APPENDIX 13.2 HAZARD TO LIFE ASSESSMENT FOR AN EXISTING SYNTHETIC NATURAL GAS (SNG) PRODUCTION PLANT

TABLE OF CONTENTS

List of Tables

List of Plates

List of Annexes

1. INTRODUCTION

1.1 Background

1.1.1.1 An existing Synthetic Natural Gas (SNG) Production Plant at the SENT Landfill is located at the north-eastern boundary of the TKO 137 separated by the Wan Po Road. The facility converts landfill gas (LFG) to SNG before it is transported to Tseng Lan Shue Station via a 12 km underground pipeline and integrated into the Towngas supply grid for customer use. Gas leakage from the SNG production plant could have potential risk impact to the surrounding population, and thus QRA is required to assess the overall risk level.

1.2 Scope of Work

1.2.1.1 The Hazard to Life Assessment requirements for the SNG production plant are shown below:

(a) Identify hazardous scenarios associated with the operation of the SNG production plant and then determine a set of relevant scenarios to be included in a QRA;

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

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

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

1.3 Hong Kong Risk Guidelines (HKRG)

1.3.1.1 Annex 4 of the EIAO-TM specifies the Individual and Societal Risk Guidelines. The Hong Kong Government Risk Guidelines (HKRG) per the EIAO TM Annex 4 states that the individual risk is the predicted increase in the chance of fatality per year to an individual due to a potential hazard. The individual risk guidelines require that the maximum level of individual risk should not exceed 1 in 100,000 per year i.e. 1×10^{-5} per year. Societal risk expresses the risks to the whole population. It is expressed in terms of lines plotting the cumulative frequency (F) of N or more deaths in the population from incidents at the installation. Two F-N risk lines are used in the HKRG that demark “Acceptable” or “Unacceptable” societal risks. To avoid major disasters, there is a vertical cut-off line at the 1,000 fatality level extending down to a frequency of 1 in a billion years. The intermediate region indicates the acceptability of societal risk is borderline and should be reduced to a level which is “as low as reasonably practicable” (ALARP). It seeks to ensure that all practicable and cost-effective measures that can reduce risk are considered. The HKRG is presented graphically in **Plate 1.1**.

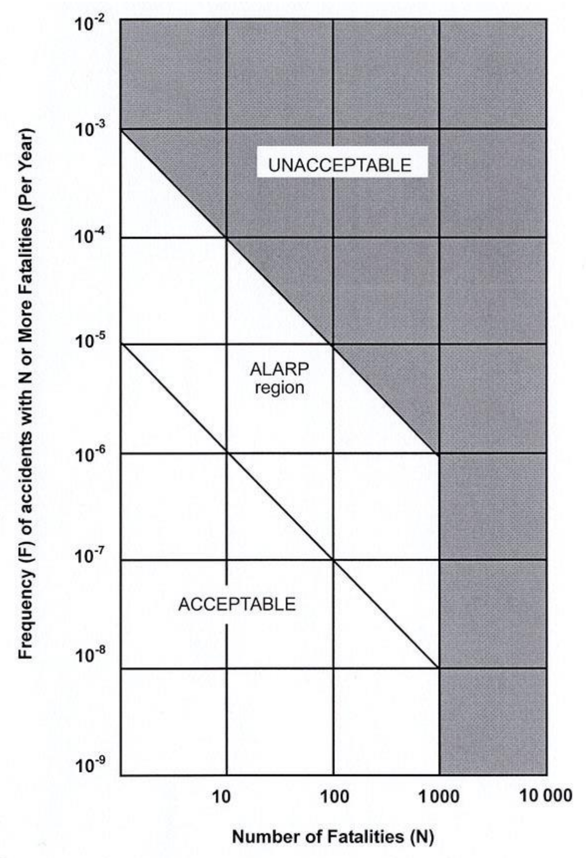

Plate 1.1 Societal Risk Guidelines

1.4 Assessment Approach

1.4.1 The QRA consisted of the following six main tasks:

(a) **Data / Information Collection and Update**: Collected relevant data / information necessary for the hazard assessment;

(b) **Hazard Identification**: Identified a credible set of hazardous scenarios associated with the operation of the SNG production plant;

(c) **Frequency Estimation**: Estimated the frequencies of each hazardous event leading to fatalities based on the collected data with the support of justifications through the review of historical accident data and previous hazard assessment of similar projects;

(d) **Consequence Analysis**: Analysed the consequences of the identified hazardous scenarios;

(e) **Risk Integration and Evaluation**: Evaluated the risks associated with the identified hazardous scenarios. The evaluated risks were compared with the HKRG Risk Guideline to determine their acceptability; and

(f) **Identification of Mitigation Measures**: Where necessary, risk mitigation measures were identified and assessed to comply with the “as low as reasonably practicable” (ALARP) principle used in the HKRG. Practicable and cost-effective risk mitigation measures were identified and assessed as necessary. The risk outcomes of the mitigated case were reassessed to determine the level of risk reduction.

1.4.1.1 The hazard assessment covered the following assessment years:

- Year 2030* (Construction phase) – The risk imposed by the operation of the existing synthetic natural gas (SNG) production plant to the existing, committed and planned population in 2030.
- Year 2041 (Operational phase) – The risk imposed by the operation of the existing synthetic natural gas (SNG) production plant to the existing, committed and planned population in 2041. This scenario took into account the full population intake of the proposed development with all the planned land users being considered.

*The Project would be commissioned in phases with the construction work scheduled for commencement in Year 2025 and completion by Year 2041 for full population intake. Based on the latest phasing plan, the earliest population intake of the proposed development in the vicinity of the SNG production plant is 2030 for PU1 site. Therefore, Year 2030 was selected as the assessment year of construction phase of the Project for risk assessment associated with the existing SNG Production Plant.

2. SITE DESCRIPTION

2.1 Study Area

2.1.1.1 The existing SNG production plant is located at the north-eastern boundary of the TKO 137 separated by the Wan Po Road. Study area of 200 m radius from the SNG production plant was adopted as shown in **Plate 2.1**.

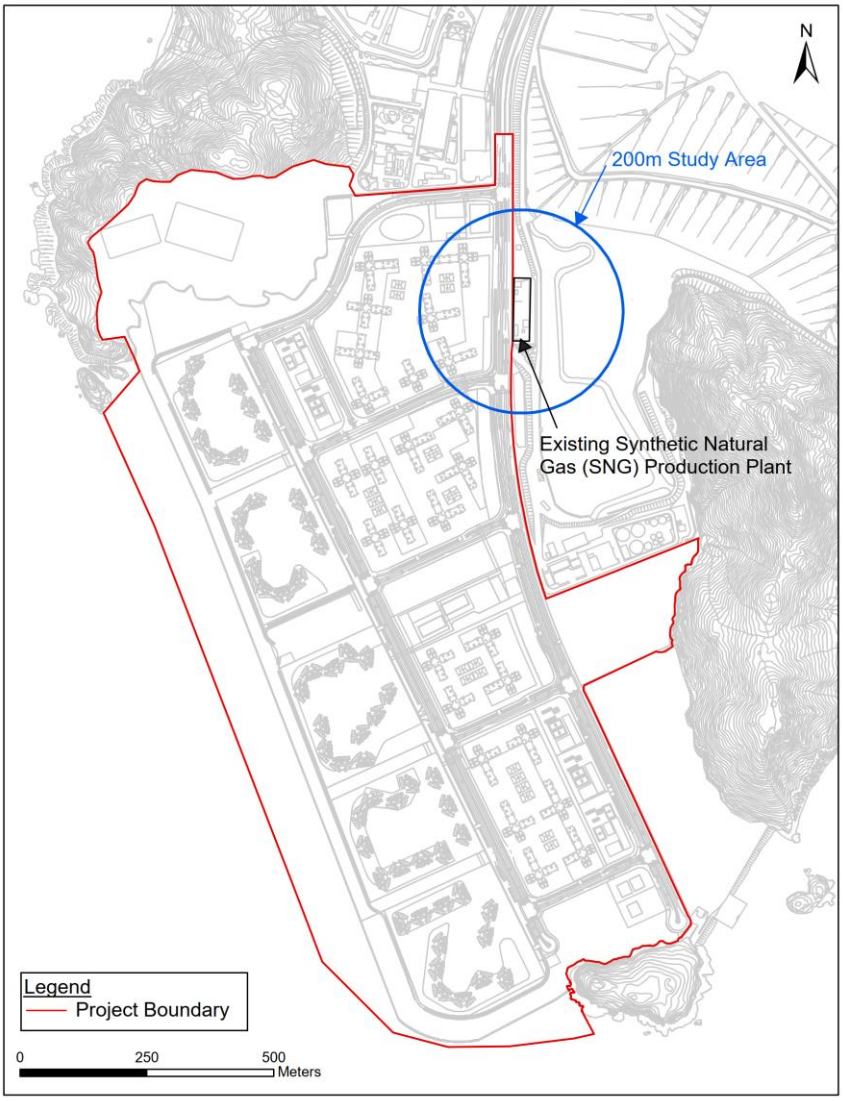

Plate 2.1 Site Location Plan

2.2 The SNG Production Plant

2.2.1.1 The SNG production plant is owned and operated by the P-Tech Landfill Gas (SENT) Company Limited, a wholly owned subsidiary of the Hong Kong and China Gas Company Limited (HKCG) and it is intended to convert LFG generated from South East New Territories (SENT) landfill to SNG before it is transported to Tseng Lan Shue Station via a 12 km underground pipeline and integrated into the Towngas supply grid for customer use.

