TABLE OF CONTENT

List of Annexes

1 INTRODUCTION

1.1 Background

1.1.1.1 An Effluent Polishing Plant (EPP) is proposed under the Project to treat the sewage generated from the development at TKO 137. This appendix assesses the potential risks associated with the biogas facilities involved in the EPP operation .

1.2 Scope of Work

1.2.1.1 The Hazard to Life Assessment requirements for the EPP are shown below:

(a) Identify hazardous scenarios associated with the operation of the EPP 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 measure

1.3 Hong Kong Risk Guidelines (HKRG)

1.3.1.1 The estimated risk levels of hazardous sources will be compared with the Hong Kong Risk Guidelines stipulated in the EIAO-TM to determine the acceptability. As set out in Annex 4 of the EIAO-TM, the risk guidelines for acceptable risk levels comprise the following two components:

1. **Individual Risk:** Maximum level of off-site individual risk should not exceed 1 in 100000 per year, i.e. 1×10^{-5} / year; and

2. **Societal Risk**: Societal risk is expressed in the form of an F-N curve (**Plate 1.1)** which represents the cumulative frequency (F) of all event outcomes leading to N or more fatalities. The F-N curve consists of three different regions defined as follows:

   - <u>Unacceptable region:</u> where risk is so high that they should usually be reduced regardless of the cost or else the hazardous activity should not proceed;
   - <u>ALARP region:</u> where risk is tolerable, provided that it has been reduced to a level As Low As Reasonably Practicable (ALARP); and
   - <u>Acceptable region:</u> where risk is broadly acceptable and does not require further risk reduction.

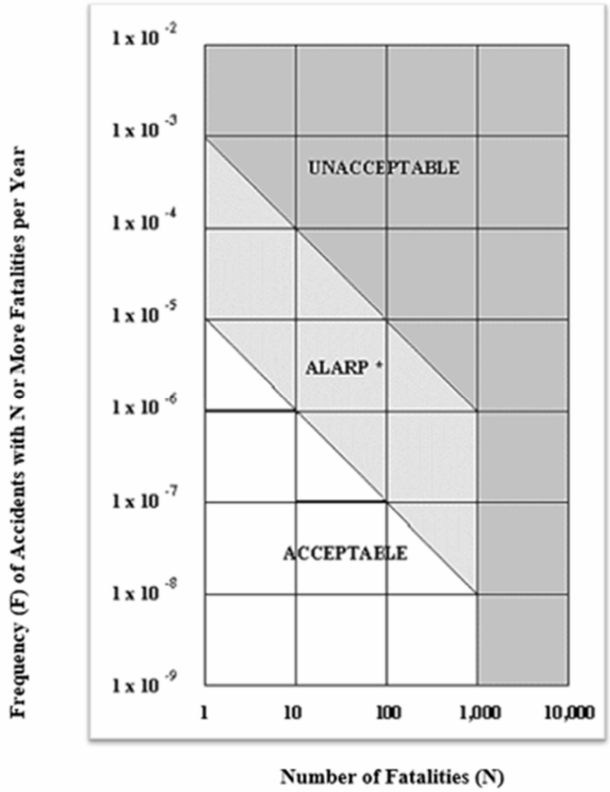


Plate 1.1 Societal Risk Criteria

1.4 Assessment Approach

1.4.1.1 Quantitative Risk Assessment (QRA) study is carried out to assess the potential hazard to life impact associated with the EPP. The main steps of QRA are further described below.

1.4.1.2 The hazard identification involves a review of the hazardous material properties and a review of the past accidents, with the objective of identifying potential hazards and scenarios to be modelled in the subsequent frequency and consequence analysis.

1.4.1.3 Consequence analysis aims to obtain an estimate of the impact on people in loss of containment events of flammable and toxic substances. This includes the following primary components which are performed with consequence modelling software, PHAST Safeti v8.7:

- Source term/ discharge modelling
- Dispersion modelling
- Fire and explosion modelling
- Effects modelling

1.4.1.4 In frequency analysis, the likelihood of each identified scenario is quantified taking into account the site-specific features and project activities.

1.4.1.5 Risk summation then combines the estimates of likelihood and consequence for the identified hazardous events to produce the risk results, which are expressed in terms of individual risk and societal risk as per EIAO-TM. Risk mitigation measures are recommended, where required to reduce the risk to As low As Reasonable Practicable (ALARP).

2 PROPOSED BIOGAS FACILITIES OF EFFLUENT POLISHING PLANT

2.1.1.1 The new proposed EPP includes a biogas facility that is designed to handle a total biogas production rate of approximately 9,300m^3 per day. The biogas system consists of the following main equipment:

- Anaerobic Digesters
- Hydrogen Sulphide (H_2S) Removal Package
- Biogas Holders
- Biogas Booster Pumps
- Biogas Transfer Pumps
- Combined Heat and Power (CHP) Generator
- Waste Gas Burner

2.1.1.2 Primary sludge after sedimentation will blend with the surplus activated sludge at the biological treatment prior to sludge thickening process. Thickened sludge will be pumped to the Anaerobic Digesters. Sludge anaerobic digestion process shall be carried out within each Anaerobic Digester under specific condition.

2.1.1.3 The body and top cover of the Anaerobic Digester shall be a water retaining structure and constructed by concrete and cylindrical in shape. Biogas generate will be collected at the top of the Anaerobic Digester to the H_2S Removal System to remove the sulfide content.

2.1.1.4 Biogas H_2S removal treatment is required to remove hydrogen sulphide (H_2S) from the biogas prior to storage, combustion or CHP. Biogas containing high concentration of H_2S shall be removed by passing through the hydrated ferric oxide media filled with iron sponge in which the H_2S content will react and be removed. The hydrated ferric oxide media will be contained in a cylindrical tank constructed of stainless steel 316L or material able to resist corrosive attack from the media and/or biogas and suitable for its working environment.

2.1.1.5 The Biogas Holders shall be of Dry Seal type with constant pressure design, mainly consists of the piston and the seal, providing a buffering of biogas usage. The Biogas Holders body shall be fabricated from carbon steel complying BS EN 10028, and the piston and accessories shall be fabricated from carbon steel complying with BS EN 10025.

2.1.1.6 The piston of the Biogas Holder moves up and down the inside of the body when the biogas enters and exits the Biogas Holder. The weight of the piston produces the pressure at which the Biogas Holder operates. The seal of the Biogas Holder rolls from the shell to the abutment surface of the piston and vice versa providing the piston with a frictionless self-centering facility.

2.1.1.7 The Biogas Booster Pumps are required to push the biogas toward the flare during emergency operations or when there is excess biogas. The Biogas Transfer Pumps are also provided for transfer between Biogas Holders.

2.1.1.8 Biogas is utilized mainly for power and heat generation. In the event of an emergency or equipment outage, biogas can be flared. The purpose of biogas storage is to provide greater flexibility to manage the biogas pressure. The biogas storage would be operated within the operating pressure of the digesters and does not rely on any kind of pressure boosting or compression.

2.1.1.9 The key operating parameters of the biogas storage and treatment facilities, based on the preliminary process design information available are summarized in the table below.

Table 2.1 Operating Conditions of Proposed Biogas System

Equipment	No. of item (No. of working + No. of standby)	Each Volume (m^3)	Pressure (bar)	Temperature (°C)
Anaerobic Digesters	3+1	2,010	1.03	35
Biogas Holders	2+1	1,206	1.03	35
H_2S Removal Package	1	46	1.03	35
Biogas Booster Pumps	1+1	-	1.03	35
Biogas Transfer Pumps	1+1	-	1.03	35

2.1.1.10 The preliminary layout of the proposed EPP is shown in **Plate 2.1**, while the process schematic of the biogas system within the EPP is shown in **Plate 2.2**. The changes of preliminary EPP layout presented in Section 2 of this EIA report have been reviewed to cause no changes to the findings and conclusion of this QRA.

