+1})^{(\frac{\gamma+1}{\gamma-1})}}$$

$$Q_t = \frac{Q_0}{1+\alpha}(e^{\frac{-t}{\alpha^2\beta}} + \alpha e^{\frac{-t}{\beta}})$$

$$\alpha = \frac{W}{\beta Q_0}$$

$$\beta \approx \frac{L\sqrt{K_\gamma}}{C\sqrt{K_A}}$$

$$\beta \approx \frac{2L}{3C\sqrt{K_F}} \text{ for large holes where } \frac{K_A{}^2}{K_F K_\gamma} > 30$$

where

$$K_F = \frac{D_P}{\gamma f L_P}$$

$$K_A = \frac{A_h}{A_p}$$

$$K_\gamma = (\frac{\gamma+1}{2})^{\frac{\gamma+1}{\gamma-1}}$$

where Q_0 is initial mass discharge rate (kg/s)

Q_t is time dependent mass flow rate (kg/s)

W is inventory in the pipeline (kg)

C_d is discharge coefficient, assume 0.8

A_p is the cross sectional area of the pipeline (m^2)

Ψ is outflow coefficient, assume 1 for critical flow

ρ_0 is initial gas density (kg/m^3)

P_0 is initial gas pressure (N/m^3)

γ is gas specific heat ratio, 1.344 for town gas

t is the time in seconds

α is the non-dimensional mass conservation factor

β is the time constant for release rate in seconds

Dp is diameter of pipeline (m)

f is pipeline friction factor given by $f = [1/-2\log(\frac{\varepsilon}{3.715D_p})]^2$

ε is wall roughness of pipeline (m) taken as 45μm as per TNO [5]

In modelling fires following a rupture, the transient nature of the release should be estimated. The equation is used to estimate the mass inventory which is discharged to the release point in an event of fireball following the rupture of a high pressure gas pipeline as descripted in **Section 5.2.3**.

5.2 Effect and Vulnerability Modelling

Consequence model of the SAFETI 8.23 by DNV is used for calculation of hazardous area under various consequences. The following section briefly describes mathematical models applied to various fire and gas dispersion in the consequence model.

5.2.1 Gas Dispersion

The DNV GL's proprietary UDM model is used for the dispersion calculation of town gas for non-immediate ignition scenarios. UDM has been extensively verified and has been validated against a large number of field experiments. These include continuous, elevated two phases and vapour releases. The model takes into account various transition phases, from dense cloud dispersion to buoyant passive gas dispersion, in both instantaneous and continuous releases.

Fire scenarios of different kinds may be developed in the presence of ignition source in the proximity of gas release. If no ignition source exists, the gas cloud may disperse downwind and be diluted to the concentration below its LFL. In this case, no harmful effect is anticipated since the gas would become too lean to be ignited.

5.2.2 Jet Fire

A jet fire is developed when a jet of high velocity gas is ignited. The direction and orientation of fire depend on the release orientation, release velocity and wind direction. The majority concern regarding jet fire is the heat radiation effect generated from the fire. The thermal effect to adjacent population is quantified in the consequence model.

5.2.3 Fireball

Fireball is more likely for immediate ignition of instantaneous release and heat is evolved by radiation. The principal hazard of a fireball arises from its thermal radiations. As suggested in IGEM/TD/2 [3], the fireball resulted from an immediate ignition of a rupture case has a transient nature and can typically last for 30 seconds.

Due to its intensity, its effects are not significantly influenced by weather, wind direction or source of ignition. The size, height, shape, duration, heat flux and radiation of a fireball will be determined in the consequence analysis. A 100% fatality is assumed for anyone within the fireball radius.

The following equations from CCPS [18] are used to estimate of the fireball diameter (D) and duration (t).

$$D = 5.8M^{\frac{1}{3}}$$

$$t = 0.45M^{\frac{1}{3}}$$

where D is final diameter of fireball (m); t is fireball duration (s); M is mass of fuel (kg).

The mass of fuel is determined by calculating the quantity of fuel at each time step that can be consumed in a fireball (as per the equation in **Section 5.2.1**) with the same burning time as the time since the start of the release. By equating the two equations [2], the sizes of fireball are determined as approximately 9 tonnes for HP town gas pipeline of diameter 600mm and 18.6 tonnes for HP town gas pipeline of diameter 750mm.

Table 17 Calculation of Fireball Inventory of 35barg DN750 Pipelines

Releasing Time, t (s)	Discharge Rate (1), Q (kg/s)	Accumulated Release Quantity (2), M (kg)	Fireball Duration, $0.45M^{1/3}$ (s)
0	2116	0	0.0
1	1998	2057	5.7
2	1887	3999	7.1
3	1784	5835	8.1
4	1688	7571	8.8
5	1597	9213	9.4
6	1513	10768	9.9
7	1434	12241	10.4
8	1360	13638	10.8
9	1290	14963	11.1
10	1225	16221	11.4
11	1165	17416	11.7
12	1108	18552	11.9

Note:

(1) Estimated by empirical correlations developed by Bell and Wilson[18][19]
(2) $M_{(t)} = M_{(t-1)} + (Q_{(t-1)} + Q_{(t)})/2$

Table 18 Calculation of Fireball Inventory of 35barg DN600 Pipelines

Releasing Time, t (s)	Discharge Rate (1), Q (kg/s)	Accumulated Release Quantity (2), M (kg)	Fireball Duration, $0.45M^{1/3}$ (s)
0	1354	0	0.0
1	1230	1292	4.9
2	1119	2466	6.1
3	1020	3536	6.9
4	933	4512	7.4
5	854	5405	7.9

Releasing Time, t (s)	Discharge Rate [(1)], Q (kg/s)	Accumulated Release Quantity [(2)], M (kg)	Fireball Duration, $0.45M^{1/3}$ (s)
6	785	6225	8.3
7	723	6979	8.6
8	668	7674	8.9
9	618	8317	9.1
10	574	8913	9.3

Note:

(1) Estimated by empirical correlations developed by Bell and Wilson[18][19]

(2) $M_{(t)} = M_{(t-1)} + (Q_{(t-1)} + Q_{(t)})/2$

5.2.4 Flash Fire

A flash fire is the consequence of combustion of gas cloud resulting from delayed ignition. The flammable gas cloud can be ignited at its edge and cause a flash fire of the cloud within the LFL and Upper Flammable Limit (UFL) boundaries. Major hazards from a flash fire are thermal radiation and direct flame contact. Since the flash combustion of a gas cloud normally lasts for a short duration, the thermal radiation effect on people near a flash fire is limited. Humans who are encompassed outdoors by the flash fire will be fatally injured. A fatality rate of unity is assumed.

Since town gas is buoyant, this reduces the flash fire effects at ground level. However, the town gas plumes may be within the LFL which could have potential impact to the adjacent high rise buildings.

5.2.5 Thermal Radiation

Town gas contains methane and it is flammable gas upon ignition. The LFL for hydrogen, methane and carbon monoxide (CO) is given below:

- Hydrogen: 4.0%;
- Methane: 5.3%; and
- CO: 12.5%

Carbon dioxide does not contribute to flammability. The LFL of town gas is estimated as 5.5%.

The fatality rate due to heat radiation is co-related by the thermal Probit equation [5]:

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

where Q is the thermal radiation intensity in W/m^2 and t is the exposure time in seconds.

5.2.6 Vapour Cloud Explosion

When flammable gas mixture burns, a vast gas cloud expansion occurs due to the high temperature of the combustion products formed. If this process happens within a congested / confined space, the presence of the confining barriers prevents the free expansion of the combustion products and results in the generation of overpressure, thus forming a VCE.

Table 19 lists the fatality probability of VCE adopted from TNO "Purple Book" [5]. Indoor fatality probability is higher due to the increased risk from flying debris such as breaking windows.

Table 19 Fatality Probability of Vapour Cloud Explosion

Overpressure (barg)	Indoor Fatality Probability	Outdoor Fatality Probability
0.3	1	1
0.1	0.025	0

5.2.7 Toxic Effect

Town gas contains carbon dioxide (16.3% – 19%) and a small amount of carbon monoxide (1% – 3.1%) which can be considered as toxic at certain concentration. The Immediate Dangerous to Life and Health concentrations for carbon dioxide and carbon monoxide are 40,000 ppm and 1,200 ppm, equivalent to town gas dose levels above 201,005 ppm and 38,710 ppm, respectively. Giving note that town gas is odorized, it is believed that people exposed to high town gas dose would notice and can find means of escape within 30 minutes without irreversible health effects. As such, the toxic risk associated with carbon dioxide is relatively small comparing to carbon monoxide, hence not further studied.

The toxic effect of the dispersion of carbon monoxide (CO) gas can be estimated by the following Probit Equation:

$Pr = -37.98 + 3.7 \ln (C*t)$ for CO,

where C is concentration in ppm and t is exposure time in minutes.

The town gas dose level equivalent to 1% fatality for 10-minutes exposure is over 190,550 ppm, which is above the LFL. Gas cloud with such high concentration of town gas is likely to be ignited. According to consequence analysis (refer **Table 25**), the hazard zone of toxic release is small comparing with the flammable effects. In view of the flammable characteristics of town gas dose level above LFL and the small toxic hazard zone, the risk of toxic release is considered insignificant, and thus, not further assessed in this study.

5.2.8 Indoor Protection Factor

Buildings are assumed to offer protection to occupants against fire. The protection factor is assumed to be 90% for flash fire event [2][20]. A 100% exposure is assumed for open space. In case of fireball event, a protection factor of 50% is assumed for indoor population within fireball radius [20].

5.2.10 Shielding Factor

Shielding factors are assumed to account for protection by the front part of the building or by other buildings from fire effects [20]. A shielding factor of 0.5 is assigned to those buildings within the fireball radius and partly inside the fireball radius. Buildings that are outside the fireball are considered being protected by the buildings in the front. The shielding factor to the following populations:

Table 20 Population with Fireball Shielding Factor

Site ID	Description	Shielding Factor
01	Helping Hand Cheung Muk Tau Holiday Centre For Elderly	0.5
02	The Outward Bound Alumni Assn of HK Activities Centre	0.5
03	Helping Hand Father Sean Burke Care Home For Elderly	0.5
04	Potential School	0.5
05	Potential Private Residential Development	0.5
08	Villa Concerto	0.5
09	Villa Rhapsody	0.5
10	HK Baptist Theological Seminary	0.5
13	Sai O Village	0.5
14	Nai Chung (South)	0.5
15	Nai Chung (North)	0.5
18	Kwun Hang Village	0.5
20	Li Po Chun United World College of Hong Kong	0.5
21	Cheung Muk Tau and Symphony Villa	0.5
22	The Entrance	0.5

5.3 Consequence Results

Since the underground HP town gas pipeline is covered with at a minimum 1.1m earth, there is no immediate ignition source and no adequate air for fireball or jet fire to occur under normal circumstances. Fireball or jet fire from underground pipes is only possible when all the earth cover of a local spot has been removed in the event of loss of containment. The HKCG has requirements for any excavation work to be carried out in the vicinity of gas mains, and boring and drilling in the vicinity of gas main is prohibited. Nonetheless, fireball and jet fire scenarios from the underground HP town gas pipeline are considered as a conservative approach in this study.

The worst-case consequence results of a release from the underground HP town gas pipelines and the Sai O Offtake and Pigging Station are tabulated in **Table 21** to **Table 25** below.

Table 21 Consequence Results of Fireball

Leak Size	Fireball Radius (m)	Fireball Duration (s)
Full bore rupture	79	11

Table 22 Consequence Results of Jet Fire

Leak Size	Effect Distance at Thermal Radiation of 12.5 kW/m^2 (m)	
	Vertical release	Inclined release
10 mm	Not reached	5.4
25 mm	Not reached	13.2
50 mm	4.0	20.7
100 mm	10.8	38.8

Table 23 Consequence Results of Flash Fire

Leak Size	Flash Fire Envelop, Distance at LFL (m)	
	Vertical release	Inclined release
10 mm	0.3	5.5
25 mm	0.8	7.4
50 mm	1.8	14.6
100 mm	3.9	28.7
Full bore rupture (750mm) (1)	13.0	N/A

Notes:
(1) Flash fire scenario under full bore rupture considers vertical release only.