2.2.1.2 The SNG production plant comprises of the following main facilities:

- Landfill Gas Compression
- Landfill Gas After-cooling
- Hydrogen Sulphide (H_2S) Removal
- Landfill Gas Purification by Cryogenic Separation
- Carbon Dioxide (CO_2) Removal by Pressure Swing Adsorption (PSA)
- Nitrogen (N_2) Injection
- Gas Odorising

2.2.1.3 The plant is designed to a maximum landfill gas intake of 8,000 Nm^3/hr. Upon extraction from the landfill, LFG at 0.2 barg is first compressed by 3 screw type compressors (3×35%). The compressed LFG gas at 5.9 barg and 110°C is then cooled to about 40°C by heat exchange with cooling water via 3 shell & tube type heat exchangers (3×35%) and the condensed liquid and vapour is knocked out by 3 separators (3×35%). The condensate is discharged to an existing treatment facility for further treatment, while the vapour is routed to the hydrogen sulphide removal process to reduce the H_2S content from 250 ppm to ≤1 ppm. The system consists of 2 vessels filled with absorbents and operating in lead-lag configuration. The pressure is slightly reduced from 5.8 barg to 5.5 barg. The LFG then undergoes the cryogenic separation system to remove the remaining moisture and other contaminants. The LFG is first cooled down to 21°C in the built-in pre-cooler and further cooled to 3 – 5°C in the 1st stage heat exchanger by glycol water. The pre-chilled gas is further chilled at 2nd stage heat exchangers (2×50%) to a pressure dew point temperature of -25°C by glycol water and sent back to the pre-cooler as cooling medium, where it is reheated to 25 – 35°C for further downstream processing.

2.2.1.4 To control the specific gravity of the gas, a portion of the CO_2 rich LFG is sent to the CO_2 removal vessels (5×20%) for CO_2 removal via pressure swing adsorption process and the CO_2 lean LFG is blend with the remaining LFG. To match the calorific value and Wobbe Index of town gas, the treated LFG is blended with 95% nitrogen in the CV Control Buffer Tank (1×100%). The treated LFG is subsequently odorised with THT (tetra-hydrothiophene) and the resulting product gas (i.e. synthetic natural gas), is then sent to the town gas off-take station in Tseng Lan Shue via a 12-km underground pipeline, where it is mixed with town gas by the ejector system.

2.2.1.5 The gas odorising unit is equipped with 2 dosing pumps (2×100%) and a THT buffer tank that is designed to hold TGT sufficient for 1 month consumption at 100% plant capacity. THT injection is performed at a dosing rate of 16-24 mg/Nm^3 of process gas.

2.3 Population

2.3.1 Surrounding Populations

2.3.1.1 Societal risk is a measure of the consequence magnitude and the frequency of the hazardous events. To establish the impact of any release (expressed as the number of people likely to be affected) in the future, it is necessary to have a good knowledge of the future surrounding population levels. These include residential population, government, institutional or community population and transport population but exclude staff of the SNG production plant since they are considered as voluntary risk takers.

2.3.1.2 The locations of population groups and roads considered for both assessment years are presented in **Plate 2.2**. Details on the estimated population for each population group are provided in **Annex A**.

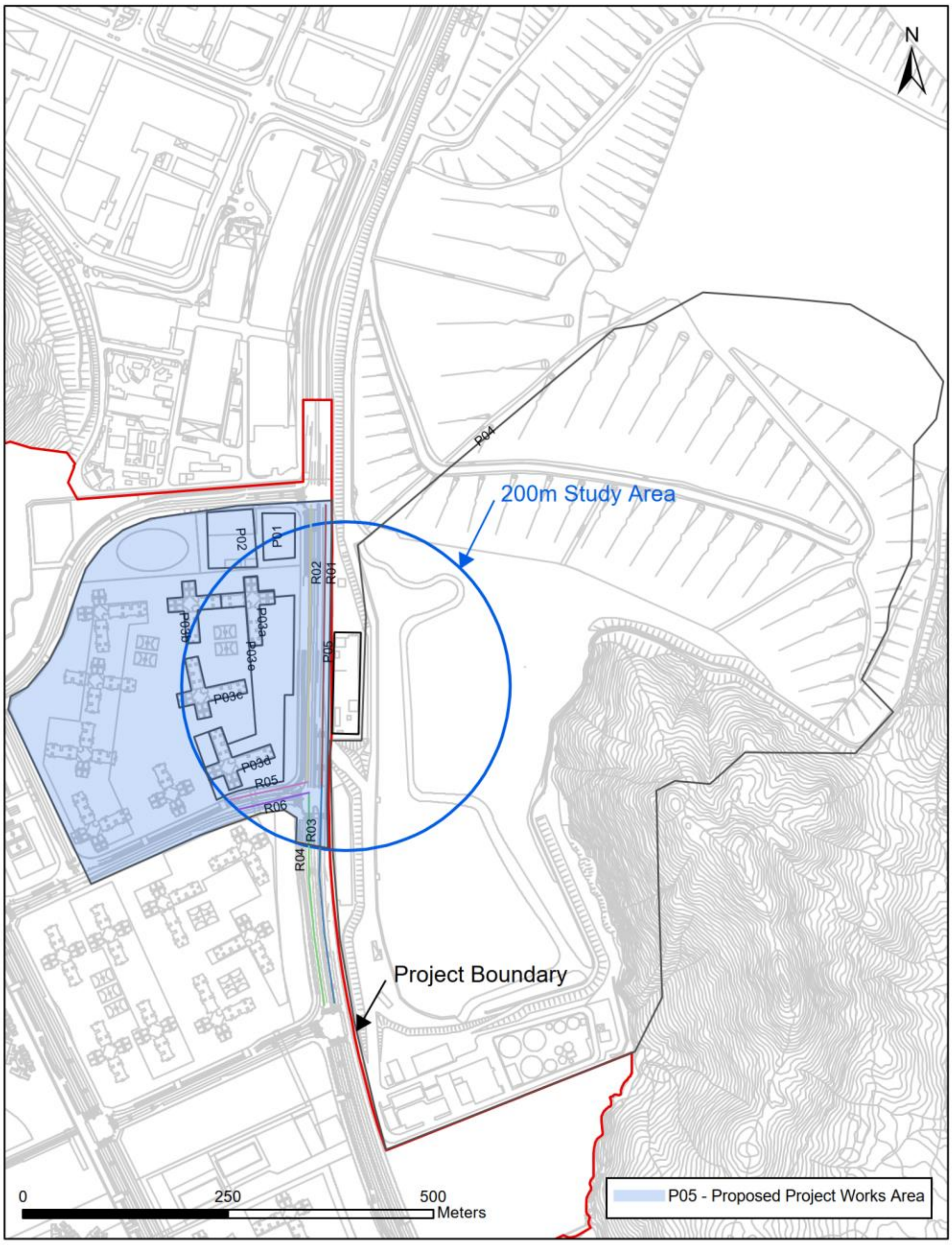

Plate 2.2 Locations of Population Groups and Road

Land and Building Population

2.3.1.3 Estimation of land and building populations was based on the latest information provided in the development schedule of the Draft RODP, while the worker estimate at SENT landfill extension (SENTX) was advised by EPD. An average of 5% population was considered to be outdoor for residential, government/ institution or community population, while 100% population was assumed to be outdoor for workers at SENTX.

Table 2.1 Land and Building Population Data

ID	Description	Population	
		Year 2030	Year 2041
P01	Divisional Police Station	-	515
P02	Sub-divisional Fire Station cum Ambulance Depot	-	190
P03	Public Housing (PU1)		
P03a	Block 1	-	3744
P03b	Block 2	-	3744
P03c	Block 3	-	3744
P03d	Block 4	-	3744
P03e	Podium 1	-	2208
P04	SENT Landfill Extension	25	25
P05	Proposed Project Works Area	150	-

Road Population

2.3.1.4 The traffic data was based on the latest Annual Traffic Census (ATC) published by Transport Department (TD) [1] and the Traffic Impact Assessment (TIA) report prepared for this Assignment. The traffic population was predicted based on the following equation:

$$Traffic\ Population = \frac{No.of\ Person\ per\ vehicle \times No.of\ Vehicle\ per\ hour \times Road\ Length}{Speed}$$

2.3.1.5 Based on the latest ATC [1], the occupancies for each vehicle type and vehicle mix were taken at the core station no. 5021 (Tseung Kwan O Tunnel (from Toll Plaza to Tseung Kwan O Tunnel Rd RA)) to represent the road traffic for this assessment.

2.3.1.6 The traffic population was assumed to be 100% outdoor. The estimated road population considered for both assessment years are presented in **Table 2.2** and the detailed calculations are provided in **Annex A**.