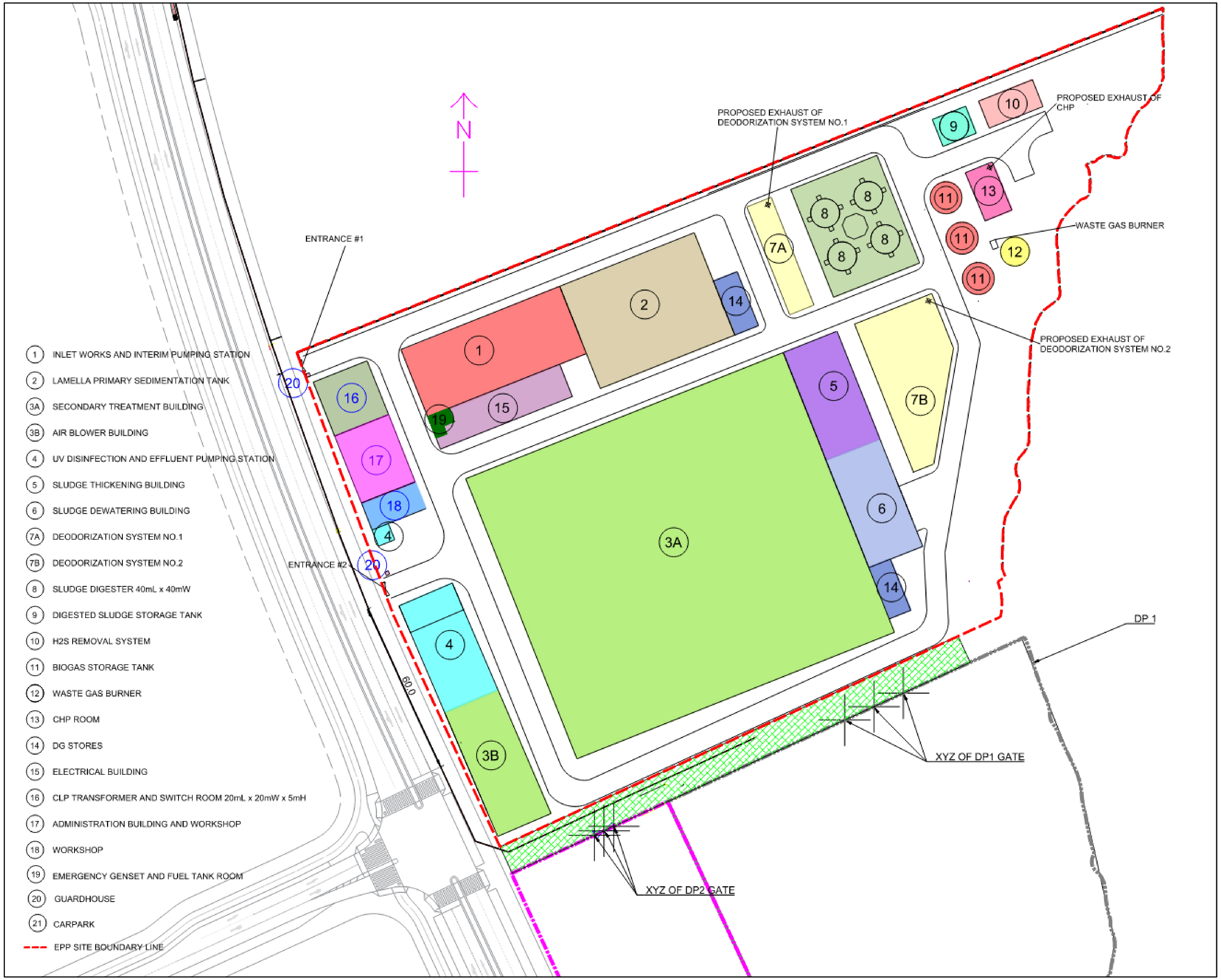


Plate 2.1 Preliminary Layout of Proposed Effluent Polishing Plant

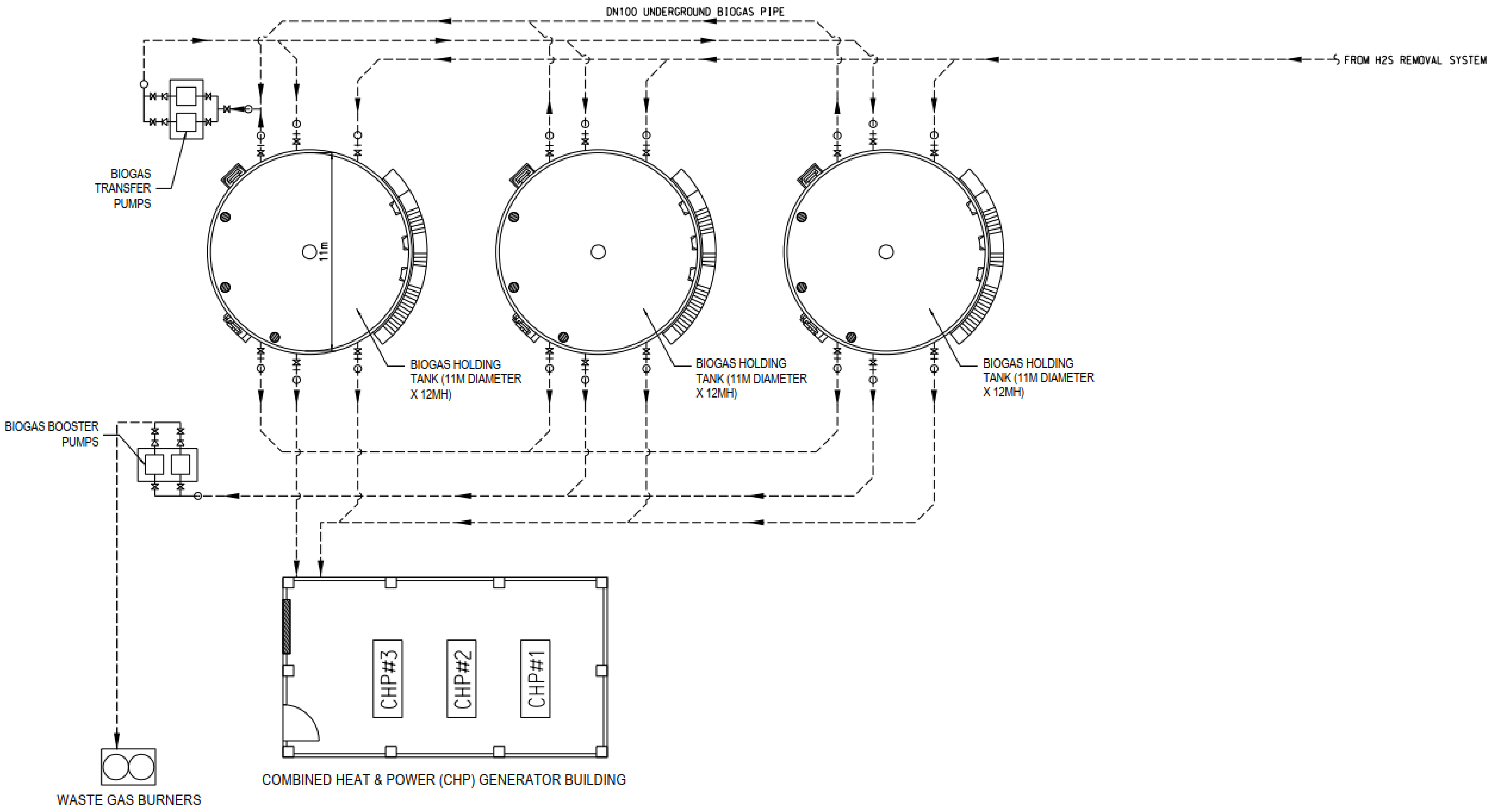


Plate 2.2 Process Schematic of Biogas System

3 METEOROLOGICAL DATA

3.1.1.1 The meteorological conditions affect the consequence of gas release in particular the wind direction, speed and stability, which influences the direction and degree of turbulence of gas dispersion. Meteorological data collected at Tseung Kwan O Weather Station for the past 7 years (2017 – 2023) are considered in the assessment. Twelve weather directions are considered, and two different sets of meteorological data are used for representing the day time and night time weather conditions. Ambient temperature and relative humidity are taken as 25 ^{o}C and 80%, respectively [3].

3.1.1.2 **Table 3.1** and **Table 3.2** present the day time and night time meteorological data, respectively. It should be noted that the categorization of weather follows the purple book guideline. Representative weather in terms of Pasquill classes and wind speeds are grouped based on site-specific weather data, as appropriate.

Table 3.1 Day Time Meteorological Data

Direction	Weather Class						Total
	2A	3B	2D	4D	1F	3E	
0 - 30	1.53	2.35	2.04	1.02	3.01	0.60	13.6
30 - 60	3.24	5.03	3.14	2.13	3.18	0.68	14.7
60 - 90	4.62	5.83	3.16	1.94	2.52	0.54	10.3
90 - 120	2.64	1.96	1.51	0.46	1.50	0.27	6.69
120 - 150	1.59	1.03	1.12	0.51	1.52	0.28	6.44
150 - 180	1.74	0.78	0.68	0.19	0.82	0.20	3.50
180 - 210	5.27	4.15	2.09	0.72	1.44	0.30	6.23
210 - 240	1.53	1.52	1.45	0.42	1.92	0.31	9.69
240 - 270	0.60	0.46	0.63	0.10	0.91	0.22	5.94
270 - 300	0.48	0.30	0.41	0.10	0.79	0.19	4.70
300 - 330	0.39	0.31	0.52	0.08	1.10	0.20	7.18
330 - 360	0.69	1.02	1.17	0.39	2.16	0.29	11.0
All	24.3	24.7	17.9	8.06	20.9	4.09	100

Table 3.2 Night Time Meteorological Data

Direction	Weather Class				Total
	2D	4D	3E	1F	
0 - 30	0.34	1.66	2.35	9.29	13.6
30 - 60	0.34	2.57	3.24	8.56	14.7
60 - 90	0.40	1.56	2.16	6.17	10.3
90 - 120	0.23	0.72	0.96	4.79	6.69
120 - 150	0.12	0.77	0.99	4.55	6.44
150 - 180	0.08	0.35	0.36	2.72	3.50
180 - 210	0.09	0.59	1.09	4.45	6.23
210 - 240	0.11	0.56	1.46	7.56	9.69
240 - 270	0.10	0.45	0.58	4.81	5.94
270 - 300	0.13	0.27	0.21	4.10	4.70
300 - 330	0.15	0.28	0.19	6.57	7.18
330 - 360	0.39	0.74	0.79	9.08	11.0
All	2.49	10.5	14.4	72.6	100

4 HAZARD IDENTIFICATION

4.1 Introduction

4.1.1.1 Hazard identification involves a review of the hazardous properties of the materials being processed. Relevant hazards and the ways in which those hazards are realised are identified.

4.2 Review of Hazardous Material

4.2.1 Biogas

4.2.1.1 Biogas is a colourless flammable combustible mixture of gases at atmospheric conditions that comprises mainly methane (CH_4) and carbon dioxide (CO_2). Generally, biogas from anaerobic digestion process has a methane content of 55% to 70% by volume. The exact composition of biogas depends on the substance that is being decomposed. If the material consists of mainly carbohydrates, such as glucose and other simple sugars and high-molecular compounds (polymers) such as cellulose and hemicellulose, the methane production is low. However, if the fat content is high, the methane production is likewise high. In general, the physical properties of biogas are also very similar to those of natural gas, except up to 2,000 ppm of H_2S is anticipated and thus the biogas can also exhibit some degree of toxicity.

4.2.1.2 A loss of containment can lead to jet fire since the system is operated slightly above atmospheric pressure. The released gas, if not ignited immediately, could form a flammable gas plume.

4.2.1.3 The properties of biogas to be used in this study are summarized in **Table 4.1** .

Table 4.1 Composition and Properties of Biogas

Property	Values
Methane Content	70%
Carbon Dioxide Content	30%
Hydrogen Sulphide	Up to 2,000 ppm
Density	1.15 kg/m^3
Flammability	Extremely Flammable
Flammable Limits	5% (Lower) – 15% (Upper)

4.2.1.4 Given that the flammability increases with increase of methane content, and the exact composition of biogas varies with the substance that is being decomposed, biogas was conservatively modelled as 0.7 methane gas and 0.3 carbon dioxide with 2,000 ppm of H_2S in consequence analysis. It is highlighted that biogas storage area is a fully open area with no major congestion, and thus the risk of vapour cloud explosion is considered to be low. Therefore, all delayed ignition events were modelled as flash fire in QRA.