Table 24 Consequence Results of Vapour Cloud Explosion

Leak Size	Distance at 0.3 barg	
	Vertical release	Inclined release
100 mm	Not reached	42.4
Full bore rupture (750mm) (1)	176.3	N/A

Notes:
(1) Vapour cloud explosion scenario under full bore rupture considers vertical release only.

Table 25 Consequence Results of Toxic Effect

Leak Size	Maximum Distance at 1% Lethality (1) (m)	
	Vertical release	Inclined release
10 mm	0.1	0.1
25 mm	0.1	0.1
50 mm	0.1	0.2

Leak Size	Maximum Distance at 1% Lethality (1) (m)	
	Vertical release	Inclined release
100 mm	0.2	0.4
Full bore rupture (750mm)(2)	1.0	NA

Notes:

(1) Based on an average exposure time of 10 minutes [5]
(2) Toxic release under full bore rupture is considered as vertical release only.

6.0 Risk Assessment

6.1 Risk Summation

Risk summation combines the estimation of likelihood and consequences of hazardous events, as well as the meteorological data, population data and other parameter in the hazard effect zones, to provide a numerical measure of the risk posed by the hazardous fatalities. DNV SAFETI v8.23 is used for modelling and risk summation.

The outcome of risk level is expressed in terms of Individual Risk and Societal Risk and compared with the risk criteria set out in the EIAO-TM.

6.2 Results of Individual Risk

The individual risk contours of the underground HP town gas pipelines and the Sai O Offtake and Pigging Station are presented separately in **Figure 7** and **Figure 8**. The cumulative individual risk contours for both the pipelines and the Sai O Offtake and Pigging Station is presented in **Figure 9**.

For the underground HP town gas pipelines, the maximum individual risk is below 1×10^{-7} per year. For the Sai O Offtake and Pigging Station, the maximum off-site individual risk is below 1×10^{-5} per year. Both the individual risk results therefore satisfy risk the individual risk criteria in Annex 4 of EIAO-TM.

The cumulative individual risk result for both HP town gas pipelines and Sai O Offtake and Pigging Station also shows a maximum individual risk below 1×10^{-5} per year.

It should be noted, however, that the individual risk from the gas facilities under concern is not related to the Proposed Sewage Pumping Station or the surrounding population; it is only governed by the nature of the gas facilities.

6.3 Results of Societal Risk

The societal risk results of the underground HP town gas pipelines and the Sai O Offtake and Pigging Station are presented in **Figure 10, Figure 11 and Figure 12**. Recapturing from **Section 1.6**, a total of three cases are studied namely:

- Case 1 - Base case;
- Case 2 - Construction case; and
- Case 3 - Operation case.

The F-N data are tabulated in **Table 26**. The societal risk results of the underground HP town gas pipelines, the Sai O Offtake and Pigging Station and cumulative societal risk for all three cases lie within the "ACCEPTABLE" region and satisfy the requirements of the Annex 4 of EIAO-TM.

The total potential loss of life (PLL) of underground HP town gas pipeline for construction case and operation case are 1.35×10^{-5} per year and 1.72×10^{-5} per year, respectively. While the total PLL of Sai O Offtake and Pigging Station for construction case and operation case are 6.57×10^{-6} per year and 8.80×10^{-6} per year, respectively. The top PLL contributors of underground HP town gas pipelines and Sai O Offtake and Pigging Station are tabulated in **Table 27**. The top most severe failure event of underground HP town gas pipelines and Sai O Offtake and Pigging Station are the full bore rupture of underground HP town gas pipeline and the full bore rupture of aboveground pipeline respectively.

The societal risks associated with the underground HP town gas pipelines are also compared with the IGEM societal risk criterion (refer **Annex D**) for reference. The societal risk results for all three cases are in compliance with the IGEM criterion.

Table 26 F-N Data

No. of Fatality	Frequency (/year)								
	Case 1 – Base Case			Case 2 – Construction Case			Case 3 – Operation Case		
	Underground HP Town Gas Pipelines	Offtake and Pigging Station	Overall	Underground HP Town Gas Pipelines	Offtake and Pigging Station	Overall	Underground HP Town Gas Pipelines	Offtake and Pigging Station	Overall
1	1.92E-07	4.08E-07	6.00E-07	1.78E-07	1.16E-06	1.34E-06	1.91E-07	5.41E-07	7.35E-07
2	1.19E-07	1.06E-07	2.24E-07	1.14E-07	2.25E-07	3.37E-07	1.19E-07	1.06E-07	2.26E-07
3	1.10E-07	1.05E-07	2.15E-07	1.10E-07	1.08E-07	2.17E-07	1.10E-07	1.05E-07	2.16E-07
4	1.09E-07	1.04E-07	2.12E-07	1.09E-07	1.07E-07	2.15E-07	1.08E-07	1.04E-07	2.14E-07
5	1.08E-07	1.03E-07	2.10E-07	1.07E-07	1.07E-07	2.13E-07	1.07E-07	1.03E-07	2.12E-07
6	1.07E-07	1.02E-07	2.09E-07	1.05E-07	1.06E-07	2.10E-07	1.06E-07	1.02E-07	2.10E-07
8	1.04E-07	1.02E-07	2.05E-07	1.01E-07	1.05E-07	2.04E-07	1.03E-07	1.02E-07	2.06E-07
10	1.00E-07	1.02E-07	2.02E-07	9.76E-08	1.03E-07	2.00E-07	9.97E-08	1.02E-07	2.03E-07
12	9.77E-08	1.02E-07	1.99E-07	9.56E-08	8.27E-08	1.77E-07	9.72E-08	1.02E-07	2.00E-07
15	9.53E-08	1.01E-07	1.97E-07	9.38E-08	6.70E-08	1.60E-07	9.50E-08	1.01E-07	1.98E-07
20	9.29E-08	1.01E-07	1.94E-07	9.26E-08	6.66E-08	1.58E-07	9.29E-08	1.01E-07	1.95E-07
25	9.16E-08	7.65E-08	1.68E-07	9.00E-08	6.63E-08	1.55E-07	9.17E-08	7.65E-08	1.69E-07
30	8.90E-08	6.64E-08	1.55E-07	8.57E-08	6.61E-08	1.51E-07	8.91E-08	6.65E-08	1.57E-07
40	8.35E-08	6.61E-08	1.50E-07	7.78E-08	6.57E-08	1.42E-07	8.36E-08	6.61E-08	1.51E-07

No. of Fatality	Frequency (/year)								
	Case 1 – Base Case			Case 2 – Construction Case			Case 3 – Operation Case		
	Underground HP Town Gas Pipelines	Offtake and Pigging Station	Overall	Underground HP Town Gas Pipelines	Offtake and Pigging Station	Overall	Underground HP Town Gas Pipelines	Offtake and Pigging Station	Overall
50	7.40E-08	6.57E-08	1.40E-07	6.26E-08	4.88E-08	1.10E-07	7.43E-08	6.57E-08	1.41E-07
60	6.31E-08	6.45E-08	1.28E-07	5.37E-08	4.69E-08	9.99E-08	6.35E-08	6.45E-08	1.29E-07
80	4.53E-08	6.27E-08	1.08E-07	3.17E-08	4.56E-08	7.68E-08	4.53E-08	6.27E-08	1.09E-07
100	2.86E-08	6.19E-08	9.05E-08	2.13E-08	3.73E-09	2.47E-08	2.87E-08	6.19E-08	9.10E-08
120	1.91E-08	3.63E-09	2.27E-08	1.16E-08	2.45E-09	1.39E-08	1.92E-08	3.64E-09	2.32E-08
150	9.11E-09	2.39E-09	1.15E-08	2.12E-09	1.01E-09	3.10E-09	9.38E-09	2.40E-09	1.19E-08
200	6.88E-10	4.75E-10	1.16E-09	4.96E-10	1.85E-11	5.07E-10	8.08E-10	4.76E-10	1.30E-09

Notes:
(1) Values less than 1E-9 per year are not shown in the figure of F-N curve.

Table 27 PLL Data of Underground HP Town Gas Pipelines and Offtake and Pigging Station

Failure Scenarios	Case 1 – Base Case		Case 2 – Construction Case		Case 3 – Operation Case	
	PLL (/year)	% of Total PLL	PLL (/year)	% of Total PLL	PLL (/year)	% of Total PLL
Underground HP town gas Pipelines						
Full bore rupture of underground pipeline	8.27E-06	49.0%	6.91E-06	51.0%	8.30E-06	48.3%
100mm leak of underground pipeline	7.95E-08	0.5%	5.96E-08	0.4%	7.86E-08	0.5%
50mm leak of underground pipeline	1.04E-08	0.1%	7.82E-09	0.1%	1.03E-08	0.1%
Others	1.57E-09	0.0%	1.21E-10	0.0%	1.38E-09	0.0%
Subtotal PLL	**8.36E-06**	**49.5%**	**6.98E-06**	**51.5%**	**8.39E-06**	**48.8%**
Offtake and Pigging Station						
Full bore rupture of aboveground pipeline	5.53E-06	30.3%	3.64E-06	26.8%	5.61E-06	32.7%
Full bore rupture of critical equipment	2.69E-06	7.9%	1.76E-06	13.0%	2.75E-06	16.0%
50mm leak of critical equipment	2.98E-07	4.2%	1.13E-06	8.4%	4.29E-07	4.9%
100mm leak of aboveground pipeline	4.13E-09	0.0%	1.57E-08	0.1%	5.95E-09	0.1%
Others	2.34E-10	0.0%	2.29E-08	0.2%	7.98E-10	0.0%
Subtotal PLL	**8.52E-06**	**50.5%**	**6.57E-06**	**48.5%**	**8.80E-06**	**51.2%**
Total PLL	**1.69E-05**	**100%**	**1.35E-05**	**100%**	**1.72E-05**	**100%**

6.4 Mitigation Measures

The individual and societal risks posed by town gas installations are acceptable as mentioned in **Section 6.2** and **Section 6.3**. The increase in population from the Project has insignificant effects on the societal risk, therefore, mitigation measure is not required.

6.5 Recommendations

Although mitigation measure is not required, the following good site practices are suggested to be implemented during the construction phase:

- ignition of fire on site should be controlled throughout the construction programme;
- any temporary storage of fuel and flammable chemical should be minimised to reduce chance of causing explosion or escalation of fire in the case of emergency event at nearby potentially hazardous sources;
- fire extinguisher or other firefighting equipment should be made easily accessible to on-site workers; and
- establish communication channel and evacuation plan in the case of emergency event at nearby potentially hazardous sources.

The following good site practices are suggested to be implemented during the operation phase:

- fire extinguishers or other firefighting equipment should be made easily accessible; and
- proper training on safety procedures and evacuation arrangement should be conducted to operator enhance the ability to handle emergency situations.

7.0 Conclusion

A Hazard to Life Assessment of the risk impacts of underground HP town gas pipelines and an offtake and pigging station to a proposed sewage pumping station and its surrounding population at Sai O has been conducted for both construction and operation cases, year 2022 and year 2025.

For the HP town gas pipelines, the individual risk and societal risk for both cases fall into the "Acceptable" region and are considered to be in compliance with risk criteria stipulated in EIAO-TM.

By considering the aboveground pipework and equipment in the Sai O offtake and pigging station, the risk in terms of individual risks and societal risks by the increase of population at construction and operation cases lie within the "Acceptable" region. Thus, the individual risks and societal risks of both cases comply with risk criteria stipulated in EIAO-TM.