Table 2.2 Estimated Road Population

ID	Description	Traffic Speed (km/hr)	Maximum Population			
			Year 2030		Year 2041	
			Daytime	Night-time	Daytime	Night-time
R01	Road L8	50	-	-	33	21
R02		50	-	-	37	21
R03		50	-	-	13	11
R04		50	-	-	16	11
R05	Road L4	50	-	-	7	7
R06		50	-	-	7	7

2.3.2 Time Modes

2.3.2.1 Four representative time modes as presented in **Table 2.3** were applied in this hazard assessment to address the variation in levels of activities that could lead to a release and the variation in population in the assessment area with time.

Table 2.3 Definitions of Time Modes

Time Period	Definition	Proportion of Time
Weekday Day	Mon-Fri, 7am-7pm	35.71%
Weekday Night	Mon-Fri, 7pm-7am	35.71%
Weekend Day	Sat-Sun, 7am-7pm	14.29%
Weekend Night	Sat-Sun, 7pm-7am	14.29%

2.4 Meteorology

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

2.4.1.2 Meteorological data was obtained from Tseung Kwan O Weather Station where wind speed, stability class, weather class and wind direction are available. This data represented the weather conditions over a five-year period (i.e. between 2019 – 2023). Six combinations (2B, 1D, 3D, 6D, 2E and 1F) and five combinations (1D, 3D, 5D, 2E and 1F) of wind speed and stability class were chosen for daytime and night-time meteorological conditions respectively. These combinations were considered adequate to reflect the full range of observed variations in these quantities. It is not necessary and efficient to consider every combination observed. The principle is to group these combinations into representative weather classes that together cover all conditions observed.

2.4.1.3 Once the weather classes have been selected, frequencies for each wind direction for each weather class can then be determined. The frequency distributions for the daytime and night-time meteorological conditions are summarised in **Table 2.4**.

Table 2.4 Weather Class-Wind Direction Frequencies at Tseung Kwan O Weather Station

Daytime							
Direction	**2B**	**1D**	**3D**	**6D**	**2E**	**1F**	**Total (%)**
0 – 30	3.60	1.05	1.95	0.06	1.33	1.91	9.9
30 – 60	7.54	1.05	4.74	0.02	2.10	1.40	16.8
60 – 90	12.84	1.10	5.25	0.07	1.79	1.15	22.2
90 – 120	7.91	1.05	2.13	0.02	0.53	0.77	12.4
120 – 150	3.22	0.55	1.10	0.04	0.40	0.53	5.8
150 – 180	1.71	0.36	0.53	0.01	0.26	0.33	3.2
180 – 210	8.70	0.68	1.45	-	0.18	0.41	11.4
210 – 240	6.97	0.71	2.17	-	0.51	0.59	10.9
240 – 270	1.03	0.39	0.48	-	0.21	0.41	2.5
270 – 300	0.42	0.17	0.09	-	0.03	0.20	0.9
300 – 330	0.24	0.16	0.08	-	0.02	0.42	0.9
330 – 360	0.85	0.35	0.44	-	0.31	0.94	2.9
All (%)	55.0	7.6	20.4	0.2	7.7	9.1	100.0

Night-time						
Direction	**1D**	**3D**	**5D**	**2E**	**1F**	**Total (%)**
0 – 30	0.37	1.02	0.02	5.34	10.7	17.4
30 – 60	0.22	1.98	0.07	9.04	6.9	18.2
60 – 90	0.30	1.64	0.03	5.71	4.3	12.0
90 – 120	0.26	0.55	0.01	2.72	3.0	6.5
120 – 150	0.05	0.47	0.03	2.49	2.9	6.0
150 – 180	0.03	0.23	0.02	1.51	1.7	3.5
180 – 210	0.02	0.15	-	1.24	1.9	3.3
210 – 240	0.04	0.29	-	4.00	4.6	9.0
240 – 270	0.04	0.03	-	3.42	4.7	8.2
270 – 300	0.08	0.02	-	0.28	2.1	2.5
300 – 330	0.11	0.02	-	0.16	4.8	5.1
330 – 360	0.26	0.15	-	1.07	6.8	8.3
All (%)	1.8	6.5	0.2	37.0	54.5	100.0

3. HAZARD IDENIFICATION AND ANALYSIS

3.1 Introduction

3.1.1.1 A hazard is described as the property of a material or activity with the potential to do harm. Potential hazards associated with generation, transfer, storage and use of LFG/ SNG in the existing SNG production plant were identified. The operation information and parameters were assumed based on information provided by The Hong Kong and China Gas Company Limited (HKCG). The initiating events resulting in a release of LFG/ SNG could occur due to various reasons, including spontaneous failure and leakage of equipment/ pipework. The main hazard is due to loss of containment leading to a gas leak, fire and explosion.

3.2 Behaviour of Landfill Gas and Synthetic Natural Gas Releases

3.2.1.1 Raw landfill gas is produced due to decomposition of organic materials from infiltration of water into a landfill. The primary constituents of LFG are methane and carbon dioxide, followed by nitrogen, oxygen and traces of hydrogen sulphide. Its density would depend on the ratio of methane to carbon dioxide but the typical LFG is likely to have a density close to or equal to that of air. Since LFG is both colourless and odourless, a special odour has been added to SNG such that it can easily be detected. LFG and SNG are considered flammable due to high methane content. The composition and physical properties of LFG and SNG as supplied by HKCG are summarised in **Table 3.1**.

Table 3.1 Compositions and Properties of Landfill Gas and Synthetic Natural Gas

Parameter		LFG	SNG
Composition	CO_2	≤ 45%	20 - 30%
	CH_4	> 45%	45%
	N_2	≤ 15%	20 - 32%
	O_2	≤ 2%	2%
	H_2S	≤ 250 ppmv	< 1 ppmv
	H_2O	60°C saturated	Dew point < 10°C
Physical Properties	Calorific Value (MJ/Sm^3)	-	17.13 - 17.41
	Wobbe Index (MJ/Sm^3)	-	17.7 - 18.3
	Specific Gravity	-	< 0.95

3.2.1.2 Release in large quantity, if ignited immediately, will produce a fireball. However, the gas inventories and pressures in this facility are expected to be too small for a significant fireball event. In view of the fireball events will be comparable to jet fires, the consequence distances of jet fire will be adopted for scenarios where short duration fireballs may occur.

3.2.1.3 If not ignited immediately, the gas will disperse and dilute. If ignition occurs when the gas concentration is between the Lower Flammability Limit (LFL) and the Upper Flammability Limit (UFL), a flame front will propagate to produce a flash fire. In case of a continuous release, fire is flashed back to the release source and leads to a jet fire.

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

3.2.1.5 H_2S of no more than 250ppm are present in the LFG feed stream and upon an accidental release may pose as a potential toxic hazard to personnel. The IDLH (immediately dangerous to life or health) concentration of H_2S is 100 ppm. Based on the dispersion results, the 100 ppm H_2S contour extends no more than 5 m from the leak source. Referring to the Purple Book probit equation and assuming a 30 minute exposure time, the H_2S concentration corresponds to 1% fatality is 196 ppm. At such concentration, the dispersion extends less than 0.5m and remain close to the leak source, Thus, it is concluded that the toxic risks due to H_2S are not significant and these are not considered further in the study.

3.2.1.6 The pressure of most streams in the facility is generally low (i.e. about 2.4 barg) and the consequences of such releases are expected to be limited. Whilst most streams contain a significant amount of inerts, all streams are modelled as pure methane as a conservative approach.

3.3 Other Dangerous Goods

3.3.1.1 Diesel is provided on-site to drive the emergency generator in the event of power outage. Given diesel is only used for emergency situation and its onsite storage capacity is expected to be limited, off-site impact due to accidental spillage of diesel is considered insignificant. Similarly, the THT stored on-site is expected to be limited, thus off-site impact is not envisaged.

3.3.1.2 Furthermore, other dangerous goods including compressed gas (UN1954), compressed gas (UN1956), compressed helium (UN1046), compressed hydrogen (UN1049), compressed methane (UN1971) and compressed nitrogen (UN1066) are stored on-site. However, none of the DG stores exceed the exempted quantity in accordance with the Dangerous Goods Ordinance (Cap. 295). Thus, significant off-site risk due to DG release is not envisaged.

3.4 Hazard Identification

3.4.1 Spontaneous Failures

3.4.1.1 A spontaneous failure involves the rupture or leak of equipment, without the influence of external events. Such failures may arise due to:

- External corrosion;
- Defect arising during design, manufacturing, construction/installation, commissioning or maintenance;
- Stress cracks and fatigue; or
- Support failure.

3.4.1.2 Spontaneous failures of the following equipment are considered in this study:

- Compressors;
- Heat Exchangers;
- Knock-out Drums, H_2S Removal Vessels, CO_2 Removal Vessels, CV Control Buffer Tank; and
- Pipework.

3.4.1.3 The following failure cases are assessed in this study:

- Catastrophic Failure: this represents a failure that results in the instantaneous, or almost instantaneous, release of most or all of the vessel/equipment contents to the atmosphere; and

- Partial Failure: this represents a split in the vessel/equipment shell that results in a continuous release to the atmosphere.