4.3 Hazardous Scenarios Identification

4.3.1 Failure Scenarios Associated with Equipment and Piping

4.3.1.1 Equipment and piping failure usually arises from the following reasons:

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

4.3.1.2 For all the various reasons that lead to failures, they are covered by generic failure frequency from worldwide databases. In case of failure, it can result in a range of different hole sizes. For vessels, it can also result in catastrophic failure which results in instantaneous release of entire static inventory.

4.3.2 External Events

4.3.2.1 A list of external events was identified to have the potential to result in a release at the proposed EPP including earthquakes, aircraft crashes, etc. The review of external events is included in **Annex D**. Based on the analysis, these events either are very infrequent or are not credible at all. As such, external events are not considered further in the QRA study.

4.3.3 Hazardous Section for QRA Study

4.3.3.1 The hazardous events considered in this QRA are summarized in **Table 4.2** below.

Table 4.2 Hazardous Sections Identified for Biogas Facilities of EPP

Section Tag	Section Name	Section Type	Hazardous Material	Flow Rate (kg/m^3)	Pipe Length (m)	Inventory (kg)	Remark
01	Anaerobic Digester	Vessel and Piping	Biogas with H_2S	79	261	6,953	
02	H_2S Removal	Vessel and Piping	Biogas with H_2S	79	145	228	
03	Biogas Holder	Vessel and Piping	Biogas	79	359	2,793	
04	Biogas Booster	Compressor	Biogas	79	-	15	Biogas Booster is only used during upset of CHP or during emergency. Operation factor of 0.1 is applied.
05	Biogas Transfer Pump	Compressor	Biogas	79	-	15	Biogas Transfer Pump is only used during inter-transfer between Biogas Holders. Operation factor of 1 day per year is applied.

5 FREQUENCY ANALYSIS

5.1 Initiating Event frequency

5.1.1 Base Frequencies

5.1.1.1 Frequency analysis is used to derive the final event outcome frequencies. By using historical failure frequency data, the number of equipment in a given isolatable section and the length of piping in a given section, the final event outcome frequency is determined. The equipment failure frequencies are taken from published international failure database applicable for process facilities, applying UK HSE database [4] as tabulated below.

Table 5.1 Failure Frequency Data

Component	Unit	Hole Size			
		10mm	25mm	Rupture	Catastrophic Rupture
Vessel	per year	2.50E-03	1.00E-04	5.00E-06	5.00E-06
Compressor	per year	1.20E-02	2.70E-04	5.80E-06	-
Piping (50 – 149mm)	per m-year	2.00E-06	1.00E-06	5.00E-07	-
Manual Valve	per year	2.00E-04	-	-	-

Component	Unit	Hole Size			
		10mm	25mm	Rupture	Catastrophic Rupture
Actuated Valve	per year	2.00E-04	-	-	-
Flange	per year	-	5.00E-06	-	-

5.1.2 Leak Frequency Estimates

5.1.2.1 Equipment count of each of the process sections was made based on a review of the drawings and pipework lengths were estimated from the plot plans. These were combined with the generic failure frequency as given in **Table 5.1** to determine the release frequency for each section. The calculated leak frequency results are summarized in **Table 5.2** .

Table 5.2 Event Frequencies

Section Tag	Section Name	Event Frequency			
		10mm	25mm	Rupture	Catastrophic Rupture
01	Anaerobic Digester	9.62E-03	6.21E-04	1.46E-04	1.50E-05
02	H_2S Removal	1.19E-02	6.05E-04	9.27E-05	2.00E-05
03	Biogas Holder	7.32E-03	6.19E-04	1.90E-04	1.00E-05
04	Biogas Booster	2.48E-02	5.70E-04	1.16E-05	0.00E+00
05	Biogas Transfer Pump	2.40E-02	5.40E-04	1.16E-05	0.00E+00

5.2 Event Tree Analysis

5.2.1.1 Various hazardous events may arise depending on the release conditions (e.g. instantaneous or continuous release, rainout, and vaporization of the released material) as well as the type of ignition (e.g. immediate or delayed ignition). The frequencies of these undesired outcome events such as flash fire, pool fire, jet fire, explosion, etc. were derived using Event Tree Analysis (ETA).

5.2.1.2 ETA is an analysis technique which identifies different possible outcomes following an initiating event and estimates the probabilities for each of these outcomes. An Event Tree (ET) starts with an initiating event and proceeds by examining each contributing factor in chronological order to identify all possible outcomes. The frequency of event outcome is estimated by multiplying the initiating event frequency and probabilities of all contributing factors leading to the specific hazardous event. In this study, Phast Safeti Event Tree was used to generate the outcome events. The detailed parameters used in PHAST Safeti are presented in **Annex B**. The figures below present the event trees for various scenarios for MPACT used in the QRA, including gaseous release, liquid release, and vessel catastrophic rupture.

5.3 Ignition Probability

5.3.1.1 In general, ignition can be separated into immediate and delayed ignition. Immediate ignition, also referred to as 'direct ignition', describes ignition near the time and point of the release itself. Immediate ignition may result through auto-ignition, electrostatic discharges or due to the presence of ignition sources in the immediate vicinity, e.g. a damaged electric cable. Delayed ignition is also considered in this study to describe the potential for ignition of the flammable cloud as it disperses from the point of release. For this study, the immediate ignition probability is assumed to be 30% of the total ignition probability.

Table 5.3 Total Ignition Probability

Leak Size	Ignition Probability	
	Gas	Liquid
Minor (<1 kg/s)	0.01	0.01
Major (1-50kg/s)	0.07	0.03
Massive (>50kg/s)	0.3	0.08

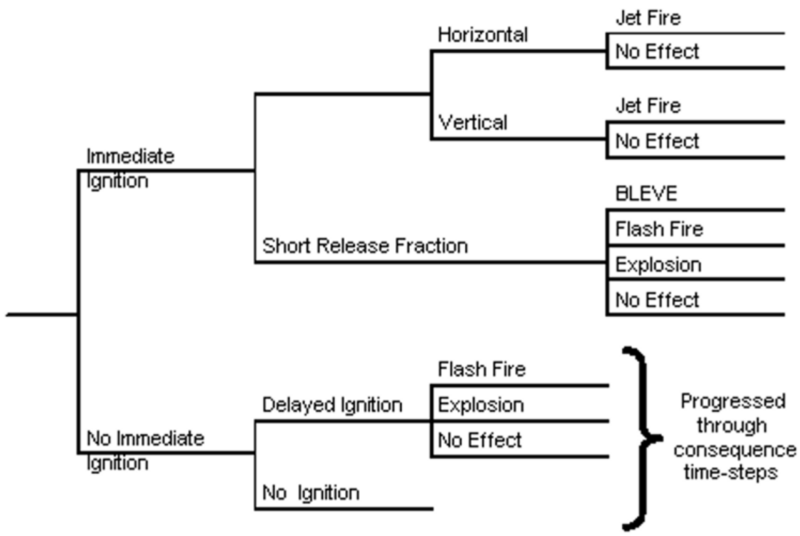


Plate 5.1 Event Tree Extracted from MPACT (for Gaseous Release)

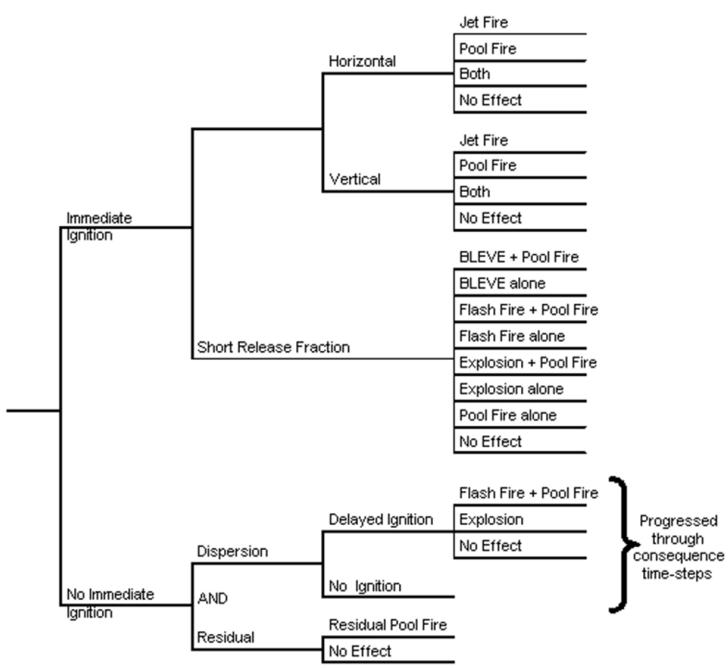


Plate 5.2 Event Tree Extracted from MPACT (for Liquid Release)

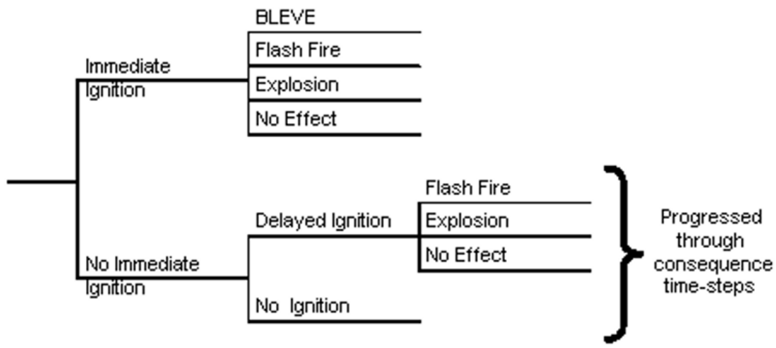


Plate 5.3 Event Tree Extracted from MPACT (for Catastrophic Rupture)

5.4 Sources of ignition

5.4.1.1 Ignition sources can cause the ignition of flammable gas releases. Specifically for delayed ignition, fire events such as Vapour Cloud Explosions and Flash Fires may result. The probability of ignition of a release upon reaching an ignition source is dependent on its ignition probability and the presence factor within the source, and approach adopted is based on published literature [5]. For industrial building and facilities, an ignition efficiency of 1 in a period of 60 seconds has been assigned. Furthermore, other populated areas in the vicinity includes office buildings and food manufacturing facilities, where smoking, cooking and use of electrical appliances are also considered as ignition sources in the modelling. An ignition efficiency of 0.4 in a period of 60 seconds has been assigned to such areas. In addition, road vehicles are considered as ignition sources, and accordingly ignition sources have been assigned to all nearby roads in the vicinity. Ignition efficiency for vehicles is taken as 0.4 in a period of 60 seconds based on similar previous QRA in Hong Kong [6].