8.0 References

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Figures

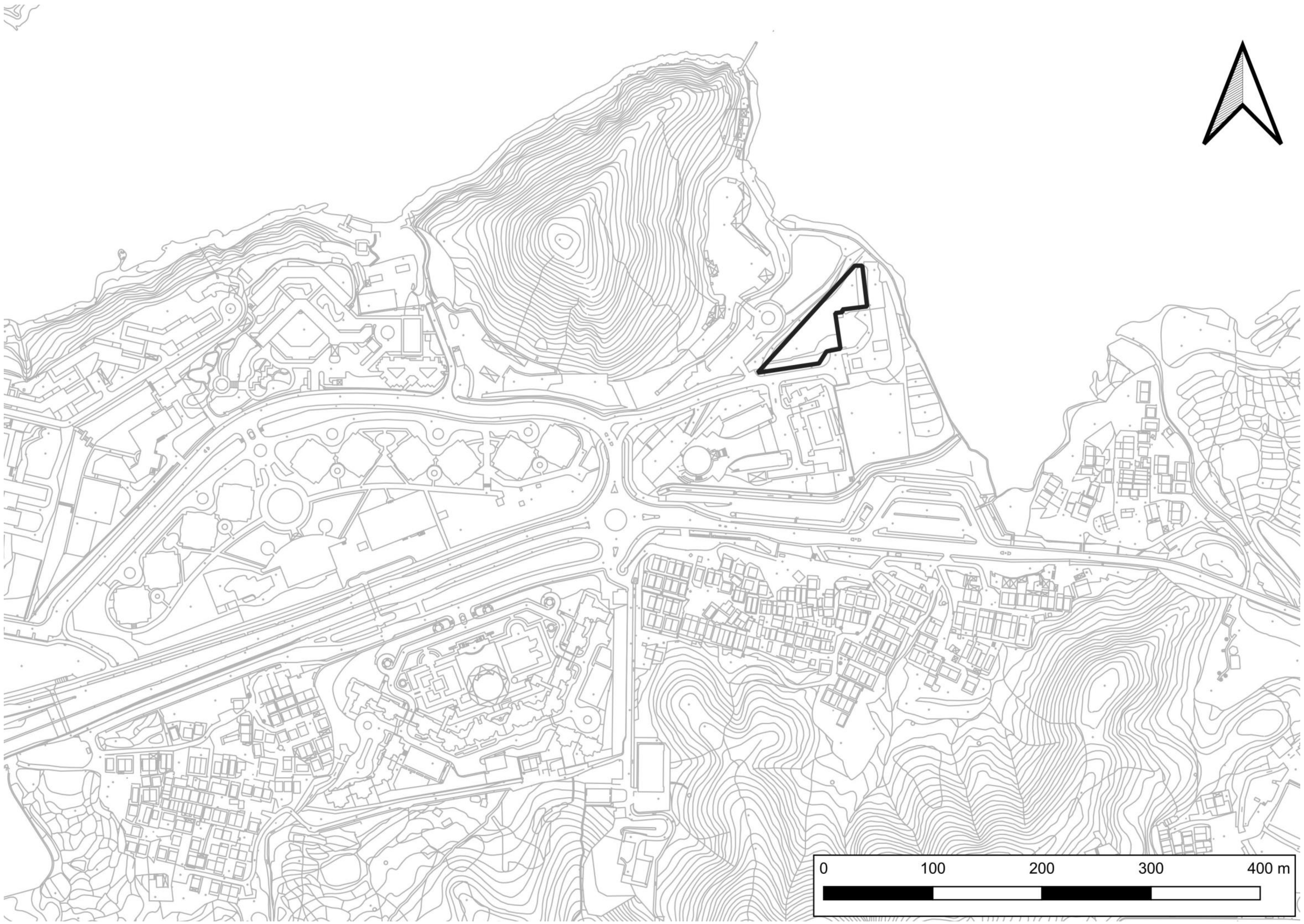


Figure 1 Location of the Project Site

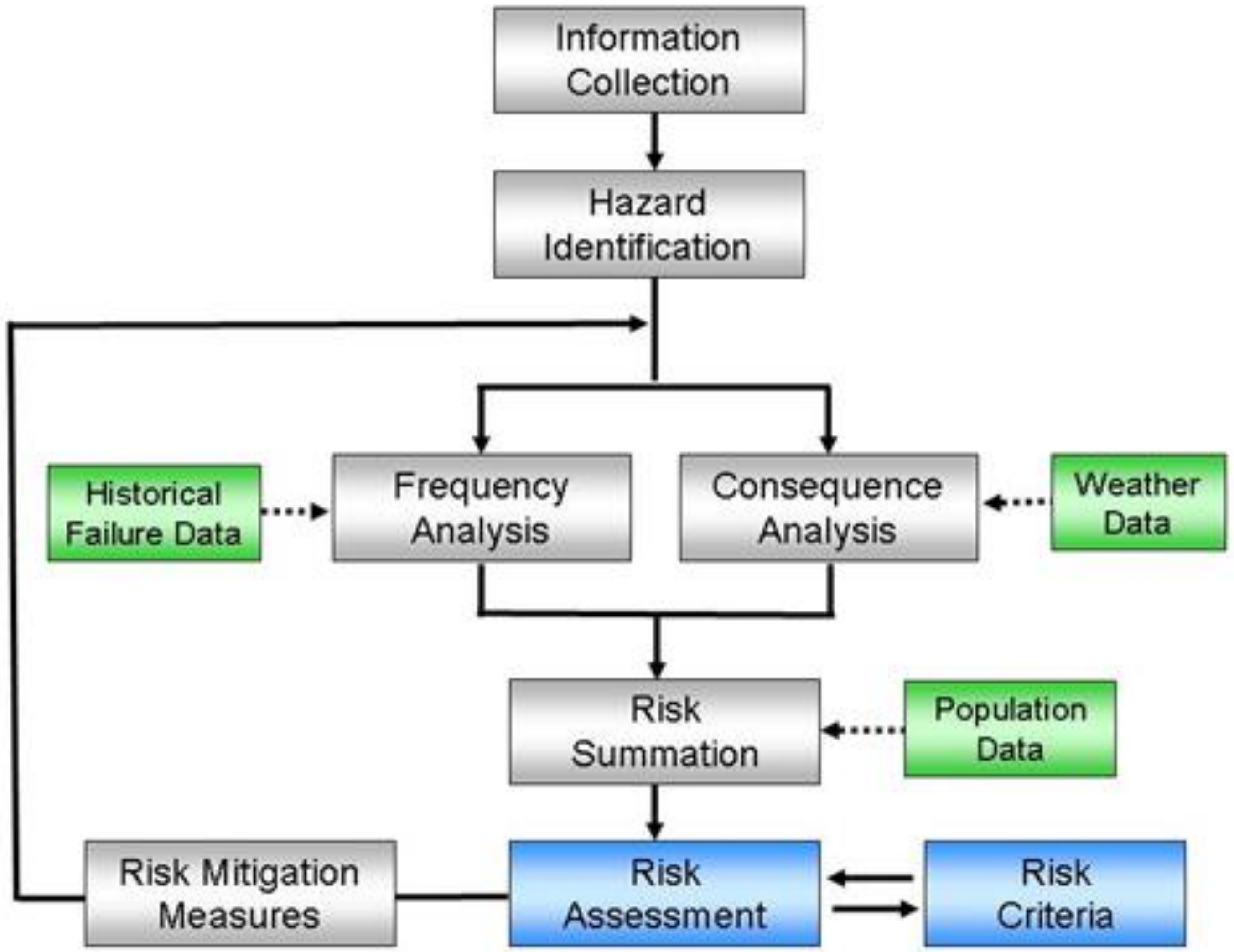


Figure 2 Quantitative Risk Assessment Methodology

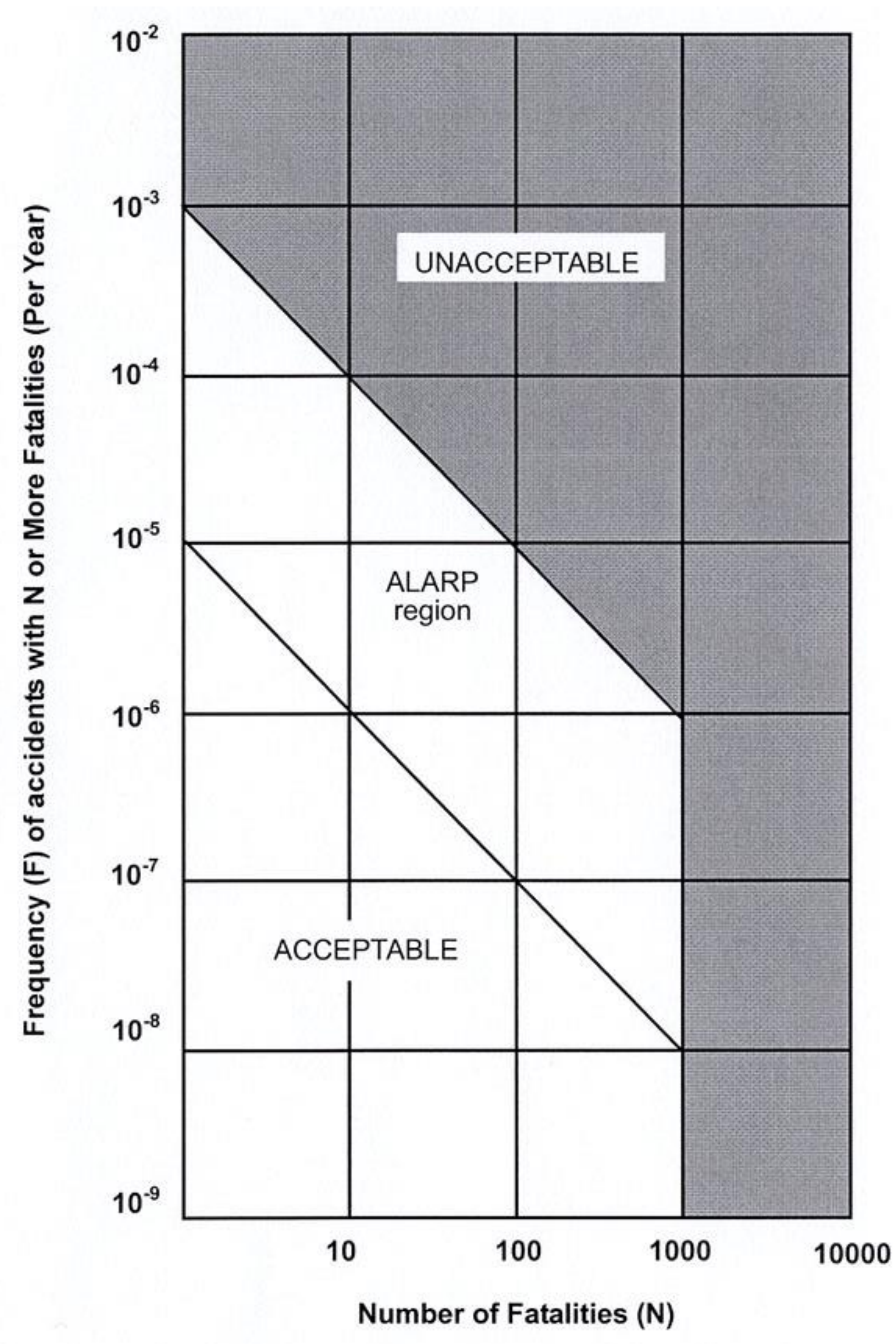


Figure 3 Societal Risk Guidelines (EIAO-TM)