3.4.2 External Events

3.4.2.1 A LFG/ SNG release event could occur due to external events and the consequences could be catastrophic. The related external events are listed as follows:

(a) Earthquake

(b) Aircraft crash

(c) Landslide

(d) Severe environmental event such as typhoon or tsunami

(e) Subsidence

(f) Lightning

(g) Third Party Damage

(h) Vehicle Impact

(i) External Fire

Earthquake

3.4.2.2 An earthquake has the potential to cause damage to the process equipment and pipework. The damage could occur due to ground movement or vibration leading to spontaneous failure of pipelines. Hong Kong is located in a region of low seismicity where an earthquake is an unlikely event. The generic failure frequencies adopted in this assessment are based on historical incidents that include earthquakes in their cause of failure. Since Hong Kong is not at disproportionate risk from earthquakes compared to other similar facilities worldwide, it is deemed appropriate to use these generic frequencies without adjustment. As such, earthquake was not considered separately in this assessment.

Aircraft Crash

3.4.2.3 Aircrafts crashing into the SNG production plant during take-off and landing as well as airway accidents along the arrival / departure flight paths were taken into account in this assessment. The method given in HSE (1997) [2] for the calculation of aircraft crash frequency was adopted.

3.4.2.4 The distance between the nearest arrival / departure flight path for the Hong Kong International Airport (HKIA) and SNG production plant is approximately 0.4km. The distance between the SNG production plant and HKIA is about 36.9km, which exceeds the criteria of 5 miles (8km) for the consideration of airfield accident. At such distances, the SNG production plant would not come into the flight paths of the critical take-off and landing phases, and therefore only the background crash rate and airway crash rate were accounted for. The frequency of aircraft crash was estimated using the methodology of the HSE (1997) [2]. The model took into account specific factors such as the target area of the SNG production plant and the distance between the SNG production plant and the runway threshold. The aircraft crash frequency per year was calculated as:

Frequency (per year) = Background Crash Rate + Airway Crash Rate

$$\text{Frequency (per year)} = (A \times B_i) + (A \times N_i \times R_i \times afac/\ alt)$$

Where,

A = Area of the SNG production plant (3.58×10^{-3} km^2)

N = Number of aircraft movements per year

B_i = Background crash rate for aircraft (2×10^{-6} per year per km^2 [3])

R_i = Aircraft in-flight reliability (4.7×10^{-11} per year per km per aircraft movement [3])

afac = Area factor obtained from Table 9 of UK HSE report [3]

Alt = Mean altitude of aircraft (5 km)

3.4.2.5 The area factor (afac) is defined as the probability of a crash at a given location relative to the airway. With reference to Table 9 of UK HSE report [3], afac of 0.395 was adopted based on the corresponding x1 of 0.08, as estimated from the below equation:

x1 = x/ alt

Where,

x = Minimum horizontal distance from the nearest flight path to the SNG production plant (0.5km)

Alt = Mean altitude of aircraft (5 km)

3.4.2.6 According to the statistic of Civil International Air Transport Movements of Aircraft [3], 427,766 movements were recorded in 2018, which is the maximum number of movements recorded since 2009. The number of movements in 2030 and 2041 were estimated through linear regression by projecting the yearly statistics of the Hong Kong International Airport in 2009-2018. Based on the growth rate of 4.85% resulting in 754,821 movements in 2030 and 1,270,365 movements in 2041, the corresponding aircraft crash frequencies of 1.7×10^{-8} per year and 2.4×10^{-8} per year were estimated.

Landslide

3.4.2.7 The SNG production plant is bounded by open spaces, roads and buildings with no slope located in its vicinity. Therefore, the probability of landslide is negligible and this external event was not further considered in this assessment.

Severe Environmental Event

3.4.3 Loss of containment owing to severe environmental events such as typhoon or tsunami (i.e. a tidal wave following an earthquake) was considered to be insignificant as the SNG production plant is situated away from the seashore. Therefore, the probabilities of failure due to severe environmental events are very small or negligible and these were not further considered in this assessment.

Subsidence

3.4.3.1 Subsidence is usually slow in movement and such movement can be observed and remedial action can be taken in time. Therefore, the probabilities of subsidence are very small or negligible and these were not further considered in this assessment.

Lightning

3.4.3.2 The installation is expected to be protected with lightning conductors to safely earth direct lightning strikes. Besides, the proposed development would also provide shielding effect to prevent the SNG production plant being struck by lightning. With sufficient protection system, no further consideration was given for the effect of lightning strike in this assessment.

Third Party Damage

3.4.3.3 Third party damage includes activities causing incidents such as work on other underground utilities, drilling for ground sampling, construction work on adjoining areas, etc. The SNG production plant is surrounded by 3m high fence wall to avoid illegal entrance of third party. Thus, third party damage was not further considered in this assessment.

Vehicle Impact

3.4.3.4 The SNG production plant is fenced and the probability of a vehicle accidentally crashes into the SNG production plant was considered negligible.

External Fire

3.4.3.5 The slope covered by vegetation is located remotely from the SNG production plant and branches of trees or shrubs are not expected to reach the SNG production plant. Since the SNG facilities are surrounded by 3m high fence wall and provision of fire protection system is available, external fire impact is considered negligible and not further considered in this Study.

3.4.4 Summary

3.4.4.1 The possible hazard events for the day-to-day operations of the SNG production plant have been identified and reviewed in previous sections. Only those possible failure cases considered to have the potential to cause off-site fatality are summarised in **Table 3.2**.

Table 3.2 Identified Failure Cases for the SNG Production Plant

Failure Types	Failure Cases
Spontaneous Failure of Pressurised LFG/ SNG Equipment	• Vessel Failure • Heat Exchanger Failure • Compressor Failure • LFG/ SNG Pipework Failure
External Event	• Earthquake MMI VIII • Aircraft Crash

4. FREQUENCY ANALYSIS

4.1 General

4.1.1.1 Subsequent to the hazard identification and analysis in the previous section, the next step is to estimate the likelihoods of various release scenarios. There are combinations of hazard initiating events, as identified in the previous section, which would lead to a LFG or SNG release.

4.2 Generic Failure Frequencies

4.2.1.1 A summary of the identified failure cases and their associated failure rates adopted in this assessment are presented in **Table 4.1**.

Table 4.1 Summary of Identified Failure Cases and Their Associated Failure Rates

Failure Cases	Failure Rates	Notes
Spontaneous Failure		
Pipework (including flanges and valves)		
Catastrophic Failure	1.6×10^{-5} per pipe-section year	Based on pipe leak frequencies reported by Pape & Nussey [4]. Failure data for flanges and valves were taken from Pape & Nussey and nuclear industry experience [5] respectively, with 5% of such failures assumed to be catastrophic ruptures. The failure rates for the study were estimated based on a pipe section length of 10m and an average of 1.75 flanges and 0.25 valves per pipe section.
Guillotine Failure (25mm)	2.8×10^{-4} per pipe-section year	
Vessels		
Catastrophic Failure	3.0×10^{-6} per vessel year	Based on a survey of pressure vessel failures in process plants reported by Arulanantham and Lees [6].
Partial Failure (25mm)	7.5×10^{-6} per vessel year	
Compressors		
Catastrophic Failure	1.6×10^{-5} per compressor year	From NPRDS data [7] for partial failures, a 'rupture' is considered to be a full bore rupture of the suction piping.
Partial Failure (25mm)	1.8×10^{-3} per compressor year	
Heat Exchangers (Shell & Tube)		
Catastrophic Failure	3.0×10^{-6} per vessel year	Same as vessels
Partial Failure (25mm)	7.5×10^{-6} per vessel year	
External Event		
Aircraft Crash	Year 2030: 1.7×10^{-8} per year Year 2041: 2.4×10^{-8} per year	Refer to **Section 3.4.2.6**

Frequency of Events and Event Outcomes

4.2.1.2 The event frequencies of different hazardous scenarios were derived based on generic failure frequencies presented in **Table 4.1**, estimated length of pipelines and number of equipment. List of all identified failure cases together with their failure frequency are summarized in **Table 4.2**.

Table 4.2 Estimated Events of Significant LFG/ SNG Releases

ID	Description	Equipment Count				Hole Size (2)	Failure Frequency (per year)	
		Pipework Sections (1)	Vessels	Compressors	Heat Exchangers		Spontaneous	Total (3)
S1	LFG Feed Line	4	-	-	-	25mm	1.06E-03	1.06E-03
						CAT	6.08E-05	6.08E-05
S2	LFG Pre-treatment	5	3	3	3	25mm	6.87E-03	6.87E-03
						CAT	1.48E-04	1.48E-04
S3	H_2S Removal	3	2	-	-	25mm	8.27E-04	8.27E-04
						CAT	5.24E-05	5.24E-05
S4	Cryogenic Purification	10	-	-	4	25mm	2.75E-03	2.75E-03
						CAT	1.67E-04	1.67E-04
S5	CO_2 Removal	7	5	-	-	25mm	1.89E-03	1.89E-03
						CAT	1.21E-04	1.21E-04
S6	Gas Odorisation	3	1	-	-	25mm	9.04E-04	9.04E-04
						CAT	5.42E-05	5.42E-05
S7	SNG Export Line	6	-	-	-	25mm	1.62E-03	1.62E-03
						CAT	9.28E-05	9.28E-05

Notes:
(1) Pipework sections measured in 10-metre units, with the consideration of flange and valve failures.
(2) CAT refers catastrophic release.
(3) The total failure frequency is taken as the sum of spontaneous failure frequency and aircraft crash frequency of 1.7×10^{-8} per year (Year 2030) and 2.4×10^{-8} per year (Year 2041).