Table 5.4 Summary of Ignition Sources Assumed in QRA

Ignition Sources	Description	Ignition Efficiency
Flare and furnace	Open flame or very hot surfaces	1
Combined Heat and Power Generation System (CHP) in Proposed EPP	Hot surface and combustion	1
Office buildings	Smoking, cooking and use of electrical appliances	0.4

6 CONSEQUENCE ANALYSIS

6.1 Introduction

6.1.1.1 Consequence modelling is used to predict the size, shape, and orientation of hazard zones resulting from releases of hazardous materials. It generally comprises the following elements:

- Source term / discharge modelling: This involves estimation of discharge rate, release duration and other physical properties of the released material, such as temperature and pressure. These estimated parameters are then set as the initial conditions for the subsequent dispersion or fire effects modelling.
- Dispersion modelling: This involves mathematical simulation of how the released materials disperse in the ambient atmosphere. Downwind and crosswind concentrations

are determined to find the gas cloud hazard footprint.

- Fire and explosion modelling: If the released material comes into contact with an ignition source, it can result in a range of possible fire outcomes such as jet fire, pool fire, flash fire, fireball or explosion, depending on the source term conditions, time of ignition, the strength of ignition source, etc. It is possible to predict the fire behavior with numerical or empirical models, whereby the size of the flame and the heat radiation zone can be estimated. Similarly, blast overpressure resulting from a gas explosion can also be predicted with mathematics models.
- Effects modelling: This involves the determination of the magnitude of damage caused by exposure to fire, heat radiation or overpressure. With the help of probit functions, the probability of fatality or injury can be related to thermal radiation levels and exposure duration. Similarly, the harm probability can be determined for different explosion overpressure levels.
- Mitigation: By altering the source term of the models, it is possible to quantify the reduction of hazardous zone from a release due to the effects of mitigation measures.

6.1.1.2 Consequence modelling has been performed using Phast Safeti v8.7 for the sections of proposed EPP considered in the study. The consequence distances are presented in **Annex C**. In the event of a release or rupture of pipeline or equipment, no isolation has been assumed as a conservative approach for assessment. All leak scenarios were modelled as continuous releases (i.e. 30 min), which are anticipated to result in the worst-case consequences. For catastrophic rupture of equipment, the entire volume of the process equipment was taken to consideration.

6.2 Leak Sizes

6.2.1.1 For each of the hazardous system, a range of leak sizes have been modified to represent the potential failure scenarios following previous QRA study:

- 10mm hole
- 25mm hole
- Full bore rupture of piping
- Catastrophic failure of pressure vessel

6.2.2 Leak Frequency Estimates

6.2.2.1 In the event of a catastrophic rupture of a vessel, the Instantaneous Model in PHAST was used to model the rapid release of the entire inventory, where the material in the vessel is expanded from initial conditions to atmospheric pressure. For releases from holes in pipes/ vessels, the release rate was calculated using standard orifice type calculations based on process conditions and leak size.

6.2.2.2 For gas releases, the pressure in the system, and hence the release rate, will slowly decrease following isolation, resulting in a time-dependent release. As a conservative approach, the calculated initial release rate was assumed constant over the release duration.

6.2.2.3 For large leaks from liquid streams, the release rate calculated from orifice type calculations is compared with the pumping rate. If the calculated release rate exceeds the normal pumping rate, the discharge rate is capped at 1.3 times the pumping rate to reflect pump curve characteristics. This was applied to all leak locations downstream of a pump.

6.2.3 Release Duration & Inventory

6.2.3.1 Release duration is another important output from the discharge modelling which is determined by the upstream inventory and means of leak detection and isolation. The total release inventory was calculated as the sum of the piping / equipment inventory within the isolatable section and the flow rate to the system until isolation. The total release inventory was calculated for each of the identified hazardous sections.

6.2.3.2 For this facility, it was assumed that isolation can be achieved by manual intervention through remote-controlled blocking system. In particular, operator's on-site validation is required for detection of the leakage, after which the isolation could be initiated in the control room. In this case, the time to isolation is considered as 30 minutes.

6.3 Dispersion Modelling

6.3.1.1 Dispersion modelling involves mathematical simulation of how the released materials disperse in the ambient atmosphere. Downwind and crosswind concentrations were determined to find the gas cloud hazard footprint. Vapor dispersion modelling was conducted using PHAST's Unified Dispersion Model (UDM). The model considers the following aspects of vapor cloud behavior in dispersion modelling:

- Continuous, instantaneous or time-varying releases;
- Jet, heavy-gas and passive dispersion;
- Elevated, touchdown and ground level dispersion;
- Droplet dispersion, rainout and droplet vaporization; and,
- Dispersion over land or water surfaces.

6.4 Physical Effects Modelling

6.4.1.1 Physical effect modelling determines the magnitude of damage caused by exposure to fire, heat radiation, toxic, or overpressure. The following possible hazardous outcomes were considered in the QRA:

6.4.2 Flash Fire

6.4.2.1 A flash fire results from delayed ignition of a flammable vapor cloud, generated either through vaporization directly from the release, or from vaporizing pools. The main hazards of a flash fire being direct flame contact.

6.4.2.2 The area of possible direct flame contact effects is determined as the distance to the lower flammability limit (LFL) of the vapor cloud. Due to the extremely short duration of a flash fire, radiation effects outside the flash fire envelope are negligible.

6.4.3 Jet Fire

6.4.3.1 A jet fire results from the immediate ignition of the flammable gas or liquid from a pressurized release. The main hazards from a jet fire are direct flame contact and radiation, both of which are modelled using default parameters in PHAST, with release orientation set at horizontal non-impinging.

6.4.4 Fireball

6.4.4.1 A fireball would result from the immediate ignition of a release resulting from cold catastrophic rupture of a pressurized vessel. Ignition of the rapidly released materials will form a ball of flame rising rapidly into the air and burning out in a short time. Fireballs were considered for the instantaneous failure of process vessels.

6.4.5 VCE Overpressure

6.4.5.1 When a flammable vapour cloud is formed and gets accumulated in areas with congestion or confinement, ignition of such vapour cloud may result in Vapour Cloud Explosion (VCE). Since location and layout of the proposed EPP is fairly open without large area of congestion and confinement, VCE has not been modeled in this QRA. Instead, all delay ignition has been modelled as Flash Fire to be conservative.

6.4.6 Toxic

6.4.6.1 In case the process steam contains toxic material, it is possible for impact to personnel inside the gas cloud in case the cloud is not ignited.

6.5 End Point Criteria

6.5.1.1 Probit functions were used to estimate the probability of fatality due to a physical effect, e.g. thermal radiation, etc.

6.5.2 Flash Fires

6.5.2.1 All persons outdoor within the flash fire envelope (LFL contour) were assumed to be fatally injured i.e. fatality rate of 100%.

6.5.3 Thermal Radiation

6.5.3.1 The main hazard for jet fire and fireball is personnel being exposed to the thermal radiation. The probability of fatality due to the exposure to thermal radiation can be calculated with the probit equation in the following form:

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

Where,

Pr is the probit;

Q is the heat radiation (Wm^{-2}); and

t is the exposure time (s).

6.5.4 Toxic Effects

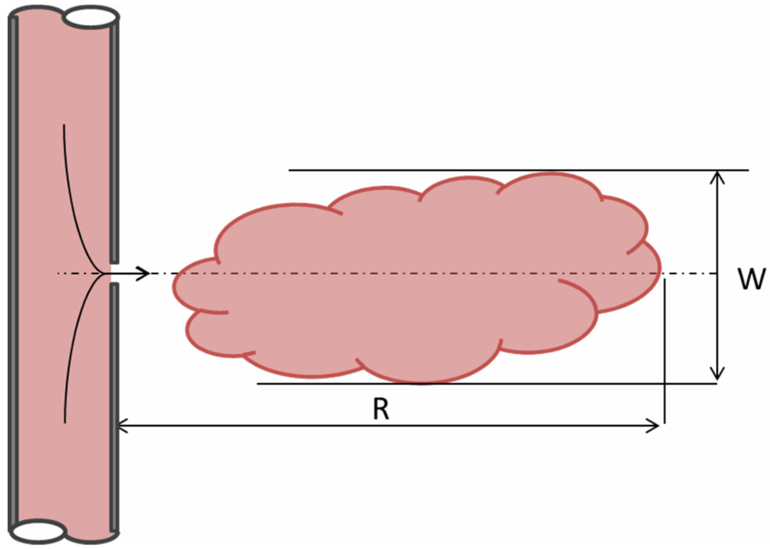
6.5.4.1 The probability of fatality due to exposure to toxic H2S gas can be calculated with the following probit equation, as shown in PHAST Risk's built-in toxic probit equation.

$$Pr = -8.53 + 0.44\ln(C^{4.55}t)$$

Where:
Pr is the probit;
C is the gas concentration (ppm); and,
t is the exposure time (min).

6.6 Consequence Results and Analysis

6.6.1.1 The effects zone for each hazardous outcome is presented in terms of the maximum downwind extent and hazard width as shown in **Plate 6.1**. A full set of the consequence modelling results are presented in the **Annex C**.