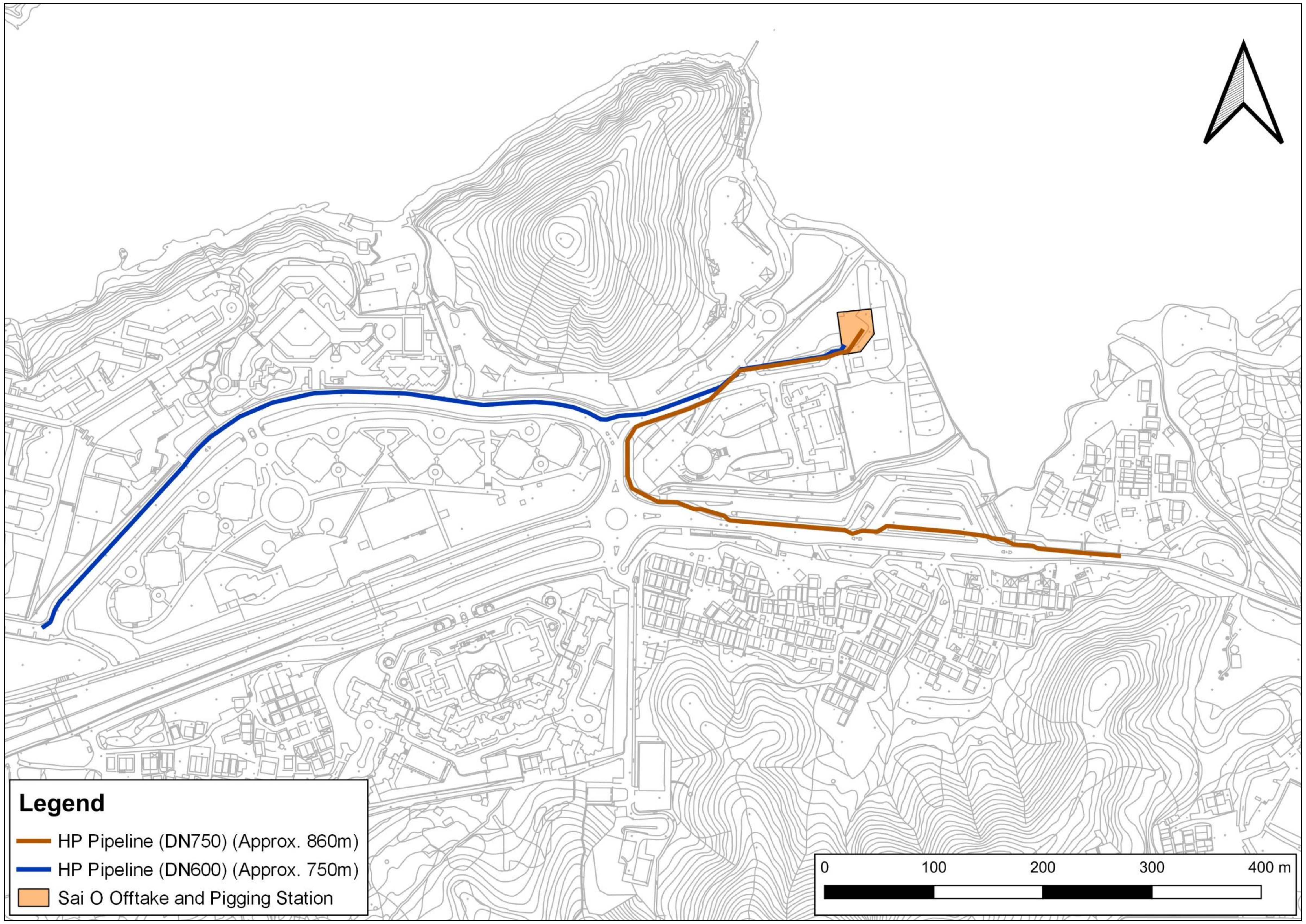


Figure 4 Existing Alignments of Underground HP Town Gas Pipelines

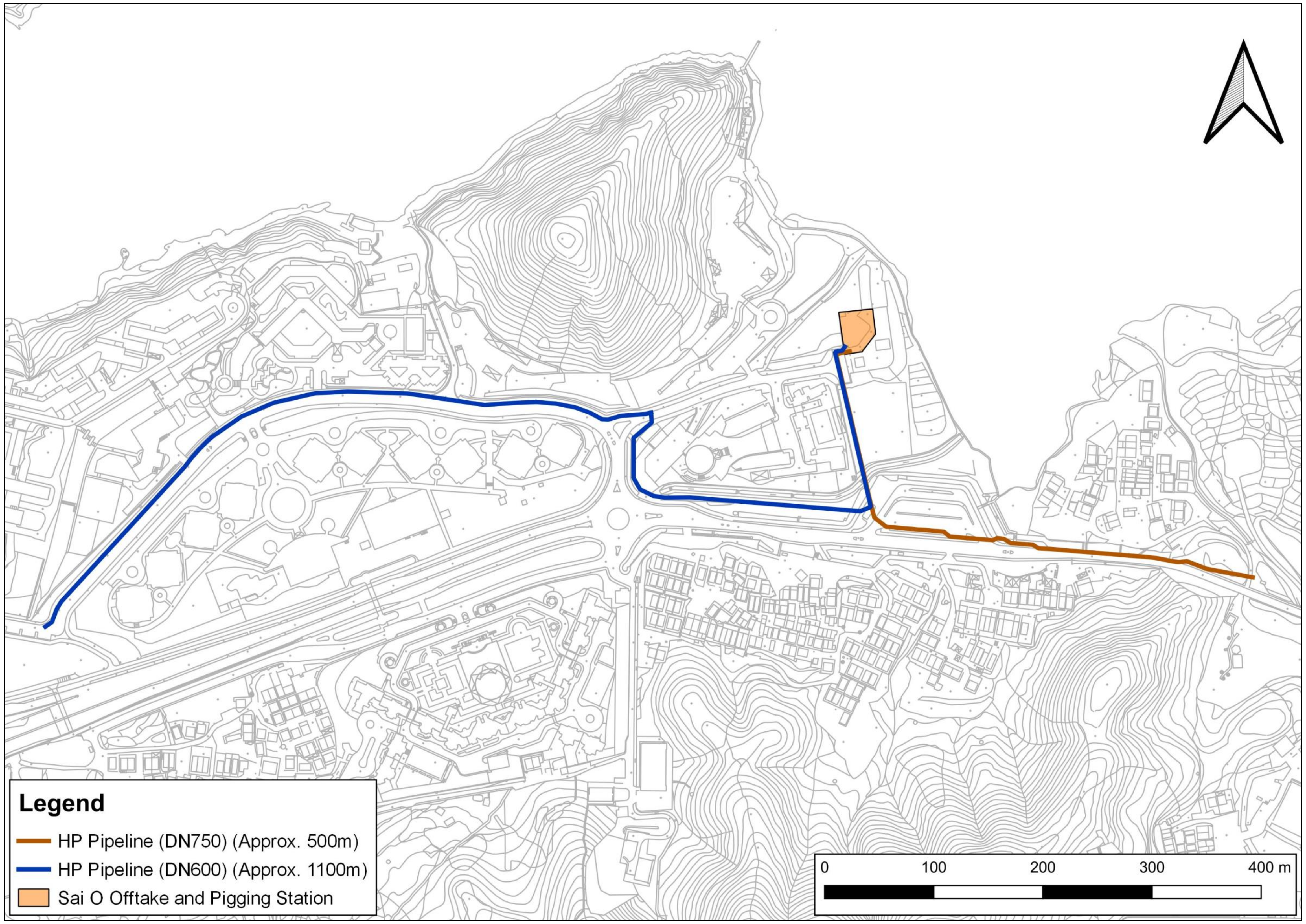


Figure 5 Modified Alignments of Underground HP Town Gas Pipelines Considered in this Study