4.2.1.3 The failure frequencies of the hazardous outcomes considered in this assessment are summarised in **Table 4.3** based on the results of event tree and frequency analysis. The event tree analysis for hazardous events are provided in **Annex B**.

Table 4.3 Estimated Occurrence Frequencies of Significant LFG/ SNG Releases

ID	Description	Hole Size (1)	Total Failure Frequency (per year)	Outcome Frequencies (per year)		
				Jet Fire	Flash Fire	VCE
S1	LFG Feed Line	25mm	1.06E-03	5.32E-06	5.11E-06	2.13E-07
		CAT	6.08E-05	2.13E-06	1.87E-06	2.55E-07
S2	LFG Pre-treatment	25mm	6.87E-03	3.44E-05	3.30E-05	1.37E-06
		CAT	1.48E-04	5.17E-06	4.55E-06	6.20E-07
S3	H_2S Removal	25mm	8.27E-04	4.14E-06	3.97E-06	1.65E-07
		CAT	5.24E-05	1.83E-06	1.61E-06	2.20E-07
S4	Cryogenic Purification	25mm	2.75E-03	1.37E-05	1.32E-05	5.49E-07
		CAT	1.67E-04	5.85E-06	5.15E-06	7.02E-07
S5	CO_2 Removal	25mm	1.89E-03	9.43E-06	9.05E-06	3.77E-07
		CAT	1.21E-04	4.22E-06	3.71E-06	5.07E-07
S6	Gas Odorisation	25mm	9.04E-04	4.52E-06	4.34E-06	1.81E-07
		CAT	5.42E-05	1.90E-06	1.67E-06	2.28E-07
S7	SNG Export Line	25mm	1.62E-03	8.12E-06	7.80E-06	3.25E-07
		CAT	9.28E-05	3.25E-06	2.86E-06	3.90E-07

Note:
(1) CAT refers catastrophic release.

5. CONSEQUENCE AND IMPACT ANALYSIS

5.1 Introduction

5.1.1.1 Consequence and impact analysis were conducted to provide a quantitative estimate of the likelihood and number of deaths associated with the range of possible outcomes (i.e. jet fire, flash fire etc.) which would result from the failure cases identified in the previous sections. The consequence assessment consists of two major parts, including:

- Source term modelling – to determine the appropriate discharge models to be used for calculation of the release rate, duration and quantity of the release; and
- Effect modelling – to determine dispersion modelling, fire modelling and explosion modelling from the input of source term modelling.

5.1.1.2 Releases from hazardous sources and their consequences were modelled using SAFETI 8.7.

5.2 Source Term

5.2.1.1 Catastrophic failure is modelled by guillotine failure of the largest bore pipework within a section. For continuous release, release parameters such as release rate and exit velocity are calculated by a discharge model according to the equipment conditions. Release duration is based on the time to empty the equipment content within a section. Release parameters together with release duration are then fed into the dispersion model to calculate the effect.

5.3 Potential Hazardous Outcomes and Effect Modelling

5.3.1.1 This section gives a brief description of the physical effects models that were used to assess the effects zones for the following hazardous outcomes:

(a) Jet fire;

(b) Flammable gas dispersion and flash fire; and

(c) Vapour Cloud Explosion (VCE).

5.3.1.2 The event trees evaluated the hazard event outcomes following a gas release and these are presented in **Annex B**.

5.3.2 Jet Fire

5.3.2.1 A jet fire occurs following the ignition and combustion of a pressurised flammable gas, which burns close to the release source. The jet fire which follows the fire ball was assumed to be directed vertically upwards out of the crater. The jet fire shape is the frustum of a cone, while the location and orientation of the frustum are dependent on a number of factors such as release rate and wind speed.

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

5.3.3 Gas Dispersion and Flash Fire

5.3.3.1 Release of LFG/ SNG tends to rise rapidly due to the buoyancy nature of the gas under atmospheric conditions. It will propagate and be diluted as a result of air entrainment with the influence of wind. The Unified Dispersion Model (UDM) model is used for the dispersion calculation of LFG/ SNG for non-immediate ignition scenarios. The model takes into account various transition phases, from dense cloud dispersion to buoyant passive gas dispersion, in both instantaneous and continuous releases.

5.3.3.2 The principal hazard arising from a cloud of dispersing LFG/ SNG is the delayed ignition of the flammable cloud that cause a flame to flash back to the release location and develop into a stable jet or crater fire. Large scale experiments on the dispersion and ignition of flammable gas clouds show that ignition is unlikely when the average concentration is below the Lower Flammable Limit (LFL) or above the Upper Flammable Limit (UFL).

5.3.3.3 Major hazards from flash fire are thermal radiation and direct flame contact. It is considered that there is no scope for escape within the LFL of a flammable cloud in a flash fire. Therefore, a fatality probability of 100% of persons present within the flammable cloud is assumed for flash fires.

Vapour Cloud Explosion

5.3.3.4 A vapour cloud explosion can occur when a flammable vapour is ignited in a confined or partially confined situation. When there is a large amount of pressurised gas rapidly releasing to the atmosphere from a pressurised tank, a vapour cloud could be formed, dispersed and mixed with the surrounding air. If the vapour cloud is passing through a confined / semi-confined environment and gets ignited, the confinement could limit the degree of expansion of the burning cloud and create an overpressure and explosion.

5.3.3.5 The risk model will be accounted for the VCE hazard according to probabilities for delayed ignition in consequence modelling. The program models the delayed ignition effect by considering the flammable cloud area and location of ignition sources at each time step. Potential damage from a VCE is caused by overpressure.

5.4 Impact Assessment

5.4.1 Thermal Radiation

5.4.1.1 Fatality rates due to exposure to thermal radiation from a fire were determined by the following probit function which is set as the default in the SAFETI:

$$Pr = -36.38 + 2.56\ ln\left(I^{\frac{4}{3}} \times t\right)$$

where I = thermal radiation intensity at the target (W/m^2); and

t = duration of exposure (s).

5.4.1.2 For jet fires, the exposure duration was estimated as 20s, which was assumed as the time taken for people to take evasive action such as seeking refuge etc.

5.4.2 Overpressure

5.4.2.1 The probability of fatality due to overpressure is taken from CIA guidelines [8] as shown in **Table 5.1**. The indoors fatality probability is higher taken into account the increased risk from flying debris such as breaking windows [9].

Table 5.1 End Point Criteria for Vapour Cloud Explosions

Overpressure (psi)	Fatality Probability (Outdoors)	Fatality Probability (Indoors)
5	0.09	0.55
3	0.02	0.15
1	0.00	0.01

5.5 Ignition Sources

5.5.1 General

5.5.1.1 To calculate the risk from flammable materials, information on ignition sources presented in the study area needs to be identified. Such data was included in the risk model for each type of ignition source (i.e. point sources, line sources and area sources). The risk calculation program (MPACT) in SAFETI predicts the probability of a flammable cloud being ignited (delayed ignition) as the cloud moves downwind over ignition sources.

5.5.2 Point Source

5.5.2.1 No major point source was identified in the vicinity of the SNG production plant.

5.5.3 Line Source

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

(a) The probability of ignition for a vehicle was taken to be 0.4 in 60 seconds [10]; and

(b) The traffic density was based on the projected traffic flow adopted for population estimation as detailed in **Annex A**.

5.5.3.2 Ignition line sources are summarized in **Table 5.2**.

Table 5.2 Summary of Road Ignition Sources

ID	Description	Traffic Speed (km/hr)	Traffic Density (veh/hr)			
			Year 2030		Year 2041	
			Daytime	Night-time	Daytime	Night-time
R01	Road L8	50	-	-	1540	843
R02		50	-	-	1666	740
R03		50	-	-	461	243
R04		50	-	-	587	253
R05	Road L4	50	-	-	341	154
R06		50	-	-	519	299

5.5.4 Area Source

5.5.4.1 SAFETI considers a residential population as an ignition source (as a result of activities such as cooking, smoking, heating appliances etc.). The ignition probability was derived from the population densities in the concerned area by SAFETI.

5.6 Ignition and Explosion Probability

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

5.6.1.2 Possible ignition sources include hot surfaces, static electricity, flame and hot particles from external fire etc. [11]. The ignition probabilities are further split between immediate ignition and delayed ignition in equal proportions. Immediate ignition of LFG/ SNG could lead to a jet fire, whereas delayed ignition could cause a flash fire or vapour cloud explosion. **Table 5.3** presents the total ignition probabilities and explosion probabilities according to gas release size [11].

Table 5.3 Ignition and Explosion Probabilities for Gas Releases

Leak Size	Ignition Probability	Explosion Probability
Minor (<< 1kg/s)	0.01	0.04
Major (1-50 kg/s)	0.07	0.12
Massive (>50kg/s)	0.3	0.3

5.7 Protection Factors

5.7.1.1 With reference to previous practice of assessments with SAFETI in Hong Kong, protection factors were considered and applied to the concerned population groups if applicable.