Where
R: maximum downwind range of consequence
W: maximum width of consequence

Plate 6.1 Presentation of Consequence Results

7 RISK SUMMATION AND EVALUATION

7.1 Introduction

7.1.1.1 Risk summation involves combining the predicted consequences of an event with the event probabilities, as well as the meteorological data to give estimates of the resulting frequencies of varying levels of fatalities. DNV PHAST Safeti v8.7 is used for modelling and risk summation.

7.2 Individual Risk Contours

7.2.1.1 The individual risk contours of the proposed EPP are presented in **Plate 7.1** and **Plate 7.2**. The maximum IR of this project is found to be less than 1 x 10^{-4} /yr hence risk to onsite personnel can be considered acceptable. With regard to the offsite risk, the 1 x 10^{-5} /yr contour generated from the EPP is found to be within the site boundary. As such, it is concluded that the proposed development and associated activities can meet the IR criteria of HKRG.

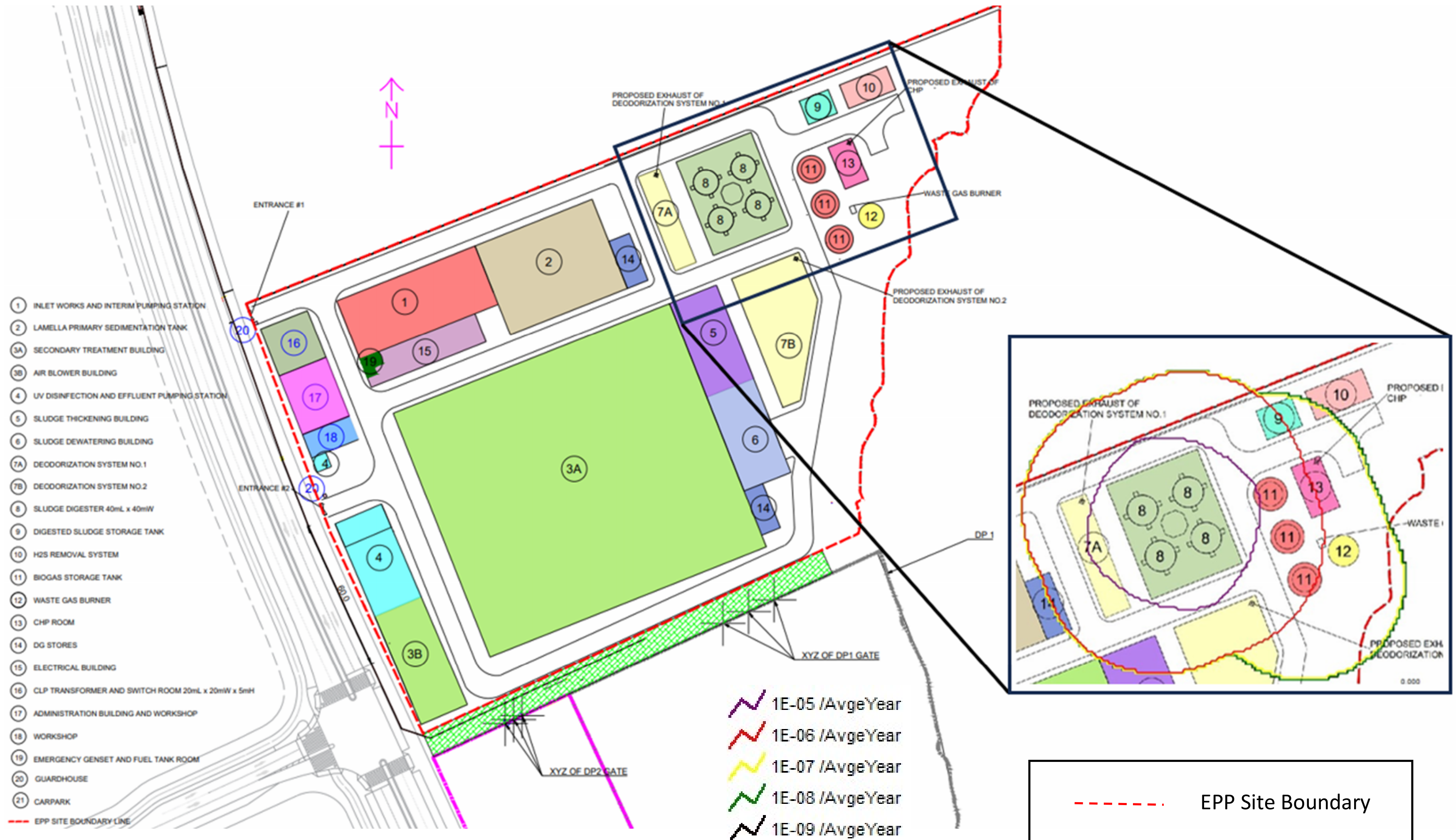


Plate 7.1 IR Contour Result

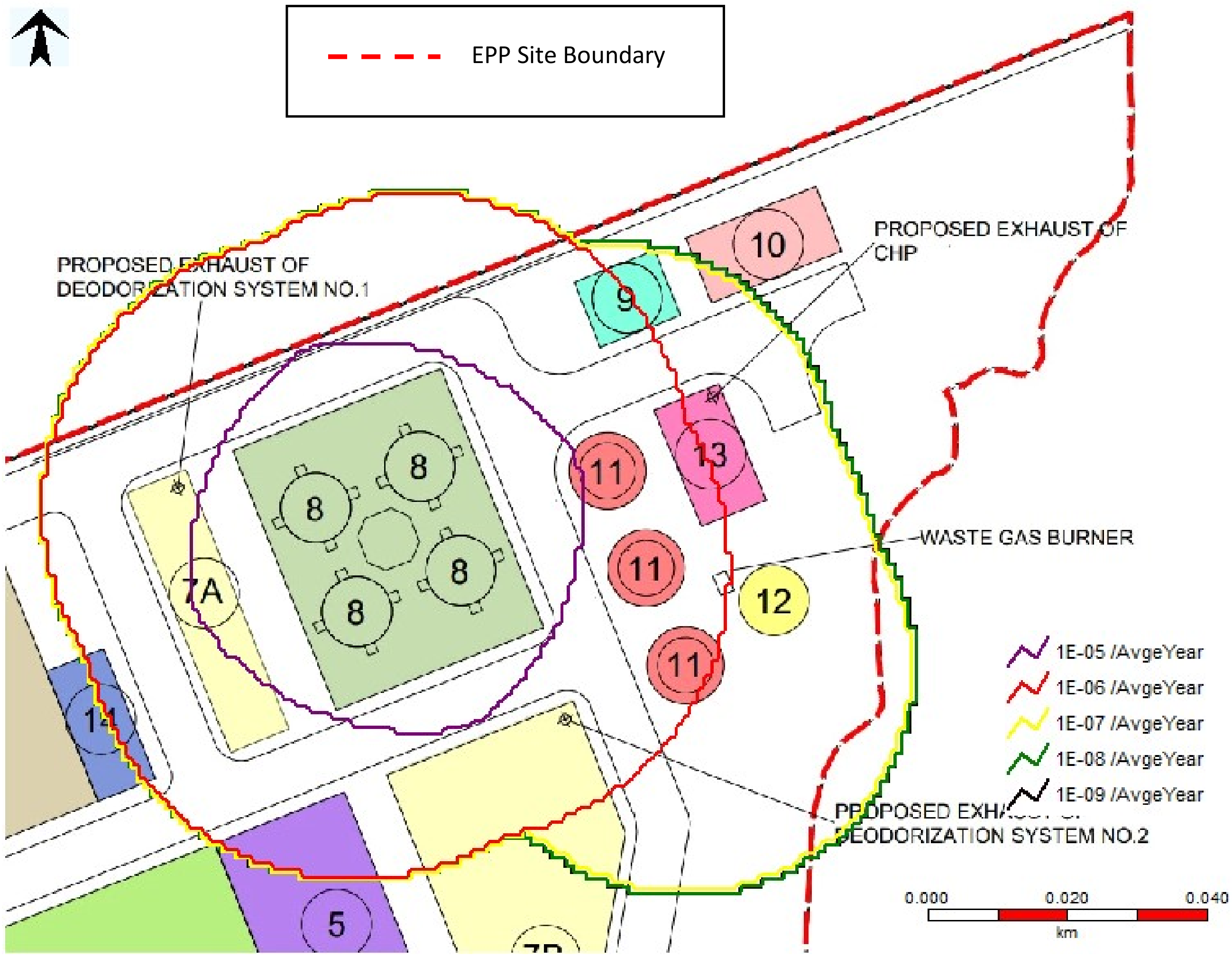


Plate 7.2 IR Contour Result (Enlarged)

8 SOCIETAL RISK

8.1.1.1 The societal risk results have been expressed in the form of Frequency and Fatalities (F-N) curve, overlaid on the societal risk criteria for comparison. The FN curves for EPP are presented in **Plate 8.1**. Since the IR contours only covered a very small area of the SENTX site which also has limited population, the Number of Fatalities (N) is found to be only 1 for all modeled cases. The associated frequency is also found to be only 3 x 10^{-7} /yr.

8.1.1.2 As such, it can be concluded that all FN curves are in the Acceptable region and therefore the societal risk associated with EPP is considered to be acceptable.