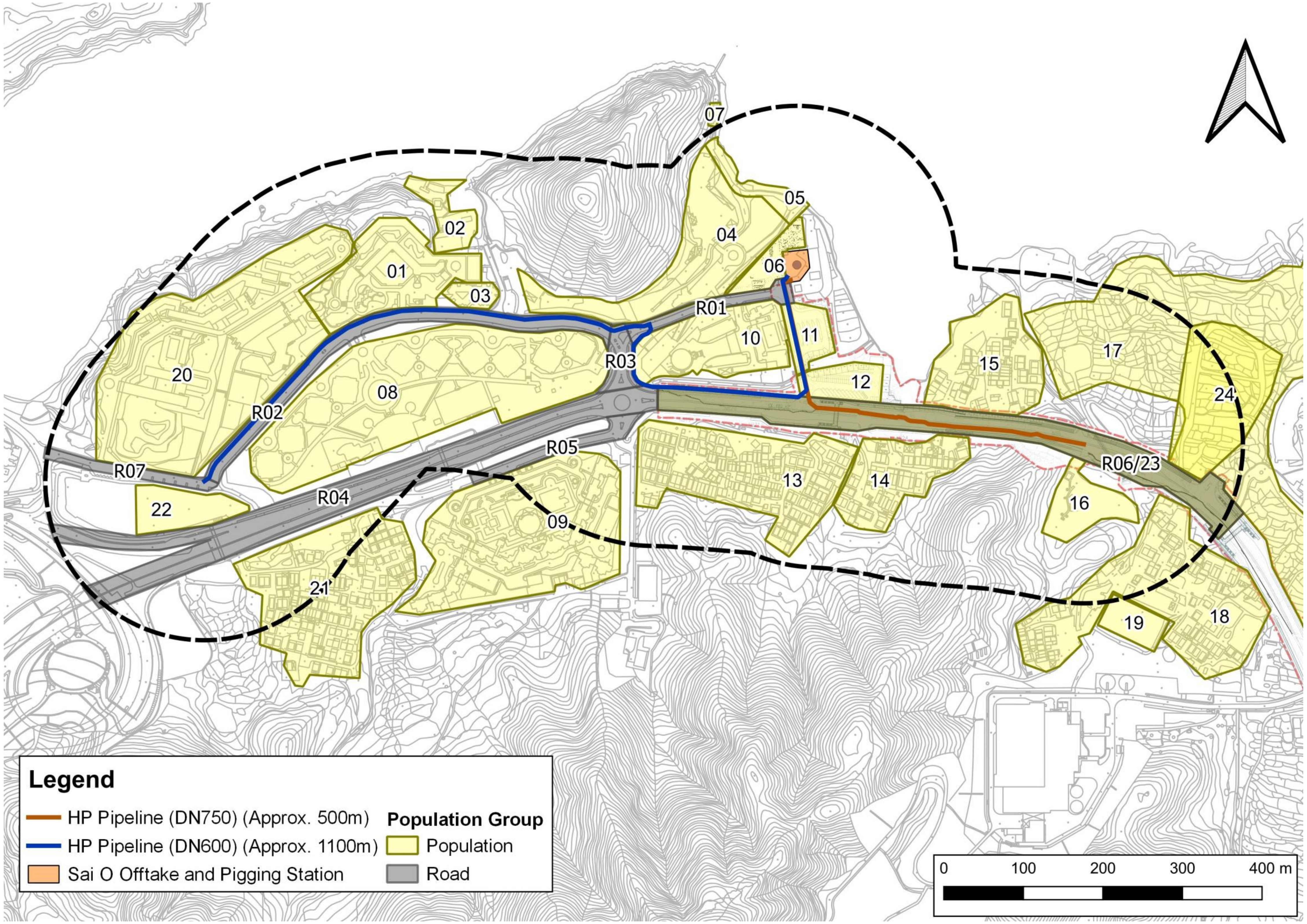


Figure 6 Population in the Vicinity

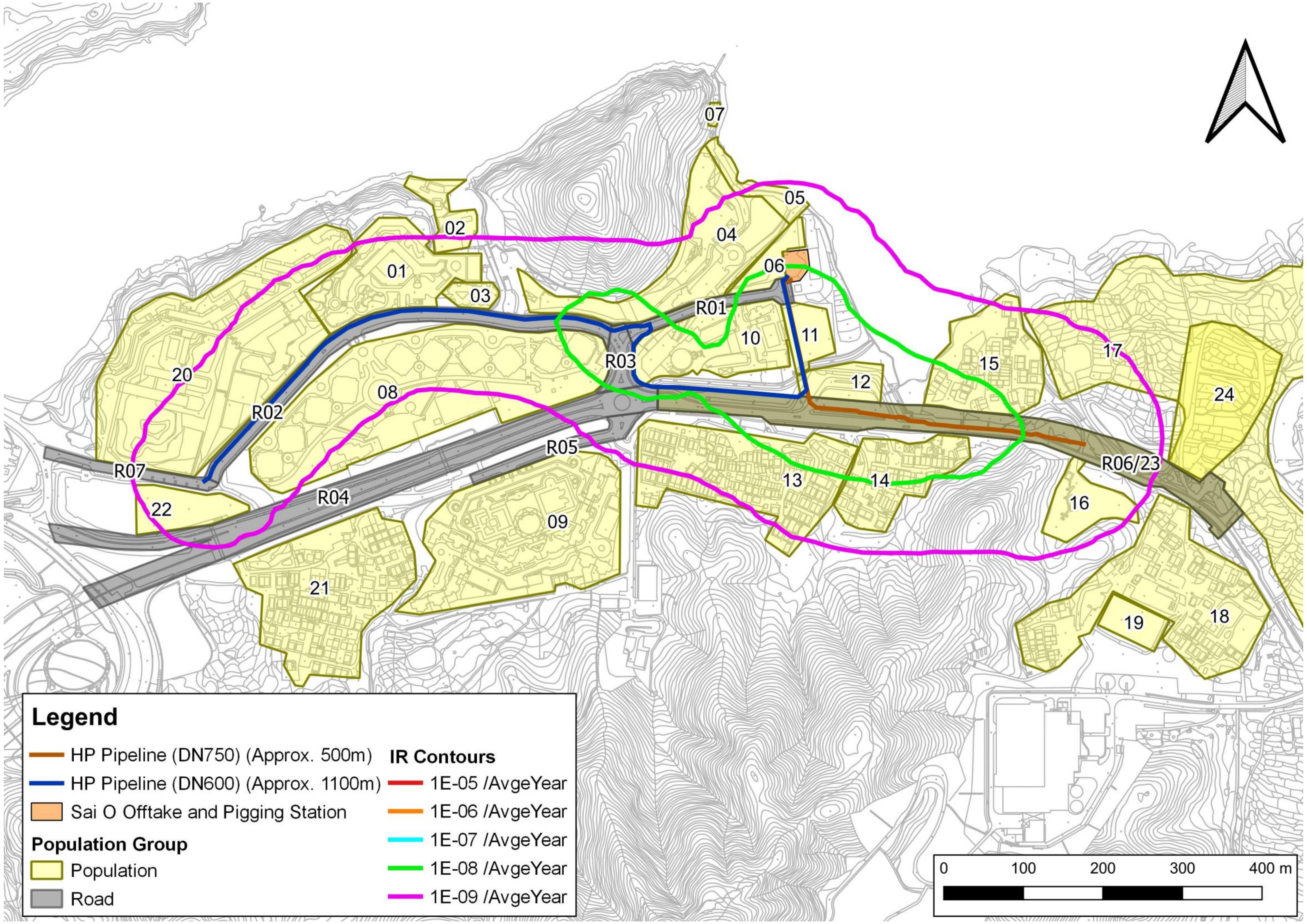


Figure 7 Individual Risk Contours of the Underground HP Town Gas Pipelines

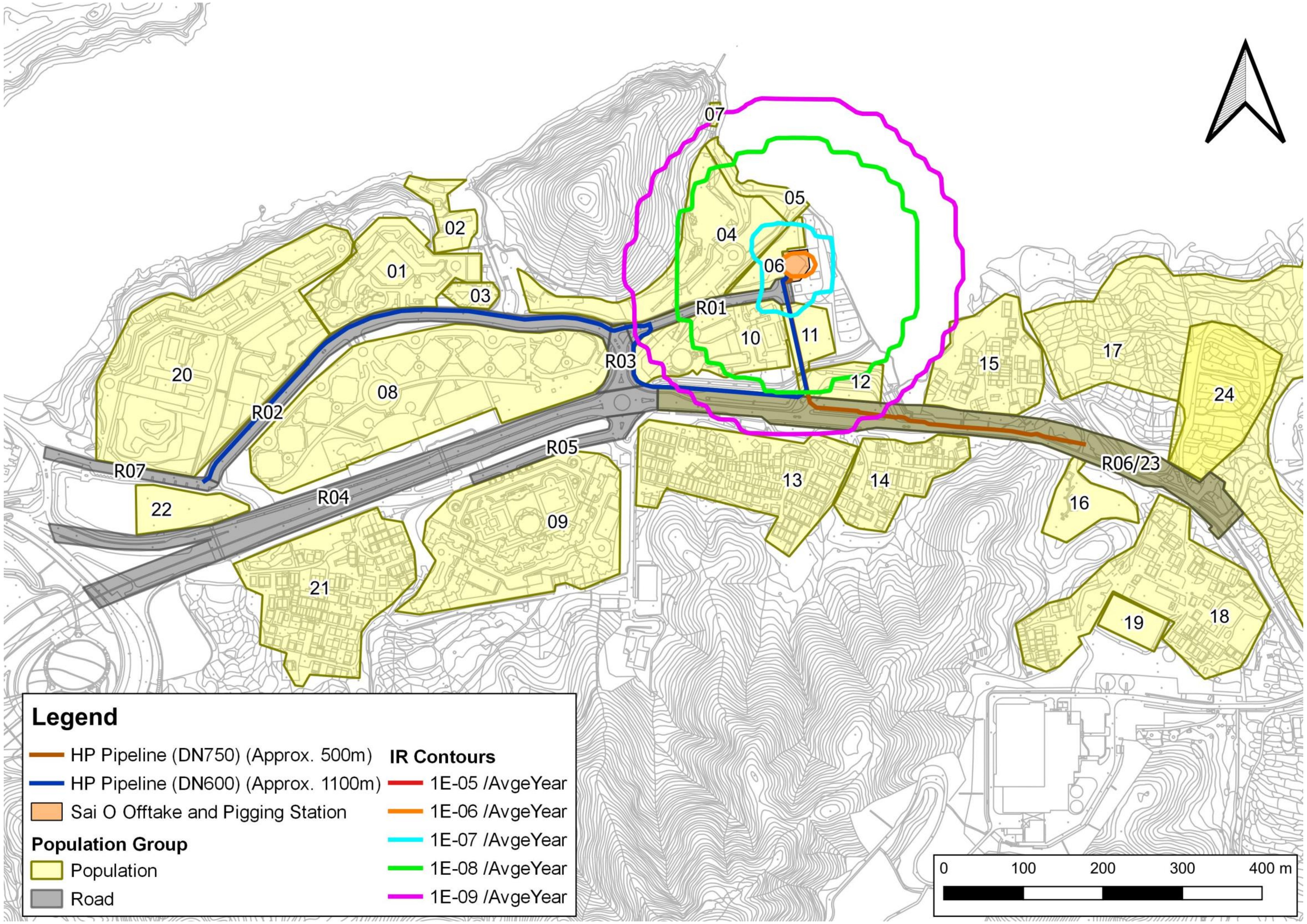


Figure 8 Individual Risk Contours of the Sai O Offtake and Pigging Station

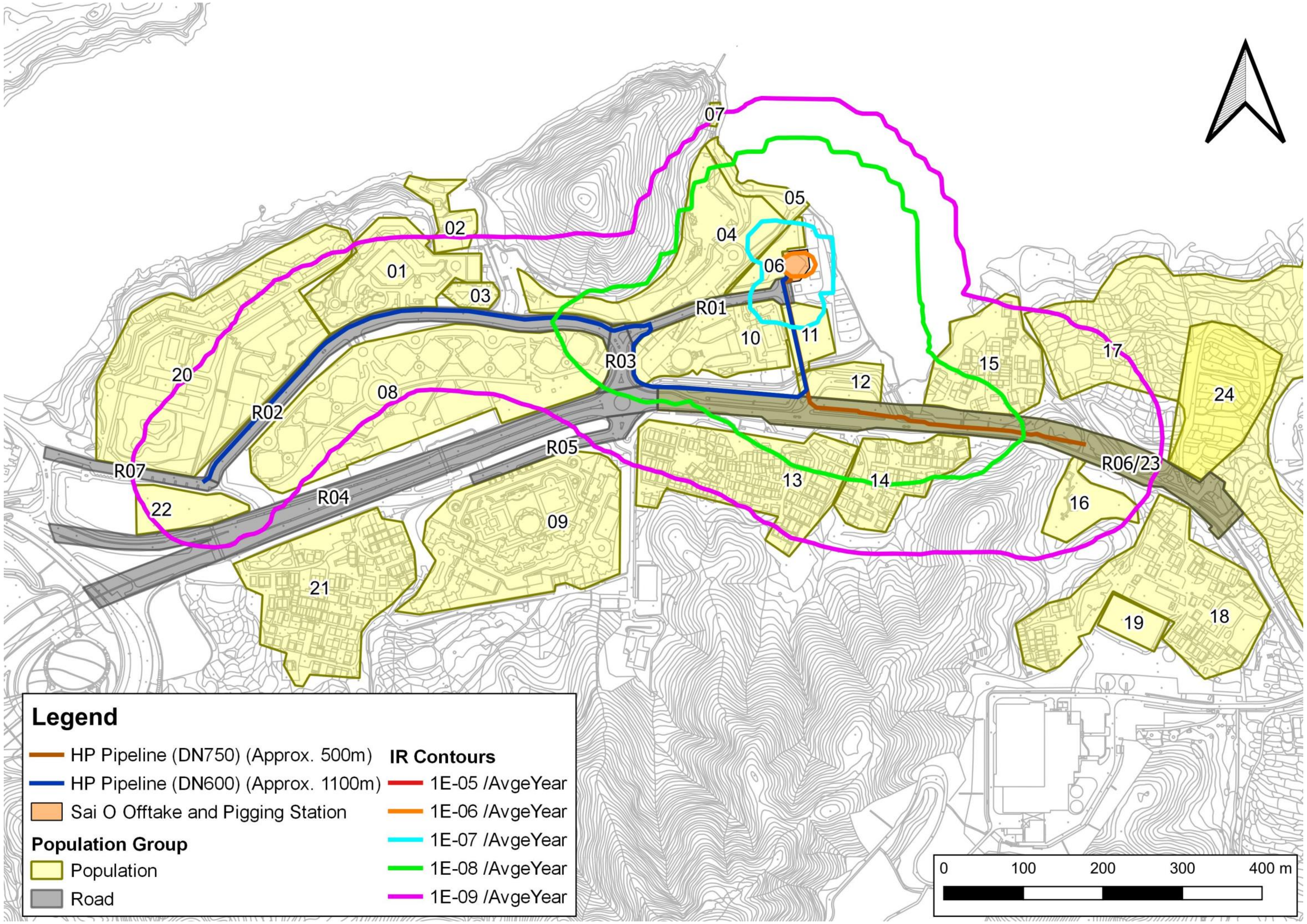


Figure 9 **Individual Risk Contour of the Underground HP Town Gas Pipelines and Sai O Offtake and Pigging Station**