5.7.2 Protection afforded to persons indoors in a building

5.7.2.1 It was generally assumed that the respective outdoor/ indoor population are 5% and 95% at the time of an accident.

5.7.2.2 For flash fire consequence, the fatality rate for indoor persons was assumed to be one tenth of the outdoor fatality rate.

6. RISK EVALUATION

6.1 Introduction

6.1.1.1 In this section, the risks arising from the SNG production plant were evaluated in terms of both individual and societal risks.

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

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

6.2 Individual Risk

6.2.1 Risk Level

6.2.1.1 The predicted individual risk (IR) levels associated with operation of the SNG production plant are shown in **Plate 6.1**. The risk levels were estimated based on 100% occupancy with no allowance made for shelter or escape, as specified in the user manual of SAFETI.

6.2.1.2 The HKRG criterion for individual risk is that no person off-site should be subject to an additional risk of $1×10^{-5}$ per year.

6.2.2 Acceptability

6.2.3 The $1×10^{-5}$ per year contour is confined within the boundary of the SNG production plant. Given that there is no off-site risk with frequency greater than $1×10^{-5}$ per year, the level of individual risk posed by the operation of the facility to the surrounding population is considered acceptable and in compliance with the HKRG.

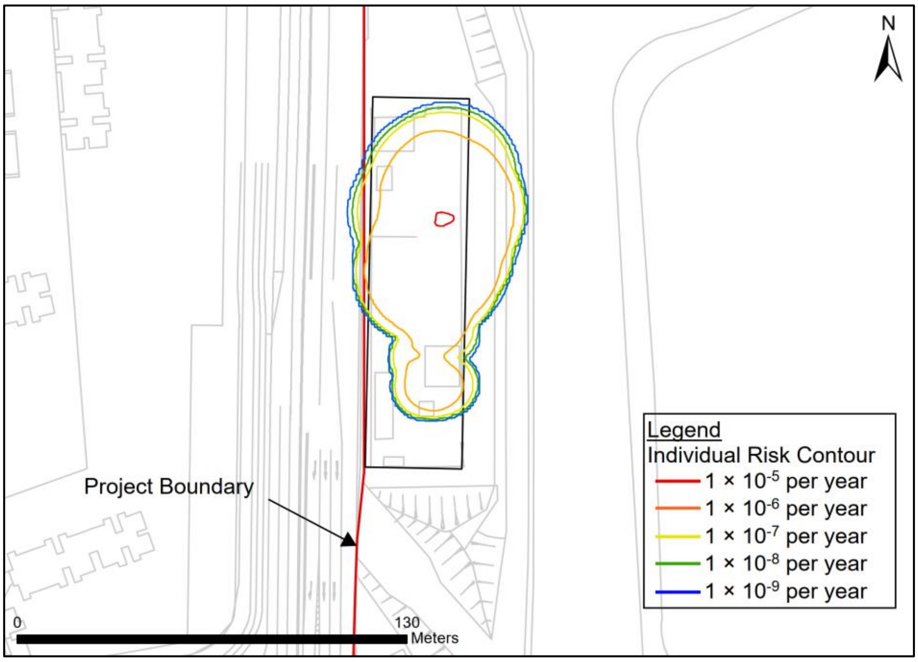

Plate 6.1 Individual Risk Contours for the SNG Production Plant

6.3 Societal Risk

6.3.1 Risk Level

6.3.1.1 The expression of the level of societal risk is more complex than that for individual risk but, in essence, comprises three regions:

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

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

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

6.3.2 Acceptability

6.3.2.1 The societal risks associated with the operation of the SNG production plant fall within the "Acceptable" region in both assessment years as presented in **Plate 6.2**. Furthermore, the potential loss of life (PLL) for the facility were found to be about 2.6×10^{-8} and 2.3×10^{-8} per year for year 2030 and 2041 respectively. The top ten most significant contributing events for the assessed scenarios are tabulated in **Table 6.1**. For both assessment years, jet fire due to catastrophic failure of SNG export line was found to be the major contributor to the overall risk with an estimated PLL contribution of about 2.1×10^{-8} per year and 1.9×10^{-8} per year for 2030 and 2041 respectively (i.e. about 80% and 82% of the total PLL).

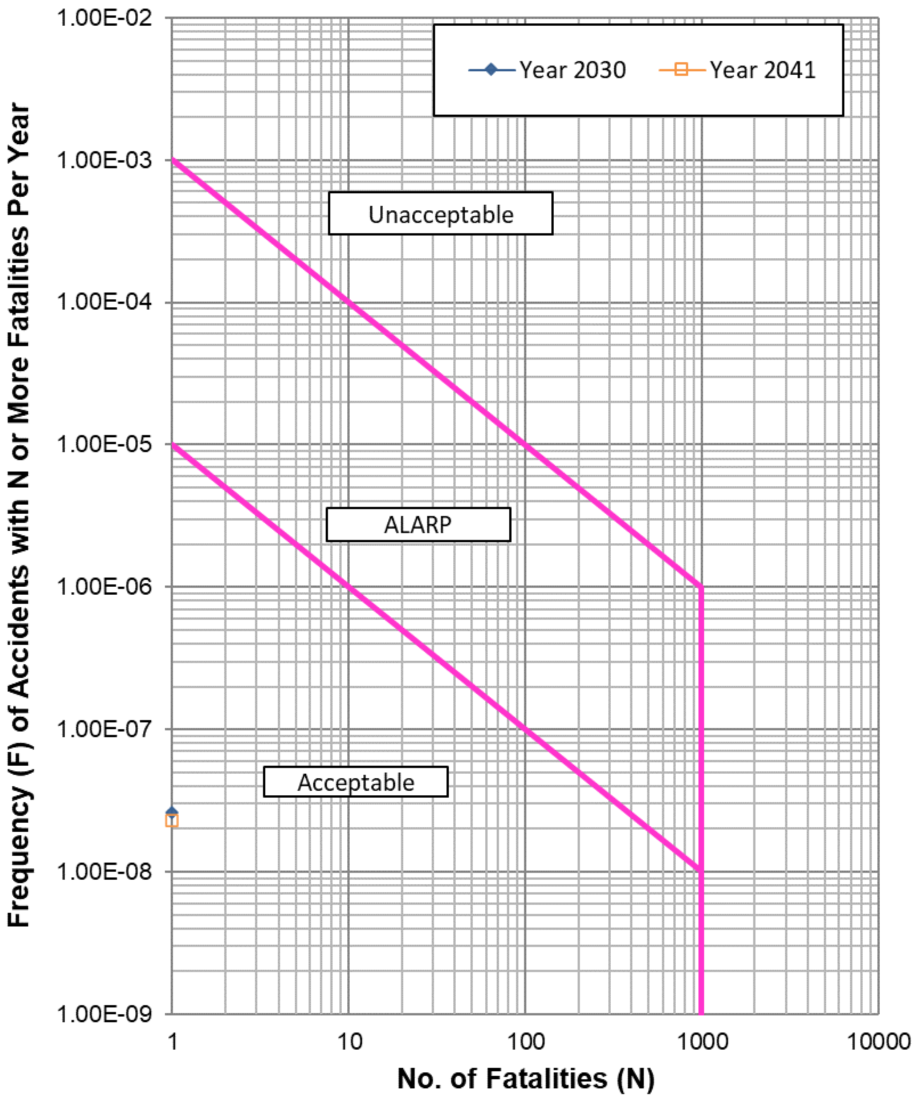

Plate 6.2 Societal Risk Curves

Table 6.1 PLL Breakdown Summary

Year 2030			
Event Description	**Outcome Event**	**PLL (per year)**	**PLL (%)**
Catastrophic failure of SNG Export Line	JF	2.08E-08	79.9%
Catastrophic failure of LFG Feed Line	JF	4.81E-09	18.5%
Catastrophic failure of LFG Pre-treatment	JF	2.39E-10	0.9%
Catastrophic failure of H_2S Removal	JF	1.80E-10	0.7%
Catastrophic failure of Cryogenic Purification	JF	1.90E-12	<0.01%
Catastrophic failure of SNG Export Line	FF	4.81E-13	<0.01%
Catastrophic failure of SNG Export Line	VCE	6.53E-14	<0.01%
Catastrophic failure of H_2S Removal	FF	5.50E-14	<0.01%
Catastrophic failure of CO_2 Removal	JF	3.91E-14	<0.01%
Catastrophic failure of Cryogenic Purification	FF	2.10E-14	<0.01%
Others	-	2.84E-14	<0.01%
	Total	**2.60E-08**	**100%**

Year 2041			
Event Description	**Outcome Event**	**PLL (per year)**	**PLL (%)**
Catastrophic failure of SNG Export Line	JF	1.86E-08	81.5%
Catastrophic failure of LFG Feed Line	JF	3.54E-09	15.5%
Catastrophic failure of LFG Pre-treatment	JF	2.39E-10	1.0%
Catastrophic failure of SNG Export Line	FF	2.31E-10	1.0%
Catastrophic failure of H_2S Removal	JF	1.80E-10	0.8%
Catastrophic failure of SNG Export Line	VCE	3.13E-11	0.1%
Catastrophic failure of H_2S Removal	FF	5.07E-12	0.02%
Catastrophic failure of Cryogenic Purification	JF	1.90E-12	<0.01%
Catastrophic failure of H_2S Removal	VCE	6.91E-13	<0.01%
Catastrophic failure of Cryogenic Purification	FF	5.46E-14	<0.01%
Others	-	6.04E-14	<0.01%
	Total	**2.29E-08**	**100%**

Note: “JF” refers to Jet Fire, “FF” refers to “Flash Fire” and “VCE” refers to Vapour Cloud Explosion.