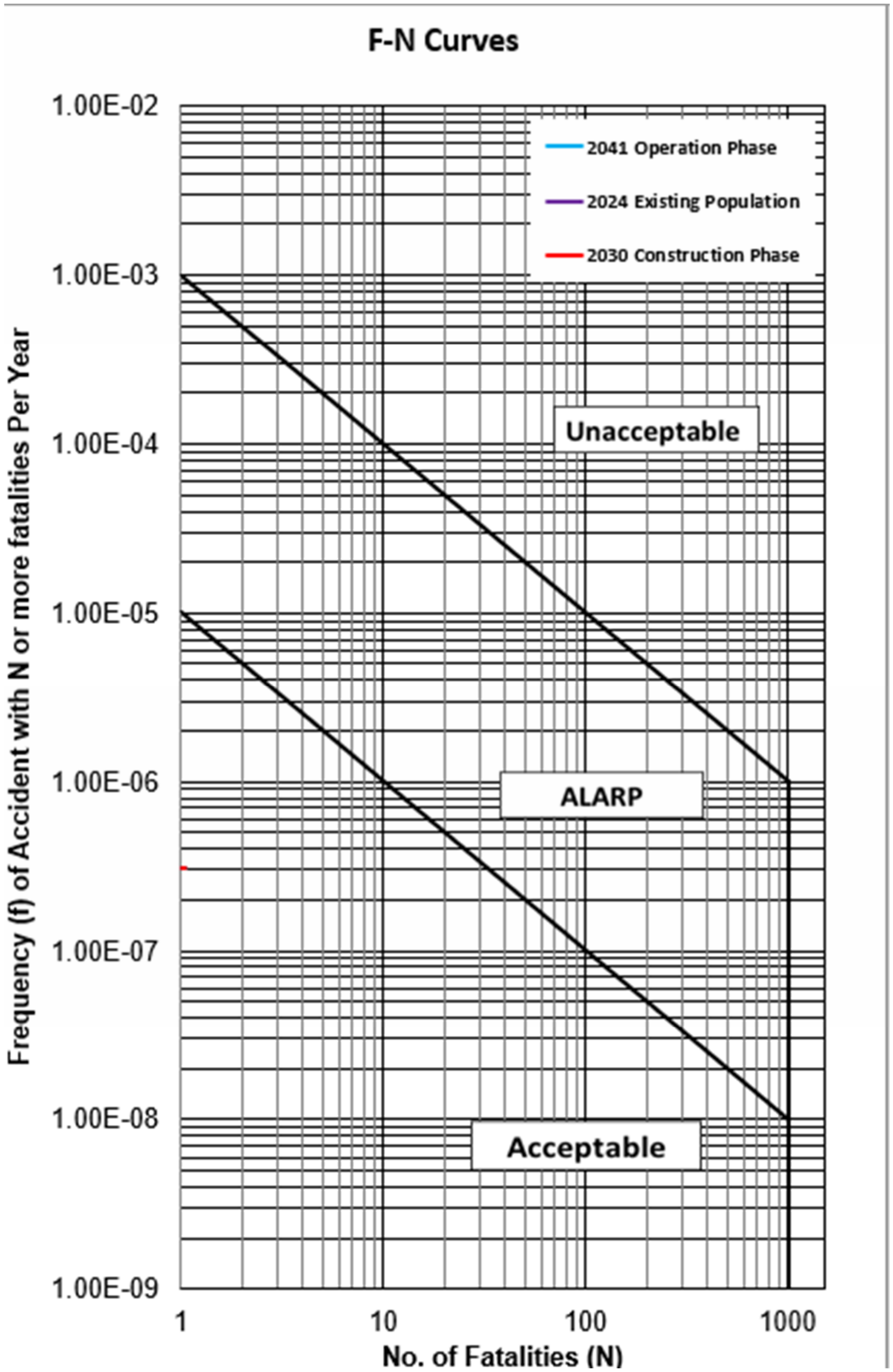


Plate 8.1 FN Curves Result

9 RISK MITIGATION MEASURES

9.1.1.1 The risk of the proposed EPP is not significant and can meet the Hong Kong Risk Guidelines. No risk mitigation measure is proposed.

10 CONCLUSION

10.1.1.1 A Quantitative Risk Assessment (QRA) was carried out to assess the potential hazard to life risk due to the biogas system within the proposed EPP as part of the TKO 137 Development.

10.1.1.2 The maximum IR of proposed EPP is less than 1 x 10^{-4} /yr and the 1 x 10^{-5} /yr IR contour is confined within the site boundary. As such, it is concluded that the proposed development and associated activities do not impose any significant risk to the nearby population and can meet the IR criteria of Hong Kong.

10.1.1.3 IR contours of 1 x 10^{-6} /yr or lower are found to only cover small part of the SENTX site to the north. As a result, the Number of Fatalities (N) is only 1 for all modelling cases. The associated frequency is also found to be only 3 x 10^{-7} /yr. As such, all FN curves are within acceptable region and meets the societal risk criteria of Hong Kong. No risk mitigation measure is required.

11 REFERENCE

[1] Technical Memorandum of Environmental Impact Assessment Process (EIAO-TM).

[2] Hong Kong Observatory, Tseung Kwan O Weather Station.

[3] Hong Kong Observatory, Climate of Hong Kong, https://www.hko.gov.hk/en/cis/climahk.html

[4] UK Health and Safety Executive (UKHSE), *Failure Rate and Event Data for use within Risk Assessments*, 2012.

[5] Committee for the Prevention of Disasters, *Guidelines for Quantitative Risk Assessment "Purple Book",* CPR18E, 2005

[6] *Kai Tak Development Engineering Study cum Design and Construction of Advance Works – Investigation, Design and Construction*, Agreement No. CE 35/2006(CE)

[7] Tierney, K. J., & Anderson, R. (1990). Risk of hazardous materials release following an earthquake. Preliminary Paper #152. University of Delaware, Disaster Research Centre.

[8] ERM (2016), Additional Gas-fired Generation Units Project – EIA Study, EIA237/2016

[9] "Air Traffic Statistics." Civil Aviation Department, HKSAR. 29 November 2021. https://www.cad.gov.hk/english/statistics.html.

[10] Alan B. Reeves, Francis C. Minah, Vincent H.K. Chow, Quantitative Risk Assessment Methodology for LPG Installations, Paper 6, Conference on Risk & Safety Management in the Gas Industry, EMSD & HKIE, Hong Kong, 1997.

[11] GEO Information Note 21/2022, Seismicity of Hong Kong, Geotechnical Engineering Office, Civil Engineering and Development Department, 2022.

[12] GEO Report No. 311, Seismic Hazard Analysis of the Hong Kong Region, Geotechnical Engineering Office, Civil Engineering and Development Department, 2015.

[13] Scott, D.N., Pappin, J.W., Kwok, M.K.Y., Seismic Design of Buildings in Hong Kong, Hong Kong Institution of Engineers, Transactions, Vol. 1, No. 2, p.37-50, 1994.

[14] Health and Safety Executive (UK HSE), Failure Rate and Event Data for use within Land Use Planning Risk Assessments.

[15] Google Maps, Tseung Kwan O, Hong Kong

[16] The Planning Department of HKSAR, *Hong Kong Planning Standards and Guidelines*, 2008

[17] *Appendix 11.2.2*, *Kai Tak Development Engineering Study cum Design and Construction of Advance Works – Investigation, Design and Construction*, Agreement No. CE 35/2006(CE).

[18] Reference Manual Bevi Risk Assessments, National Institute of Public Health and the Environment (RIVM), 2009

[19] Ove Arup & Partners Hong Kong Ltd, Hazard to Life Assessment for the Airport Fuel Tank Farm (AFTF), July 2009, https://www.epd.gov.hk/eia/register/report/eiareport/eia_1722009/html/Section%2013%20(Hazard%20to%20Life)/Section%2013%20(Hazard%20to%20Life)%20.htm

[20] Hazard to Life Assessment for the Permanent Aviation Fuel Facility (PAFF), ESR Technology, February 2007, ESR/D1000190/001/Issue 2

[21] Hong Kong PHI Register 2017

[22] Singapore Government, QRA Technical Guidance, 9 November 2016

[23] Hazard to Life Assessment for Kai Tak Development (EIA-157/2008)

[24] Byrne, J. P. (1997). The calculation of aircraft crash risk in the UK, HSE\R150. Health and Safety Executive.

Annex A

Population Data

Population Data

This section presents the population data in 2024 and in the estimated years 2030, and 2041. The population data considered in this assessment are presented in the table below. Locations of the identified populations are shown in **Figure 2.4** in Section 2 of this EIA report. The proposed EPP is tentatively scheduled for commissioning in 2034.

ID	Description	Type	Population			Indoor Ratio	Reference
			2024	2030	2041		
OU4	Proposed EPP	Employment	0	0	100	95%	Project information
		Visitors	0	0	42	95%	
PU1&2	Public Housing (PU1&2)	Residential	0	33,692	33,692	95%	Project information
		Employment	0	2,445	2,445	95%	Project information
PU3&4	Public Housing (PU3&4)	Residential	0	0	28,058	95%	Project information
		Employment	0	0	1,974	95%	Project information
PU5	Public Housing (PU5)	Residential	0	0	11,847	95%	Project information
		Employment	0	0	858	95%	Project information
PU6	Public Housing (PU6)	Residential	0	0	19,380	95%	Project information
		Employment	0	0	1,390	95%	Project information
PR1	Private Housing (PR1)	Residential	0	0	8,907	95%	Project information
		Employment	0	0	794	95%	Project information
PR2	Private Housing (PR2)	Residential	0	0	9,596	95%	Project information
		Employment	0	0	834	95%	Project information
PR3	Private Housing (PR3)	Residential	0	0	8,977	95%	Project information
		Employment	0	0	2,883	95%	Project information
PR4	Private Housing (PR4)	Residential	0	0	6,741	95%	Project information
		Employment	0	0	869	95%	Project

ID	Description	Type	Population			Indoor Ratio	Reference
			2024	2030	2041		
							information
PR5	Private Housing (PR5)	Residential	0	0	7,813	95%	Project information
		Employment	0	0	978	95%	Project information
OU3	Green Fuel Station	Employment	0	0	10	95%	Project information
E1	Secondary School	Employment & Student	0	0	221	95%	Project information
E2	Primary School	Employment & Student	0	0	121	95%	Project information
E3	Primary School	Employment & Student	0	0	121	95%	Project information
E4	Primary School	Employment & Student	0	0	121	95%	Project information
E5	Secondary School	Employment & Student	0	0	221	95%	Project information
G1	Divisional Police Station	Employment	0	0	515	95%	Project information
G2	Fire Station cum Ambulance Depot	Employment	0	0	190	95%	Project information
G3	Government Office cum Sport Complex	Employment	0	0	18	95%	Project information
G4	Integrated Complex	Employment	0	0	469	95%	Project information
SENTX	SENT Landfill Extension	Employment	25	25	25	0%	Project information
TKODP	TKO Desalination Plant	Employment & Visitors	103	160	160	0%	Project information
Road L5	Road L5	Road	0	1,371	430	0%	Transient Population
Road L5	Road L6	Road	0	85	209	0%	Transient Population
Road L8	Road L8	Road	607	4,978	3,226	0%	Transient Population