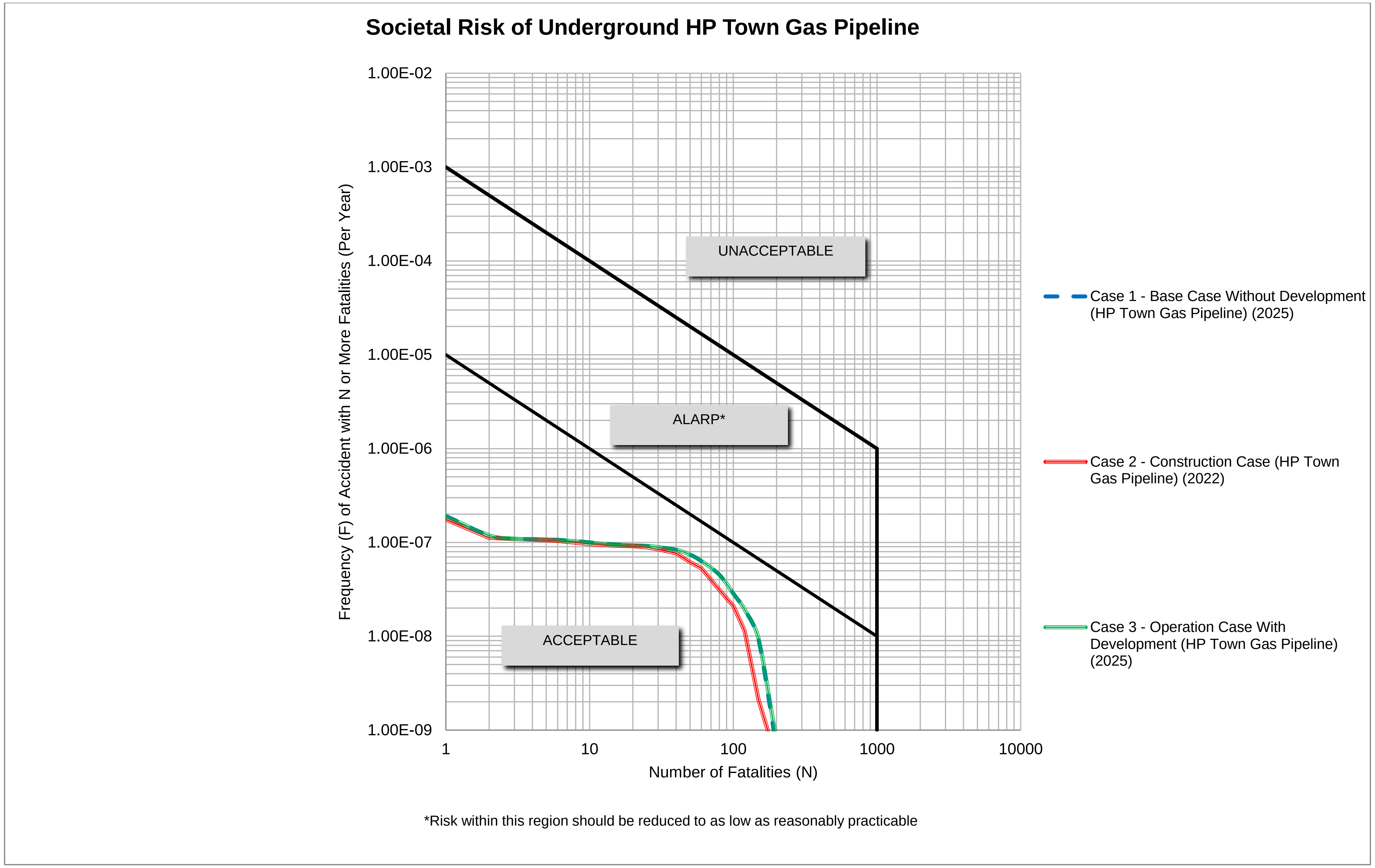


Figure 10 Societal Risk Result of the Underground HP Town Gas Pipelines

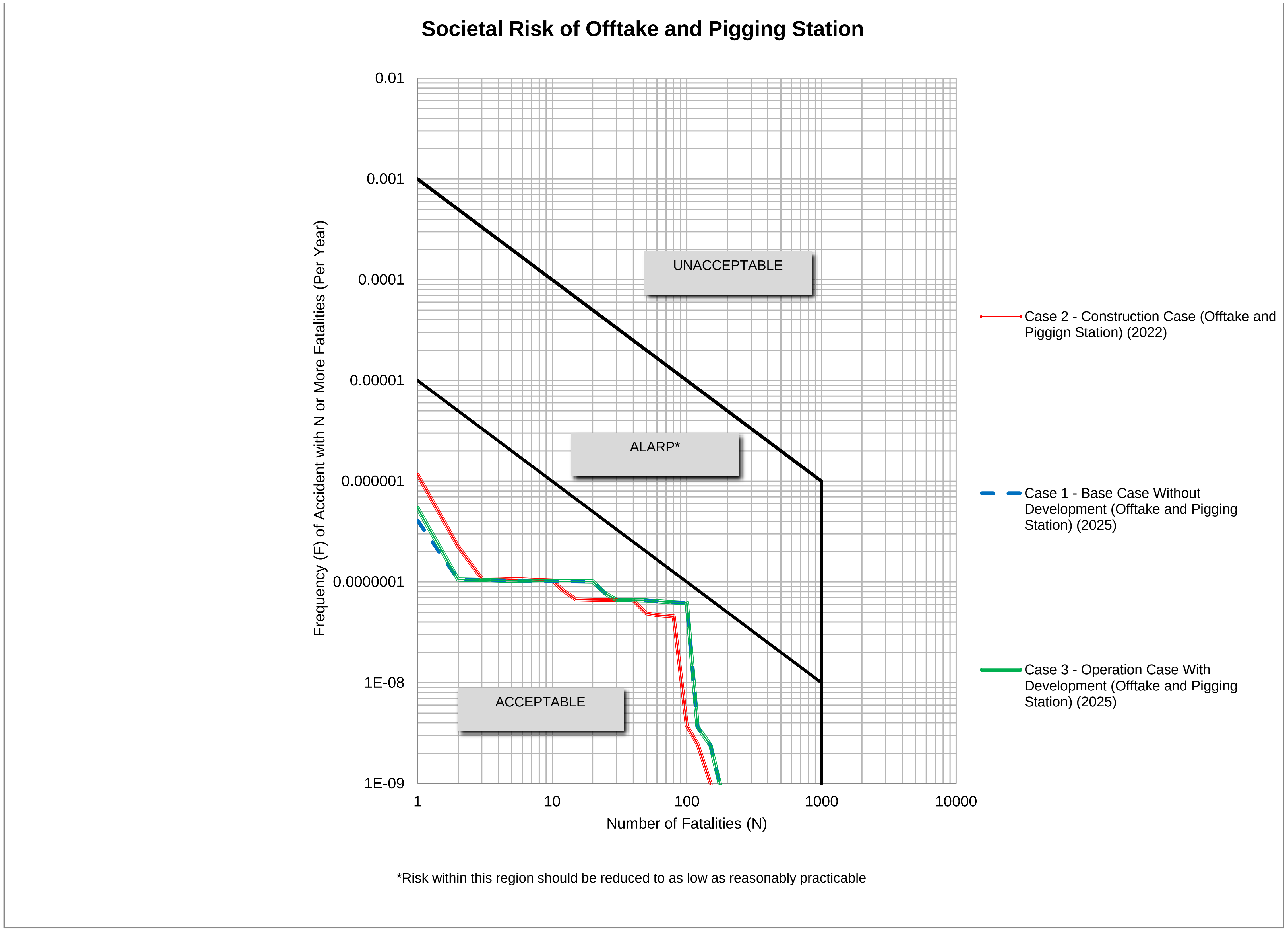


Figure 11 Societal Risk Result of Sai O Offtake and Pigging Station

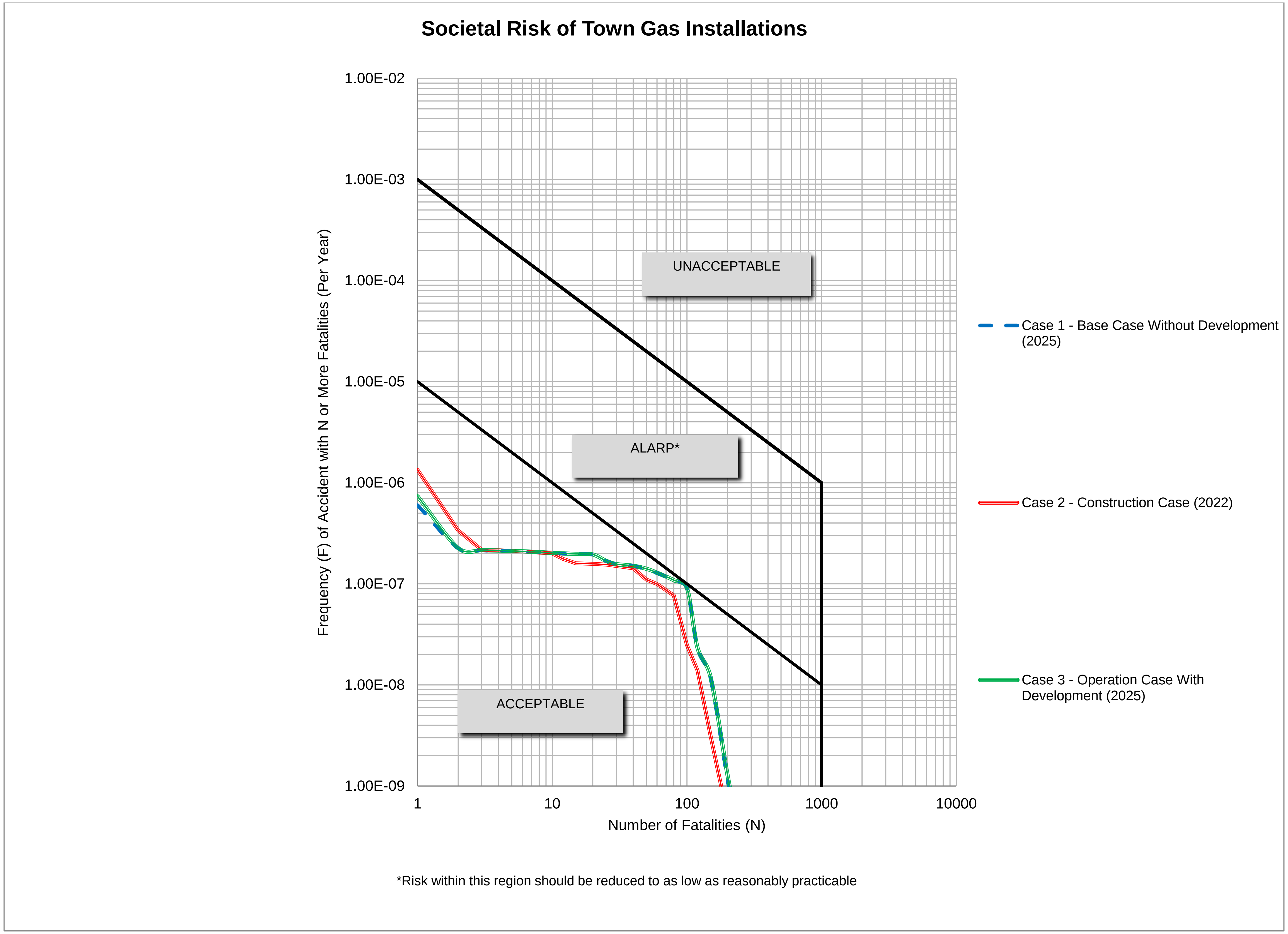


Figure 12 Societal Risk Result of the Underground HP Town Gas Pipelines and Sai O Offtake and Pigging Station

Annex A: Details of Underground HP Town Gas Pipeline and Sai O Offtake and Pigging Station

A1. Information of the Underground HP Town Gas Pipeline

Item	Description	Information
1	Pipeline diameter(s)	600mm / 750mm
2	Pressure(s) of pipeline	35 barg
3	Flowrate(s)	≤ 20m/s
4	Minimum cover to the pipeline	1.1m (Old pipe) / 1.2m (New pipe)
5	Pipe wall thickness	12.7mm
6	Pipe Material	Steel (API 5L X42/X52 for Pipe/X52 for fittings)
7	Testing method and corresponding code	Hydrostatic Test to 900psig (BGC/PS/PT3)
8	Protection against corrosion and external impact	External Coating: 3mm PE Coating Surrounded by 150mm thick fresh water sand plus selected soil Sacrificial anode at about 200~300m interval
9	Related Code of Practice for working / excavating near town gas pipeline	"Code of Practice - Avoidance of Damage to Gas Pipes 2nd Edition " - EMSD "General Requirements for Construction Work in the Vicinity of Gas Main" - HKCG
10	Nearest distances to the automation isolation points of the town gas pipeline upstream and downstream	Upstream of Sai O Offtake and Pigging Station: 8.0km (Sha Tin North Offtake and Pigging Station) Downstream of Sai O Offtake and Pigging Station: 19.1km (Tseng Lan Shue Offtake and Pigging Station)
11	Approximate time required for the isolation in Item 10	<5 minutes
12	Nearest distances to the manual isolation points of the town gas pipeline upstream and downstream	Upstream of Sai O Offtake and Pigging Station: 3.1km (Valve number: BV 24230) Downstream of Sai O Offtake and Pigging Station: 4.2km (Valve number: BV 30236)
13	Approximate time required for the isolation in Item 12	2 hours

A2. Information of the Sai O Offtake and Pigging Station

1. **Pipeline Routing:** Refer to attached drawing

2. **Operating Temperature**: 0 - 50°C

3. **Design Capacity**: 24,000 scmh (With inlet pressure of 10 bar and outlet pressure of 2.4 bar)

4. **Town gas composition:**

Composition	Percentage (%)	Physical Properties	Values
Hydrogen (H_2)	46.3 – 51.8%	Calorific Value (MJ/m^3)	17.27
Methane (CH_4)	28.2 – 30.7%	Specific Gravity	0.52
Carbon Dioxide (CO_2)	16.3 -19.9%	Wobbe Index	24
Carbon Monoxide (CO)	1 – 3.1%	Weaver Flame Speed	35
Nitrigen & Oxygen (N_2 & O_2)	0-3.3%	Lower Flammable Limit (LFL) (%)	5.5
Total	**100**		

5. **Project Design Basis/ Codes & Standards:** Made reference from the IGEM/TD/1 and IGEM/TD/13

6. **Equipment Data Sheet**
The station consists of filters, gas meters, slam shut valves, pressure reduction valves and ball valves as follows:

Description	Size (mm)	Offtake Unit Qty	Remarks
Pressure Regulator Valve	100	4	automatic operation
Slam Shut Valve	150	2	
Filter	300	2	NA
Gas Meter	200	1	
Ball Valve	50	15	manual operation
	100	2	
	150	4	
	200	10	
	300	2	
	600	1	
	750	1	
	250	2	
	600	1	can be operated from remote
Flange Joint	50	23	NA

Description	Size (mm)	Offtake Unit Qty	Remarks
	100	16	
	150	10	
	200	19	
	300	4	
	600	1	
	750	1	

Pipe Length (m)	Size (mm)
5	100
17	150
51	200
18	250
10	300
21	600
15	750

Total: 137m

7. Safety Philosophy

Gas Detection: Leakage survey is carried out weekly using gas detector.