7. CONCLUSIONS AND RECOMMENDATIONS

7.1.1.1 A hazard assessment was conducted to assess the risks associated with the operation of the existing synthetic natural gas (SNG) production plant in year 2030 and year 2041 (full population intake).

7.1.1.2 Both the individual and societal risk levels were found to meet relevant requirements stipulated in the HKRG, i.e. the off-site individual risk level is far below 1×10^{-5} per year and the societal risk falls into the "Acceptable" region. Therefore, no mitigation measure is required.

8. REFERENCES

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Annex A

Population Data

Annex A - Population Data

Table A1 - Surrounding Population Estimates

ID	Population Group	Land_ID	Land Use Zoning	Maximum Population (Year 2030)	Maximum Population (Year 2041)	Indoor Ratio	% of Occupancy				Population (Year 2030)				Population (Year 2041)			
							Weekday Day	Weekday Night	Weekend Day	Weekend Night	Weekday Day	Weekday Night	Weekend Day	Weekend Night	Weekday Day	Weekday Night	Weekend Day	Weekend Night
P01	Divisional Police Station	G1	G/IC	-	515	0.95	1	1	1	1	-	-	-	-	515	515	515	515
P02	Sub-divisional Fire Station cum Ambulance Depot	G2	G/IC	-	190	0.95	1	1	1	1	-	-	-	-	190	190	190	190
P03	Public Housing (PU1)																	
P03a	Block 1	PU1	RSc	-	3744	0.95	0.5	1	0.7	1	-	-	-	-	1872	3744	2621	3744
P03b	Block 2	PU1	RSc	-	3744	0.95	0.5	1	0.7	1	-	-	-	-	1872	3744	2621	3744
P03c	Block 3	PU1	RSc	-	3744	0.95	0.5	1	0.7	1	-	-	-	-	1872	3744	2621	3744
P03d	Block 4	PU1	RSc	-	3744	0.95	0.5	1	0.7	1	-	-	-	-	1872	3744	2621	3744
P03e	Podium 1	PU1	RSc	-	2208	0.95	1	0.1	1	0.1	-	-	-	-	2208	221	2208	221
P04	SENT Landfill Extension	-	-	25	25	0	1	0.1	0.5	0.1	25	3	13	3	25	3	13	3
P05	Proposed Project Works Area	-	-	150	-	0	1	0.1	0.5	0.1	150	15	75	15	-	-	-	-
R01	Road L8	Road	Road	-	33	0	-	-	-	-	-	-	-	-	33	21	33	21
R02	Road L8	Road	Road	-	37	0	-	-	-	-	-	-	-	-	37	21	37	21
R03	Road L8	Road	Road	-	13	0	-	-	-	-	-	-	-	-	13	11	13	11
R04	Road L8	Road	Road	-	16	0	-	-	-	-	-	-	-	-	16	11	16	11
R05	Road L4	Road	Road	-	7	0	-	-	-	-	-	-	-	-	7	7	7	7
R06	Road L4	Road	Road	-	7	0	-	-	-	-	-	-	-	-	7	7	7	7

Annex A - Population Data

Table A2 - Road Population

Daytime Road Population

	Road Length (km)	Designed Speed (km/h)	Traffic Flow (veh/hr) at Daytime (Year 2041)										
			Motorcycle	Private Car	Taxi	Private Light Bus	Public Light Bus	Light Goods Vehicle	Medium/ Heavy Goods Vehicles	Non-franchised Bus	Franchised Bus (Single Deck)	Franchised Bus (Double Deck)	Total
R01 - Road L8													
Total Vehicle per hour	0.3	50	51	866	268	29	3	169	79	33	1	42	1540
Person per vehicle [1]	-		1.1	1.4	2	1.3	14	1.4	1.2	13.8	0	33.8	-
No. of Person	-		1	9	4	1	1	2	1	4	0	10	33
Person (%)	-		3%	27%	12%	3%	3%	6%	3%	12%	0%	30%	100%

	Road Length (km)	Designed Speed (km/h)	Traffic Flow (veh/hr) at Daytime (Year 2041)										
			Motorcycle	Private Car	Taxi	Private Light Bus	Public Light Bus	Light Goods Vehicle	Medium/ Heavy Goods Vehicles	Non-franchised Bus	Franchised Bus (Single Deck)	Franchised Bus (Double Deck)	Total
R02 - Road L8													
Total Vehicle per hour	0.3	50	56	911	303	33	4	181	85	36	1	56	1666
Person per vehicle [1]	-		1.1	1.4	2	1.3	14	1.4	1.2	13.8	0	33.8	-
No. of Person	-		1	9	5	1	1	2	1	4	0	13	37
Person (%)	-		3%	24%	14%	3%	3%	5%	3%	11%	0%	35%	100%

	Road Length (km)	Designed Speed (km/h)	Traffic Flow (veh/hr) at Daytime (Year 2041)										
			Motorcycle	Private Car	Taxi	Private Light Bus	Public Light Bus	Light Goods Vehicle	Medium/ Heavy Goods Vehicles	Non-franchised Bus	Franchised Bus (Single Deck)	Franchised Bus (Double Deck)	Total
R03 - Road L8													
Total Vehicle per hour	0.3	50	14	239	74	8	1	64	30	9	1	21	461
Person per vehicle [1]	-		1.1	1.4	2	1.3	14	1.4	1.2	13.8	0	33.8	-
No. of Person	-		1	2	1	1	1	1	1	1	0	4	13
Person (%)	-		8%	15%	8%	8%	8%	8%	8%	8%	0%	31%	100%

	Road Length (km)	Designed Speed (km/h)	Traffic Flow (veh/hr) at Daytime (Year 2041)										
			Motorcycle	Private Car	Taxi	Private Light Bus	Public Light Bus	Light Goods Vehicle	Medium/ Heavy Goods Vehicles	Non-franchised Bus	Franchised Bus (Single Deck)	Franchised Bus (Double Deck)	Total
R04 - Road L8													
Total Vehicle per hour	0.3	50	19	307	103	11	2	71	33	12	1	28	587
Person per vehicle [1]	-		1.1	1.4	2	1.3	14	1.4	1.2	13.8	0	33.8	-
No. of Person	-		1	3	2	1	1	1	1	1	0	5	16
Person (%)	-		6%	19%	13%	6%	6%	6%	6%	6%	0%	31%	100%

	Road Length (km)	Designed Speed (km/h)	Traffic Flow (veh/hr) at Daytime (Year 2041)										
			Motorcycle	Private Car	Taxi	Private Light Bus	Public Light Bus	Light Goods Vehicle	Medium/ Heavy Goods Vehicles	Non-franchised Bus	Franchised Bus (Single Deck)	Franchised Bus (Double Deck)	Total
R05 - Road L4													
Total Vehicle per hour	0.1	50	12	200	66	7	0	32	15	8	0	0	341
Person per vehicle [1]	-		1.1	1.4	2	1.3	14	1.4	1.2	13.8	0	33.8	-
No. of Person	-		1	1	1	1	0	1	1	1	0	0	7
Person (%)	-		14%	14%	14%	14%	0%	14%	14%	14%	0%	0%	100%

	Road Length (km)	Designed Speed (km/h)	Traffic Flow (veh/hr) at Daytime (Year 2041)										
			Motorcycle	Private Car	Taxi	Private Light Bus	Public Light Bus	Light Goods Vehicle	Medium/ Heavy Goods Vehicles	Non-franchised Bus	Franchised Bus (Single Deck)	Franchised Bus (Double Deck)	Total
R06 - Road L4													
Total Vehicle per hour	0.1	50	19	323	99	11	0	38	18	12	0	0	519
Person per vehicle [1]	-		1.1	1.4	2	1.3	14	1.4	1.2	13.8	0	33.8	-
No. of Person	-		1	1	1	1	0	1	1	1	0	0	7
Person (%)	-		14%	14%	14%	14%	0%	14%	14%	14%	0%	0%	100%

Note:
[1] Person per vehicle is based on the occupancy in Year 2022 from Station 5021 (Tseung Kwan O Tunnel (from Toll Plaza to Tseung Kwan O Tunnel Rd RA)) from Transport Department - The Annual Traffic Census 2022.