Annex B

PHAST Risk Parameter

Input Report

Workspace: TKO Project_Biogas_Expand_240320

Dispersion parameters

Dispersion parameters

TKO Project_Biogas_Expand_240320\Parameters

Tab	Group	Field	Value	Units
Building wake	Model in use	Model in use	Best estimate	
	Calculation control	Lee length	Calculate	
		Lee half-width	Calculate	
		Lee height	Calculate	
		K-factor	Calculate	
		Switch distance	Calculate	
		Specified lee length		m
		Specified lee half-width		m
		Specified lee height		m
		Specified k-factor		
		Specified switch distance		m
	Output granularity	Maximum initial step size	10	m
		Maximum number of output steps	1000	
Near field	Momentum jet – continuous	Jet model	Morton (crosswind modified)	
		Coefficients	Use recommended	
		Drag coefficient between plume and air	0.39	
		Jet entrainment coefficient alpha1	0.17	
		Jet entrainment coefficient alpha2	0.35	
	Initial energetic expansion – instantaneous	Modelling of instantaneous expansion	New standard method	
		Kinetic-energy fraction of discharge expansion energy	0.04	fraction
		Rainout coefficient	1	
		Air drag coefficient to radial expansion	0	
		Ratio droplet/ expansion velocity for inst. release	0.8	
		Expansion energy cutoff for droplet angle	0.69	kJ/kg

DNV

	Dense cloud	Dense cloud parameter gamma - continuous	0	
		Dense cloud parameter gamma - instantaneous	0.3	
		Dense cloud parameter K - continuous	1.15	
		Dense cloud parameter K - instantaneous	1.15	
		Gravity spreading collapse	Allow gravity collapse	
	Atmospheric entrainment	Near field passive entrainment parameter	1	
Far field	Criteria for transition to passive dispersion	Maximum cloud/ambient velocity difference	0.1	
		Maximum cloud/ambient density difference	0.015	
		Maximum non-passive entrainment fraction	0.3	
		Maximum Richardson number	15	
	Modeling the transition	Distance multiple for full passive entrainment	2	
	Modeling passive dispersion	Ratio instantaneous/continuous sigma-y	1	
		Ratio instantaneous/continuous sigma-z	1	
		Core averaging time	18.75	s
	End of dispersion	Criterion for halting dispersion model	Mixed basis	
Liquid	Droplet modelling	Droplet evaporation thermodynamics model	Rainout, non-equilibrium	
Ground	Modelling of heat and water transfer	Flag for heat/water vapour transfer	Heat and water	
	Modelling of impingement	Impingement option	Use velocity modification factor	
		Impinged velocity limit	500	m/s
		Impinged velocity factor	0.25	fraction
	Cloud impact and lift-off	Richardson number criterion for cloud lift-off	-20	
Time-varying and finite duration	Observer release control	Suggested number of pool observers	10	
	Modelling of finite duration or time-varying dispersion	Method for non-instantaneous dispersion	Along wind diffusion (AWD)	
		Quasi-instantaneous transition parameter	0.8	

		Time averaging for concentrations	Do not average concentrations over time	
		Observer mass correction	Apply observer mass correction	
		Minimum release duration for time-varying dispersion	3	s
		Method to handle mass conservation failure	Recommended	
		Fraction of mass lost to trigger equivalent pool	0.25	fraction
	Gravity spreading	Gravity spreading correction	Correct for gravity spreading for large gravity-spread rate only	
Accuracy and speed	Integration in calculations	Relative tolerance for dispersion calculations	0.001	
	Step sizes for cloud integration	Maximum integration step	300	s
		Fixed step size	0.01	s
		Number of fixed size output steps	20	
		Multiplier for output step sizes	1.2	
	Concentration grid definition	Critical separation ratio	0.2	fraction
		Spacing parameter for the grid in the x dimension	0.1	
		Number of grid points in time dimension	100	
		Number of grid points in Y and Z direction	50	
		Use grid	Use grid	
Limits	Minimum limits	Minimum temperature allowed	-262.2	degC
		Minimum release velocity for cont. release	0.1	m/s
		Minimum continuous release height	0	m
	Maximum limits	Maximum temperature allowed	926.9	degC
		Maximum distance for dispersion	5E+04	m
		Maximum height for dispersion	1000	m
	Treatment of mixing layer	Treatment of top mixing layer	Constrained	

Discharge parameters

Discharge parameters

TKO Project_Biogas_Expand_240320\Parameters

Tab	Group	Field	Value	Units
Discharge constants	Capping options	Velocity capping method	Fixed velocity	
		Maximum release velocity	1E+08	m/s
	Short pipe modelling	Minimum RV diameter ratio	1	
		Relief valve safety factor	1.2	
		Critical pressure greater than flow phase	0.3447	bar
		Capping of pipe flow rates	Use leak scenario cap, disallow flashing	
	Equation constants	Continuous critical Weber number	12.5	
		Instantaneous critical Weber number	12.5	
		Venting equation constant	24.82	
Reference	Droplet handling	Droplet method - continuous only	Modified CCPS	
	Phase data	Minimum drop diameter allowed	0.01	um
		Maximum drop diameter allowed	1E+04	um
		Default liquid fraction	1	fraction
		Use Bernoulli for forced -phase liq-liq discharge	Use compressible flow eqn	
	Short pipe modelling	Tolerance	0.0001	
Scenario	Release location	Elevation	1	m
Short pipe	Pipe characteristics	Pipe roughness	0.045	mm
	Frequencies	Frequency of bends in pipe	0	/m
		Frequency of couplings in pipe	0	/m
		Frequency of junctions in pipe	0	/m
	Frequencies of valves	Frequency of excess flow valves	0	/m
		Frequency of non-return valves	0	/m
		Frequency of shut-off valves	0	/m
	Velocity head losses	Excess flow valve velocity head losses	0	
		Non-return valve velocity head losses	0	
		Shut-off valve velocity head losses	0	
Long pipe	Long pipe	Model heat transfer	No modelling of heat	

			transfer	
		Thermodynamic option for gas pipelines	Non-ideal gas	
		Number of time steps	100	
		Maximum number of data points	1000	
	Pipe characteristics	Friction factor method	Fannelop's (GSPP)	
	Small holes method (Long pipelines only)	Small hole size discharge method	Steady state orifice model	
		Relative size for "small" breach - liquid	0.2	
		Relative size for "small" breach - vapour	0.04	
	Crater modelling	Fracture length	12	m
Time varying releases	Modelling of time-varying leaks and line ruptures	Vacuum relief valve	Operating	
		Vacuum relief valve set point	0	bar
	Safety system modelling for time-varying releases	Safety system modelling (isolation and blowdown)	No	
Safety systems	Isolation for time-varying releases	Time to isolation	0	s
	Blowdown for time-varying releases	Time to blowdown actuation	0	s
Discharge parameters	Model settings	Atmospheric expansion method	DNV recommended	
		Phase change upstream of orifice?	Disallow liquid phase change only (metastable liquid)	
	Droplet break-up mechanism	Droplet break-up mechanism - instantaneous	Use flashing correlation	
		Droplet break-up mechanism - continuous	Do not force correlation	

DNV

Jet fire parameters

Jet fire parameters

TKO Project_Biogas_Expand_240320\Parameters

Tab	Group	Field	Value	Units
Jet fire reference data	Constant for jet fire calculation	Jet fire averaging time	20	s
	Constants for radiation calculation	Maximum SEP for a jet fire	350	kW/m2
	Flammable-probit inner-ellipse risk calculations	Measure to use for critical radiation	Intensity	
	Miller model parameters	Radiative fraction method	Miller	
		Lift off option	DNV	
		Radiation intensity capping method	Use Boltzmann's law	
Jet fire	Jet fire method	Jet fire method	Cone model	
	Result types to calculate	Calculate probit	No	
		Calculate dose	No	
		Calculate lethality	No	
	Radiation levels	Number of input radiation levels	3	
		Intensity levels	9.8, 19.5, 35	kW/m2
		Probit levels		
		Dose levels		
		Lethality levels		fraction
	Parameters	Rate modification factor	3	
		Jet fire maximum exposure duration	20	s
	Cone model data	Horizontal options	Use standard method	
		Correlation	Recommended	
		Flame-shape adjustment if grounded	Yes	
	Surface emissive power	Calculation method for surface emissive power	Calculate SEP	
		Flame emissive power		kW/m2
		Emissivity fraction		fraction
	Stoichiometric mass fraction calculation	Use material property system	No	

method

Pool fire parameters

Pool fire parameters

TKO Project_Biogas_Expand_240320\Parameters

Tab	Group	Field	Value	Units
Pool fire reference data	Minimum pool duration for pool fire risk	Instantaneous releases	10	s
		Continuous releases	10	s
	Maximum duration for pool fire sizing	Apply maximum duration?	No	
		Cut off duration for pool fire sizing	300	s
	Flammable-probit inner-ellipse risk calculations	Measure to use for critical radiation	Intensity	
	Constants for radiation calculation	Maximum surface emissive power for pool fires	350	kW/m2
Pool fire	Result types to calculate	Calculate probit	No	
		Calculate dose	No	
		Calculate lethality	No	
	Radiation levels	Number of input radiation levels	3	
		Intensity levels	9.8, 19.5, 35	kW/m2
		Probit levels		
		Dose levels		
		Lethality levels		fraction
	Parameters	Radiative fraction for general fires	0.4	fraction
		Pool fire maximum exposure duration	20	s
		Two-zone pool fire model	No	