Facility Safety Management: Regular preventive maintenance is carried out for the pigging and offtake stations. The maintenance activities for the installations is listed out in the table below.

Type and Schedule of Maintenance	Activities carried out
Category A Maintenance (Weekly)	• Compound security and condition check • Leakage check • Chart changing and clock winding • Filter differential check • Inlet and outlet pressure check • Slam shut equipment check • Regulator operation visual check • Valves and actuators in normal operating position check • General equipment check

Type and Schedule of Maintenance	Activities carried out
Category D Maintenance (Half-Yearly)	Category A Weekly Maintenance plus ● Filter drain and element check ● Prove operation & settings of regulators, monitor overrides, relief valves, slam shut valves and check all other ancillary equipment associated with the stream ● Pressure check on pneumatic valve actuators ● Telemetry and slam shut alarm checks ● Calibrate/check pressure gauges
Category E Maintenance (Annually)	Category D Half-yearly maintenance plus ● Overhaul of filter housing seals & recalibration of filter differential gauge ● Grease orifice carriers and check orifice plates, pilot tubes & turbine meters ● Changeover pressure regulator streams and overhaul working streams after 12 months work ● Pressure check on pneumatic actuators ● Lubricate valves and gear boxes and fully operate where possible ● Pig trap maintenance

Normal Operating Conditions

1. The gas stations will be equipped with CCTV systems which allow 24-hour monitoring of the activities inside.

2. An air-conditioned instrument room, which stores the electronic equipment for data transmission to the Grid Control Centre, will be constructed in each gas station.

3. The stations will be monitored and controlled through the SCADA (Supervisory Control And Data Acquisition) system by the Grid Control Centre, which is manned 24 hours a day by competent control engineers.

4. 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.

5. Emergency team is always on stand-by and they will arrive at the scene within 30 minutes in case of emergency.

6. HKCGC has developed its in-house guidelines which detail the procedures of general principles, safety procedures, procedures and recommendation for the maintenance of Above Ground Installations (AGIs) with inlet pressure exceeding 400kPa.

   It also sets forth the requirement for operation and maintenance of the gas transportation system to ensure any gas transportation above 400kPa is in good condition.

7. HKCGC has regular inspection and maintenance of the stations.

8. The gas stations are subject to regular audits by the Gas Standards Office (GasSO) of Electrical and Mechanical Services Department (EMSD).

9. A permit-to-work (PTW) system will also be adopted for works inside the proposed gas station. It is to ensure there is no unauthorized entry to the gas stations and all operations are carried out according to the controlled guidelines / procedures.

Emergency

1. Fire extinguishers are provided for general fire fighting. Stringent rules to prohibit naked flame and smoking in gas stations are strictly followed to reduce the potential of fire.

2. HKCGC has a set of stringent in-house guidelines and procedures recognized by the Government to deal with emergency.

3. Should the emergency team be required to be dispatched, they will arrive at the scene within 30 minutes.

4. HKCGC always commits to achieve high standards of gas safety and there has not been any incident recorded from all gas stations since the operation started in early 80’s (i.e., more than 30 years).

Annex B: Calculation of Transient Population

Estimation of Traffic Flow and Traffic Population

Occupancy of Various Vehicle Type

	Car, Taxi	Light	Heavy (Good)	Heavy (Bus)	Small Couch0
Occupancy (person/veh)	2	2	2	74	24

Calculation of Average Occupancy (Case 3 – Operation Case)

Road	Probability					Average Occupancy (1) (person / veh)
	Car, Taxi	Light	Heavy (Good)	Heavy (Bus)	Small Couch	
Nin Ming Road	0.77	0.08	0.05	0.00	0.10	4.2
Nin Wah Road Section 1	0.83	0.10	0.07	0.00	0.00	2.0
Nin Wah Road Section 2	0.80	0.08	0.05	0.00	0.06	3.4
Sai Sha Road Section 1	0.87	0.05	0.03	0.05	0.01	5.6
Nin Fung Road	0.84	0.10	0.07	0.00	0.00	2.0
Sai Sha Road Section 2 (Widened)	0.87	0.04	0.02	0.05	0.00	5.5
Lo Wo Sha Lane	0.83	0.10	0.07	0.00	0.00	2.0

Note:
(1) Average occupancy $= \sum(Probability_i \times Occupancy_i)/\sum Probability_i$

Forecasted Traffic Flow (Case 3 – Operation Case)

ID	Road	Daytime Hourly Traffic (1) (2) (veh/hr)	Night-time Hourly Traffic (1) (2) (veh/hr)
R01	Nin Ming Road	426	277
R02	Nin Wah Road Section 1	284	188
R03	Nin Wah Road Section 2	701	478
R04	Sai Sha Road Section 1	4357	3720
R05	Nin Fung Road	845	732
R06	Sai Sha Road Section 2 (Widened)	3189	2730
R07	Lo Wo Sha Lane	284	188

Note:
(1) As per traffic forecast data of this Project
(2) Assume traffic flow in morning peak hour as the daytime traffic flow and traffic in evening peak hour as the night time traffic flow

Calculation of Population (Case 3 – Operation Case)

ID	Road Name	Average Occupancy	Speed (km/hr)	Road Length (m)	Daytime Traffic Populat-ion	Pedestr-ian	Daytime Transient Populat-ion
R01	Nin Ming Road	4.2	50	213	5	20	25
R02	Nin Wah Road Section 1	2.0	50	590	5	20	25
R03	Nin Wah Road Section 2	3.4	50	81	3	10	13
R04	Sai Sha Road Section 1	5.6	50	980	412	20	432
R05	Nin Fung Road	2.0	50	218	7	20	27
R06	Sai Sha Road Section 2 (Widened)	5.5	50	760	228	50	278
R07	Lo Wo Sha Lane	2.0	50	215	2	20	22

Note: Daytime Traffic Population = Daytime Hourly Traffic × Average Occupancy × Road Length / Speed

Calculation of Average Occupancy (Case 2 – Construction Case)

Road	Probability					Average Occupancy [(1)] (person / veh)
	Car, Taxi	Light	Heavy (Good)	Heavy (Bus)	Small Couch	
Nin Ming Road	0.68	0.19	0.12	0.00	0.00	2.0
Nin Wah Road Section 1	0.83	0.10	0.07	0.00	0.00	2.0
Nin Wah Road Section 2	0.78	0.13	0.09	0.00	0.00	2.0
Sai Sha Road Section 1	0.84	0.07	0.05	0.04	0.00	4.7
Nin Fung Road	0.84	0.10	0.06	0.00	0.00	2.0
Sai Sha Road Section 2	0.80	0.06	0.11	0.03	0.00	4.4
Lo Wo Sha Lane	0.83	0.10	0.07	0.00	0.00	2.0

Note:
(1) Average occupancy = $\sum(Probability_i \times Occupancy_i)/\sum Probability_i$

Forecasted Traffic Flow (Case 2 – Construction Case)

ID	Road	Daytime Hourly Traffic (1)(2) (veh/hr)	Night-time Hourly Traffic (1)(2) (veh/hr)
R01	Nin Ming Road	174	102
R02	Nin Wah Road Section 1	280	186
R03	Nin Wah Road Section 2	445	301
R04	Sai Sha Road Section 1	2741	2447
R05	Nin Fung Road	838	726
R06	Sai Sha Road Section 2	1876	1681
R07	Lo Wo Sha Lane	280	186

Note:

(1) As per traffic forecast data of this Project

(2) Assume traffic flow in morning peak hour as the daytime traffic flow and traffic in evening peak hour as the night time traffic flow

Calculation of Population (Case 2 – Construction Case)

ID	Road Name	Average Occupancy	Speed (km/hr)	Road Length (m)	Daytime Traffic Populat-ion	Pedestr-ian	Daytime Transient Populat-ion
R01	Nin Ming Road	2.0	50	213	2	20	22
R02	Nin Wah Road Section 1	2.0	50	590	7	20	27
R03	Nin Wah Road Section 2	2.0	50	81	2	10	12
R04	Sai Sha Road Section 1	4.7	50	980	252	20	272
R05	Nin Fung Road	2.0	50	218	8	20	28
R06	Sai Sha Road Section 2	4.4	50	760	127	50	177
R07	Road to Tseng Tau	2.0	50	213	3	20	23

Note: Daytime Traffic Population = Daytime Hourly Traffic × Average Occupancy × Road Length / Speed

Annex C:
Event Tree Analysis

UNDERGROUND HIGH PRESSURE TOWNGAS PIPELINE

Underground Pipelines

Underground Land Pipeline Failure (per km-yr)
1.00E-05

Assume jet fire inclined from horizontal by 45 deg

Release Frequency (/km-yr)	Failure Probability	Release Orientation	Immediate Ignition	Delayed Ignition	Explosion after Ignition	Outcome Frequency (/km-yr)	Outcome Consequence
1.00E-05	0.20 leak 10mm 2.00E-06 /km-yr	Vertical 0.5	Yes 0.01			1.00E-08	Vertical jet fire
			No 0.99	Yes 0.1		9.90E-08	Flash fire
				No 0.9		8.91E-07	No ignition
		Inclined 0.5	Yes 0.01			1.00E-08	Inclined jet fire
			No 0.99	Yes 0.1		9.90E-08	Flash fire
				No 0.9		8.91E-07	No ignition
	0.30 leak 25mm 3.00E-06 /km-yr	Vertical 0.5	Yes 0.07			1.05E-07	Vertical jet fire
			No 0.93	Yes 0.1		1.40E-07	Flash fire
				No 0.9		1.26E-06	No ignition
		Inclined 0.5	Yes 0.07			1.05E-07	Inclined jet fire
			No 0.93	Yes 0.1		1.40E-07	Flash fire
				No 0.9		1.26E-06	No ignition
	0.30 leak 50mm 3.00E-06 /km-yr	Vertical 0.5	Yes 0.1			1.50E-07	Vertical jet fire
			No 0.9	Yes 0.1		1.35E-07	Flash fire
				No 0.9		1.22E-06	No ignition
		Inclined 0.5	Yes 0.1			1.50E-07	Inclined jet fire
			No 0.9	Yes 0.1		1.35E-07	Flash fire
				No 0.9		1.22E-06	No ignition
	0.19 leak 100mm 1.90E-06 /km-yr	Vertical 0.5	Yes 0.2			1.90E-07	Vertical jet fire
			No 0.8	Yes 0.2	Yes 0.12	1.82E-08	Flash fire followed by explosion
					No 0.88	1.34E-07	Flash fire
				No 0.8		6.08E-07	No ignition
		Inclined 0.5	Yes 0.2			1.90E-07	Inclined jet fire
			No 0.8	Yes 0.2	Yes 0.12	1.82E-08	Flash fire followed by explosion
					No 0.88	1.34E-07	Flash fire
				No 0.8		6.08E-07	No ignition
	0.01 Full bore rupture 1.00E-07 /km-yr	Vertical 1	Yes 0.5			5.00E-08	Fireball
			No 0.5	Yes 0.5	Yes 0.3	7.50E-09	Flash fire followed by explosion
					No 0.7	1.75E-08	Flash fire
				No 0.5		2.50E-08	No ignition

OFFTAKE AND PIGGING STATION (ABOVE GROUND)

Critical Equipment (Valve, Flange etc.)