Night-time Road Population

	Road Length (km)	Designed Speed (km/h)	Traffic Flow (veh/hr) at Night-time (Year 2041)										
			Motorcycle	Private Car	Taxi	Private Light Bus	Public Light Bus	Light Goods Vehicle	Medium/ Heavy Goods Vehicles	Non-franchised Bus	Franchised Bus (Single Deck)	Franchised Bus (Double Deck)	Total
R01 - Road L8													
Total Vehicle per hour	0.3	50	25	493	230	4	1	42	11	10	1	26	843
Person per vehicle [1]	-		1.1	1.4	2	1.3	14	1.4	1.2	13.8	0	33.8	-
No. of Person	-		1	5	4	1	1	1	1	1	0	6	21
Person (%)	-		5%	24%	19%	5%	5%	5%	5%	5%	0%	29%	100%

	Road Length (km)	Designed Speed (km/h)	Traffic Flow (veh/hr) at Night-time (Year 2041)										
			Motorcycle	Private Car	Taxi	Private Light Bus	Public Light Bus	Light Goods Vehicle	Medium/ Heavy Goods Vehicles	Non-franchised Bus	Franchised Bus (Single Deck)	Franchised Bus (Double Deck)	Total
R02 - Road L8													
Total Vehicle per hour	0.3	50	27	413	186	12	2	45	13	13	1	29	740
Person per vehicle [1]	-		1.1	1.4	2	1.3	14	1.4	1.2	13.8	0	33.8	-
No. of Person	-		1	4	3	1	1	1	1	2	0	7	21
Person (%)	-		5%	19%	14%	5%	5%	5%	5%	10%	0%	33%	100%

	Road Length (km)	Designed Speed (km/h)	Traffic Flow (veh/hr) at Night-time (Year 2041)										
			Motorcycle	Private Car	Taxi	Private Light Bus	Public Light Bus	Light Goods Vehicle	Medium/ Heavy Goods Vehicles	Non-franchised Bus	Franchised Bus (Single Deck)	Franchised Bus (Double Deck)	Total
R03 - Road L8													
Total Vehicle per hour	0.3	50	7	135	63	1	1	16	4	3	0	13	243
Person per vehicle [1]	-		1.1	1.4	2	1.3	14	1.4	1.2	13.8	0	33.8	-
No. of Person	-		1	1	1	1	1	1	1	1	0	3	11
Person (%)	-		9%	9%	9%	9%	9%	9%	9%	9%	0%	27%	100%

	Road Length (km)	Designed Speed (km/h)	Traffic Flow (veh/hr) at Night-time (Year 2041)										
			Motorcycle	Private Car	Taxi	Private Light Bus	Public Light Bus	Light Goods Vehicle	Medium/ Heavy Goods Vehicles	Non-franchised Bus	Franchised Bus (Single Deck)	Franchised Bus (Double Deck)	Total
R04 - Road L8													
Total Vehicle per hour	0.3	50	9	135	61	4	1	18	5	5	0	15	253
Person per vehicle [1]	-		1.1	1.4	2	1.3	14	1.4	1.2	13.8	0	33.8	-
No. of Person	-		1	1	1	1	1	1	1	1	0	3	11
Person (%)	-		9%	9%	9%	9%	9%	9%	9%	9%	0%	27%	100%

	Road Length (km)	Designed Speed (km/h)	Traffic Flow (veh/hr) at Night-time (Year 2041)										
			Motorcycle	Private Car	Taxi	Private Light Bus	Public Light Bus	Light Goods Vehicle	Medium/ Heavy Goods Vehicles	Non-franchised Bus	Franchised Bus (Single Deck)	Franchised Bus (Double Deck)	Total
R05 - Road L4													
Total Vehicle per hour	0.1	50	6	91	41	3	0	8	2	3	0	0	154
Person per vehicle [1]	-		1.1	1.4	2	1.3	14	1.4	1.2	13.8	0	33.8	-
No. of Person	-		1	1	1	1	0	1	1	1	0	0	7
Person (%)	-		14%	14%	14%	14%	0%	14%	14%	14%	0%	0%	100%

	Road Length (km)	Designed Speed (km/h)	Traffic Flow (veh/hr) at Night-time (Year 2041)										
			Motorcycle	Private Car	Taxi	Private Light Bus	Public Light Bus	Light Goods Vehicle	Medium/ Heavy Goods Vehicles	Non-franchised Bus	Franchised Bus (Single Deck)	Franchised Bus (Double Deck)	Total
R06 - Road L4													
Total Vehicle per hour	0.1	50	9	186	87	1	0	9	3	4	0	0	299
Person per vehicle [1]	-		1.1	1.4	2	1.3	14	1.4	1.2	13.8	0	33.8	-
No. of Person	-		1	1	1	1	0	1	1	1	0	0	7
Person (%)	-		14%	14%	14%	14%	0%	14%	14%	14%	0%	0%	100%

Note:
[1] Person per vehicle is based on the occupancy in Year 2022 from Station 5021 (Tseung Kwan O Tunnel (from Toll Plaza to Tseung Kwan O Tunnel Rd RA)) from Transport Department - The Annual Traffic Census 2022.

Annex B

Event Tree Analysis

Annex B - Event Tree Analysis

E1 LFG Feed Line

Release Scenario		Leak Size	Ignition		VCE		Event Outcome	Event Frequency
1.12E-03	Leak	0.946	Immediate	0.005			Jet Fire	5.32E-06
			Delayed	0.005	yes	0.04	VCE + Flash Fire	2.13E-07
					no	0.96	Flash Fire	5.11E-06
			No	0.99			No Effect	1.05E-03
	Rupture	0.054	Immediate	0.035			Jet Fire	2.13E-06
			Delayed	0.035	yes	0.12	VCE + Flash Fire	2.55E-07
					no	0.88	Flash Fire	1.87E-06
			No	0.930			No Effect	5.65E-05

E2 LFG Pre-treatment

Release Scenario		Leak Size	Ignition		VCE		Event Outcome	Event Frequency
7.02E-03	Leak	0.979	Immediate	0.005			Jet Fire	3.44E-05
			Delayed	0.005	yes	0.04	VCE + Flash Fire	1.37E-06
					no	0.96	Flash Fire	3.30E-05
			No	0.99			No Effect	6.80E-03
	Rupture	0.021	Immediate	0.035			Jet Fire	5.17E-06
			Delayed	0.035	yes	0.12	VCE + Flash Fire	6.20E-07
					no	0.88	Flash Fire	4.55E-06
			No	0.930			No Effect	1.37E-04

E3 H2S Removal

Release Scenario		Leak Size	Ignition		VCE		Event Outcome	Event Frequency
8.79E-04	Leak	0.940	Immediate	0.005			Jet Fire	4.14E-06
			Delayed	0.005	yes	0.04	VCE + Flash Fire	1.65E-07
					no	0.96	Flash Fire	3.97E-06
			No	0.99			No Effect	8.19E-04
	Rupture	0.060	Immediate	0.035			Jet Fire	1.83E-06
			Delayed	0.035	yes	0.12	VCE + Flash Fire	2.20E-07
					no	0.88	Flash Fire	1.61E-06
			No	0.930			No Effect	4.87E-05

E4 Cryogenic Purification

Release Scenario		Leak Size	Ignition		VCE		Event Outcome	Event Frequency
2.91E-03	Leak	0.943	Immediate	0.005			Jet Fire	1.37E-05
			Delayed	0.005	yes	0.04	VCE + Flash Fire	5.49E-07
					no	0.96	Flash Fire	1.32E-05
			No	0.99			No Effect	2.72E-03
	Rupture	0.057	Immediate	0.035			Jet Fire	5.85E-06
			Delayed	0.035	yes	0.12	VCE + Flash Fire	7.02E-07
					no	0.88	Flash Fire	5.15E-06
			No	0.930			No Effect	1.55E-04

E5 CO2 Removal

Release Scenario		Leak Size	Ignition		VCE		Event Outcome	Event Frequency
2.01E-03	Leak	0.940	Immediate	0.005			Jet Fire	9.43E-06
			Delayed	0.005	yes	0.04	VCE	3.77E-07
					no	0.96	Flash Fire	9.05E-06
			No	0.99			No Effect	1.87E-03
	Rupture	0.060	Immediate	0.035			Jet Fire	4.22E-06
			Delayed	0.035	yes	0.12	VCE	5.07E-07
					no	0.88	Flash Fire	3.71E-06
			No	0.930			No Effect	1.12E-04

E6 Gas Odorisation

Release Scenario		Leak Size	Ignition		VCE		Event Outcome	Event Frequency
9.58E-04	Leak	0.943	Immediate	0.005			Jet Fire	4.52E-06
			Delayed	0.005	yes	0.04	VCE	1.81E-07
					no	0.96	Flash Fire	4.34E-06
			No	0.99			No Effect	8.94E-04
	Rupture	0.057	Immediate	0.035			Jet Fire	1.90E-06
			Delayed	0.035	yes	0.12	VCE	2.28E-07
					no	0.88	Flash Fire	1.67E-06
			No	0.930			No Effect	5.04E-05

E7 SNG Export Line

Release Scenario		Leak Size	Ignition		VCE		Event Outcome	Event Frequency
1.72E-03	Leak	0.946	Immediate	0.005			Jet Fire	8.12E-06
			Delayed	0.005	yes	0.04	VCE + Flash Fire	3.25E-07
					no	0.96	Flash Fire	7.80E-06
			No	0.99			No Effect	1.61E-03
	Rupture	0.054	Immediate	0.035			Jet Fire	3.25E-06
			Delayed	0.035	yes	0.12	VCE + Flash Fire	3.90E-07
					no	0.88	Flash Fire	2.86E-06
			No	0.930			No Effect	8.63E-05