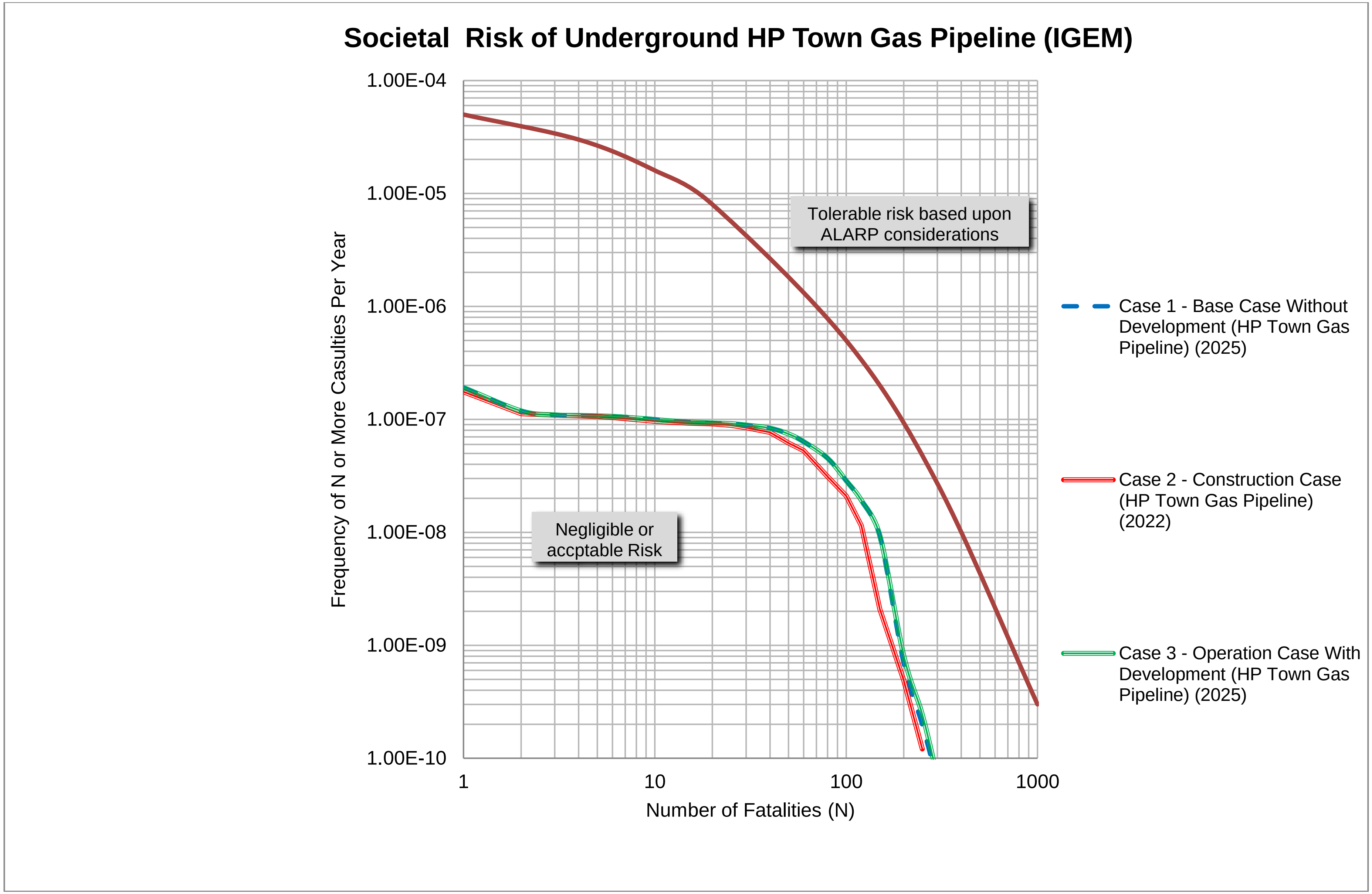
Release Frequency (/yr)	Failure Probability	Release Orientation	Immediate Ignition	Delayed Ignition	Explosion after Ignition	Outcome Frequency (/km-yr)	Outcome Consequence
1.19E-02	0.93 leak 10mm 1.11E-02 /yr	Vertical 0.50	Yes 0.01			5.54E-05	Vertical jet flame
3.87E-03 Valve 8.00E-03 Flange			No 0.99	Yes 0.10		5.48E-04	Flash fire followed by diffused jet flame
0.00E+00 Instrument Connections				No 0.90		4.93E-03	No ignition
4.57E-08 Pig Trap		Horizontal 0.25	Yes 0.05			1.38E-04	Horizontal jet flame
			No 0.95	Yes 0.15		3.94E-04	Flash fire followed by diffused jet flame
				No 0.85		2.24E-03	No ignition
		Inclined 0.25	Yes 0.01			2.77E-05	Inclined jet flame
			No 0.99	Yes 0.10		2.74E-04	Flash fire followed by diffused jet flame
				No 0.90		2.47E-03	No ignition
	0.06 leak 25mm 7.20E-04 /yr	Vertical 0.50	Yes 0.07			2.52E-05	Vertical jet flame
			No 0.93	Yes 0.10		3.35E-05	Flash fire followed by diffused jet flame
				No 0.90		3.01E-04	No ignition
		Horizontal 0.25	Yes 0.10			1.80E-05	Horizontal jet flame
			No 0.90	Yes 0.15		2.43E-05	Flash fire followed by diffused jet flame
				No 0.85		1.38E-04	No ignition
		Inclined 0.25	Yes 0.07			1.26E-05	Inclined jet flame
			No 0.93	Yes 0.10		1.67E-05	Flash fire followed by diffused jet flame
				No 0.90		1.51E-04	No ignition
	0.007 leak 50mm 8.00E-05 /yr	Vertical 0.50	Yes 0.10			4.00E-06	Vertical jet flame
			No 0.90	Yes 0.10		3.60E-06	Flash fire followed by diffused jet flame
				No 0.90		3.24E-05	No ignition
		Horizontal 0.25	Yes 0.15			3.00E-06	Horizontal jet flame
			No 0.85	Yes 0.15		2.55E-06	Flash fire followed by diffused jet flame
				No 0.85		1.45E-05	No ignition
		Inclined 0.25	Yes 0.10			2.00E-06	Inclined jet flame
			No 0.90	Yes 0.10		1.80E-06	Flash fire followed by diffused jet flame
				No 0.90		1.62E-05	No ignition
	3.8E-06 Full bore rupture 4.57E-08 /yr	Vertical 1.00	Yes 0.50			2.28E-08	Fire ball
			No 0.50	Yes 0.50	Yes 0.30	3.42E-09	Flash fire followed by explosion
					No 0.70	7.99E-09	Flash fire followed by diffused jet flame
				No 0.50		1.14E-08	No ignition

Pipeline in Offtake Station

Pipeline Failure (per km-yr) in gas station	Pipeline length in gas station (km)	Pipeline rupture due to earthquake (per yr) in gas station
2.70E-05	0.137	1.00E-07

Release Frequency (/km-yr)	Failure Probability	Release Orientation		Immediate Ignition		Delayed Ignition		Explosion after Ignition		Outcome Frequency (/km-yr)	Outcome Consequence
3.80E-06	1.95E-01	Vertical	0.5	Yes	0.01					3.70E-09	Vertical jet flame
3.70E-06 Pipeline failure	leak 10mm										
1.00E-07 Rupture due to earthquake	7.40E-07 /yr			No	0.99	Yes	0.1			3.66E-08	Flash fire followed by diffused jet flame
						No	0.9			3.30E-07	No ignition
		Horizontal	0.25	Yes	0.05					9.25E-09	Horizontal jet flame
				No	0.95	Yes	0.15			2.64E-08	Flash fire followed by diffused jet flame
						No	0.85			1.49E-07	No ignition
		Inclined	0.25	Yes	0.01					1.85E-09	Inclined jet flame
				No	0.99	Yes	0.1			1.83E-08	Flash fire followed by diffused jet flame
						No	0.9			1.65E-07	No ignition
	2.92E-01	Vertical	0.5	Yes	0.07					3.89E-08	Vertical jet flame
	leak 25mm										
	1.11E-06 /yr			No	0.93	Yes	0.1			5.16E-08	Flash fire followed by diffused jet flame
						No	0.9			4.65E-07	No ignition
		Horizontal	0.25	Yes	0.10					2.78E-08	Horizontal jet flame
				No	0.90	Yes	0.15			3.75E-08	Flash fire followed by diffused jet flame
						No	0.85			2.12E-07	No ignition
		Inclined	0.25	Yes	0.07					1.94E-08	Inclined jet flame
				No	0.93	Yes	0.1			2.58E-08	Flash fire followed by diffused jet flame
						No	0.9			2.32E-07	No ignition
	2.92E-01	Vertical	0.5	Yes	0.10					5.55E-08	Vertical jet flame
	leak 50mm										
	1.11E-06 /yr			No	0.90	Yes	0.1			5.00E-08	Flash fire followed by diffused jet flame
						No	0.9			4.50E-07	No ignition
		Horizontal	0.25	Yes	0.15					4.16E-08	Horizontal jet flame
				No	0.85	Yes	0.15			3.54E-08	Flash fire followed by diffused jet flame
						No	0.85			2.01E-07	No ignition
		Inclined	0.25	Yes	0.10					2.78E-08	Inclined jet flame
				No	0.90	Yes	0.1			2.50E-08	Flash fire followed by diffused jet flame
						No	0.9			2.25E-07	No ignition
	1.85E-01	Vertical	0.5	Yes	0.20					7.03E-08	Vertical jet flame
	leak 100mm										
	7.03E-07 /yr			No	0.80	Yes	0.2	Yes	0.12	6.75E-09	Flash fire followed by explosion
								No	0.88	4.95E-08	Flash fire followed by diffused jet flame
						No	0.8			2.25E-07	No ignition
		Horizontal	0.25	Yes	0.25					4.39E-08	Horizontal jet flame
				No	0.75	Yes	0.25	Yes	0.12	3.96E-09	Flash fire followed by explosion
								No	0.88	2.90E-08	Flash fire followed by diffused jet flame
						No	0.75			9.89E-08	No ignition
		Inclined	0.25	Yes	0.20					3.52E-08	Inclined jet flame
				No	0.80	Yes	0.2	Yes	0.12	3.37E-09	Flash fire followed by explosion
								No	0.88	2.47E-08	Flash fire followed by diffused jet flame
						No	0.8			1.12E-07	No ignition
	3.60E-02	Vertical	1	Yes	0.50					6.85E-08	Fire ball
	Full bore rupture										
	1.37E-07 (incl. rupture due to earthquak			No	0.50	Yes	0.5	Yes	0.3	1.03E-08	Flash fire followed by explosion
								No	0.7	2.40E-08	Flash fire followed by diffused jet flame
						No	0.5			3.43E-08	No ignition

Annex D: Societal Risk Results of the Underground HP Town Gas Pipeline compared to IGEM/TD/2


Societal Risk of Underground HP Town Gas Pipeline (IGEM)
Frequency of N or More Casulties Per Year
1.00E-04
1.00E-05
1.00E-06
1.00E-07
1.00E-08
1.00E-09
1.00E-10
1
10
100
1000
Number of Fatalities (N)
Tolerable risk based upon ALARP considerations
Negligible or accptable Risk
Case 1 - Base Case Without Development (HP Town Gas Pipeline) (2025)
Case 2 - Construction Case (HP Town Gas Pipeline) (2022)
Case 3 - Operation Case With Development (HP Town Gas Pipeline) (2025)

Annex E:
Atmospheric Stability Class-Wind Speed Frequencies

Day Time Atmospheric Stability Class-Wind Speed Frequencies at Sha Tin Weather Station (Year 2014 - 2018)

Wind Speed	STABILITY CLASS						Total
	A	B	C	D	E	F	
0-2	10.23	8.08	0.00	9.59	0.00	13.38	41.29
2-4	8.16	18.88	8.72	9.23	4.41	0.67	50.06
4-6	0.00	3.79	2.20	1.99	0.07	0.00	8.05
6-8	0.00	0.00	0.09	0.42	0.00	0.00	0.51
>8	0.00	0.00	0.00	0.08	0.00	0.00	0.08
Total	18.39	30.75	11.01	21.32	4.47	14.05	100.00

Night Time Atmospheric Stability Class-Wind Speed Frequencies at Sha Tin Weather Station (Year 2014 - 2018)

Wind Speed	STABILITY CLASS						Total
	A	B	C	D	E	F	
0-2	0.00	0.00	0.00	1.02	0.00	54.74	55.76
2-4	0.00	0.00	0.00	6.37	12.51	15.48	34.37
4-6	0.00	0.00	0.00	4.42	3.93	0.49	8.83
6-8	0.00	0.00	0.00	0.84	0.13	0.00	0.97
>8	0.00	0.00	0.00	0.07	0.00	0.00	0.07
Total	0.00	0.00	0.00	12.72	16.57	70.71	100.00