Fireball and BLEVE blast parameters

Fireball and BLEVE blast parameters

TKO Project_Biogas_Expand_240320\Parameters

Tab	Group	Field	Value	Units
Constants	Constants for radiation calculation	Maximum surface emissive power	400	kW/m2
	Flammable-probit inner-ellipse risk calculations	Measure to use for critical radiation	Dose	
Fireball	Result types to calculate	Calculate probit	No	
		Calculate dose	No	
		Calculate lethality	No	
	Radiation levels	Number of input radiation levels	3	
		Intensity levels	9.8, 19.5, 35	kW/m2
		Probit levels		
		Dose levels		
		Lethality levels		fraction
	Parameters	Mass modification factor	3	
		Fireball maximum exposure duration	20	s
	Calculation method	Fireball model	Martinsen time varying	
		TNO model flame temperature	1727	degC
BLEVE blast parameters	BLEVE blast parameters	Air or ground burst	Ground burst	
		Ideal gas modeling	Model as real gas	
		Model option	CCPS second edition (2010)	
		Minimum distance	0	m
		Number of distance points	100	

Flammable parameters

Flammable parameters

TKO Project_Biogas_Expand_240320\Parameters

Tab	Group	Field	Value	Units
Flammables	Modelling of immediate flash fire	UFL multiple for immediate ignition	1	
		Cut off fraction for cloud volume	0.001	fraction
	Short duration effects	For time-varying releases	Do not model short duration effects	
		Match fireball duration and mass released	No	
		Cut off time for short continuous releases	20	s
	Results grid steps	Flammable result grid step in X-direction	10	m
	Flammable concentrations in cloud	Flammable mass calculation method	Mass between LFL and UFL	
		Flammable averaging time	18.75	s
		LFL fraction to finish	1	fraction
	Wind sector modelling for flammable hazards	Number of wind subdivisions per sector	1	
Radiation	Observer properties	Observer type radiation modelling flag	Planar	
		Observer direction	Variable	
		Angle of inclination	0	deg
		Angle of orientation	0	deg
	Radiation probit values (units of dose in probit equation is (W/m2)^Probit N value).s)	Probit N value	1.333	
		Probit A value	-36.38	
		Probit B value	2.56	
	Tolerances in radiation calculations	Absolute tolerance for linked radiation calcs	1E-10	
		Relative tolerance for radiation calculations	0.01	fraction
	Radiation versus distance	Number of radiation/distance points in linked radiation calculations	50	
	Solar radiation	Solar radiation	Exclude from calculations	

Flammable risk	Risk for fireball, jet fire and pool fire	Number of lethality ellipses	5	
		Critical radiation intensity	35	kW/ m2
		Critical radiation dose (W/m2)4/3.s	2.29E+07	
		Minimum probability of death	0.01	fractio n
		Ellipse linear spacing variable	Probit	
	Flash Fires	Method for fitting ellipse to flash fire shape	ChiSq method	
	Free field modelling of delayed ignition	Use free field modelling	No free field	
		Distance to site boundary	0	m
		Late pool fire	Exclude effects	
	Flammable risk	Basis for calculations	Centreline height	
		Population omega factor	0	
		Indoor population omega factor	0	
		Inter-ellipse interpolation method	Weighted	
		Include jet fire effects with delayed ignition outcomes	Exclude effects	
	Immediate ignition method	Immediate ignition method	0	
Ignition	CCPS	CCPS type ignition source	No	
	Cox-Lees-Ang and UKOOA ignition modelling	Fraction of ignition probability for immediate ignition	0.3	

Explosion parameters

Explosion parameters

TKO Project_Biogas_Expand_240320\Parameters

Tab	Group	Field	Value	Units
Overpressures	Explosion overpressures for reporting (gauge)	Overpressure levels	0.02068, 0.1379, 0.2068	bar
	Explosion centre location criterion and minimum flammable mass parameters	Explosion location criterion	Cloud front (LFL fraction)	
		Minimum explosive mass	0	kg
Explosion parameters	Vapour liquid method	Use explosion mass modification factor	Yes	
		Explosion mass modification factor	3	
	Explosions	Minimum probability of death for explosions	0.001	
Multi-Energy	Multi-Energy: Uniform confined	Uniform confined explosion strength	10	
		Uniform confined method explosion efficiency	12.5	%
	Multi-Energy: User-defined	Unconfined explosion strength	2	
		Unconfined explosion efficiency	100	%
BST and ME	BST and ME	Cloud shape of area integration	Elliptical	
		Explosion efficiency method	100% efficiency	
		Maximum number of effect points along transect	2	
		Minimum explosion energy	0	kJ
	Curve fitting method	Explosion type calculation method	Polynomial curve-fit equations	
		Number of blast curve discretisation Points	30000	
	Calculation method	Flammable mass calculation type	Area weighted mass integral	
	Cloud view timesteps	Between cloud views	Minimise gaps	
		Maximum number of time steps	100	
		Number of time steps - continuous clouds	5	
		Number of timesteps - time varying clouds	10	

	Cloud view control	Number of X steps per view	21	
		Minimum X step	0.1	m
TNT	TNT parameters	Air or ground burst	Air burst	
ME (3D options)	3D Cloud ME / Purple Book explosions	Unconfined explosion strength	2	
		Explosion efficiency	100	%
	3D Obstructed region	Unconfined explosion strength	2	
		Explosion efficiency	100	%
BST and ME (3D options)	Critical separation specification	Separation specification	Use ratio	
		Critical separation distance	0	m
		Critical separation ratio	0.5	
	Cloud view methods	Method option	Normal dispersion	
		Cylinder height over radius ratio	3	
		Concentration method for filling	Stoichiometric	
		Elevation of floor or ceiling	0	m
	Pressure exceedance results	Pressure exceedance curves	Calculate	
		Minimum pressure filter	0.01	bar
	Buildings	Reflection method	Calculated angle	
		Building damage method	Worst point	
	Detonation of VCE in obstructed regions	Model option	Normal explosion	
		Critical VBR for detonation	0.15	fraction
		Flame speed for detonation (Mach number)	0.8	fraction
BST (3D options)	BST volume blockage criteria for congestion	Low to medium criterion	0.006	
		Medium to high criterion	0.08	
	Method for correcting the ground effect	Method option	Ground reflection	
		Reflection factor	1	
	Method for combining obstructed regions	Options available	Volume averaged	

General parameters

General parameters

TKO Project_Biogas_Expand_240320\Parameters

Tab	Group	Field	Value	Units
General reference data	Discharge and dispersion	Maximum release duration	3600	s
	Reporting of concentrations and effects	Height of interest	0	m
Long pipe	Overall pipeline parameters	Maximum number of event locations (automatic event spacing logic)	1000	
	Section / sub-section parameters	Tolerance (distance) for section boundary checking	0.1	m
		Maximum fraction of pipe length for sub-sectioning	0.2	fraction
		Minimum ideal sub-section piping length	500	m
		Maximum fractional pressure drop across a sub-section	0.8	fraction

Pool vaporisation parameters

Pool vaporisation parameters

TKO Project_Biogas_Expand_240320\Parameters

Tab	Group	Field	Value	Units
Pool vaporisation	Cut-offs for pool evaporation rates	Toxics cut-off rate for pool evaporation	0.001	kg/s
		Flammable cut-off rate for pool evaporation	0.1	kg/s
	Pool vaporisation modelling	Evaporation on land correlation	MacKay and Matsugu	
		Solver tolerance	0.001	

Toxic parameters

Toxic parameters

TKO Project_Biogas_Expand_240320\Parameters

Tab	Group	Field	Value	Units
Toxics	Calculation options	Multi-comp. toxic calc. method	Most toxic material probit	
		Probit calculation method	Use probit	
		Toxics: minimum probability of death	0.001	
		Tolerance on minimum probability of death	0.01	
		Toxic averaging time	600	s
	Toxic grid parameters	Use toxics grid?	Use grid	
		Number of grid points in X direction	99	
		Number of grid points in Y direction	50	
Toxic parameters	Exposure time data	Set averaging time equal to exposure time	Use a fixed averaging time	
		Cut-off fraction of toxic load for exposure time calculation	0.05	fraction
		Cut-off concentration for exposure time calculations	0	fraction
	Toxic contours	Number of toxic levels	4	
		Dose levels	1.3E+05, 1.3E+06, 1.3E+07, 1.3E+08	
		Probit levels	2, 3, 4, 10	
		Lethality levels	0.001, 0.01, 0.1, 0.99	fraction
Concentration based risk	Concentration based risk	ERPG 3 factor	2.54	
		Concentration type	ERPG 3	
		Use outdoor or indoor concentration	Use outdoor	
Threshold concentration	Threshold concentration (N.B. Concentrations based on mixture rather than toxic component(s))	Threshold concentration	1E+06	ppm
		Minimum fatality if threshold concentration reached	0	fraction

Weather parameters

Weather parameters

TKO Project_Biogas_Expand_240320\Parameters

Tab	Group	Field	Value	Units
Atmospheric constants	Constants	Atmospheric pressure	1.013	bar
		Atmospheric molecular weight	28.97	kg/kmol
		Atmospheric specific heat at constant pressure	1.004	kJ/kg.deg K
	Temperature and pressure data	Atmospheric T and P profile	Temp. logarithmic; Pres. linear	
		Temperature reference height	0	m
	Wind speed data	Wind speed profile	Power law	
		Wind speed reference height	10	m
		Cut-off height for wind speed profile	1	m
Atmospheric parameters	General atmospheric parameters	Atmospheric temperature	25	degC
		Relative humidity	0.8	fraction
		Solar radiation flux	0.5	kW/m2
	Mixing layer height vs. Pasquill stability	Mixing layer height for Pasquill stability A	1300	m
		Mixing layer height for Pasquill stability A/B	1080	m
		Mixing layer height for Pasquill stability B	920	m
		Mixing layer height for Pasquill stability B/C	880	m
		Mixing layer height for Pasquill stability C	840	m
		Mixing layer height for Pasquill stability C/D	820	m
		Mixing layer height for Pasquill stability D	800	m
		Mixing layer height for Pasquill stability E	400	m
		Mixing layer height for Pasquill stability F	100	m
		Mixing layer height for Pasquill stability G	100	m
	Building data	Building exchange rate	4	/hr

		Tail time	1800	s
Substrate data	Surface temperature	Surface temperature for dispersion calculations	25	degC
		Surface temperature for pool calculations	25	degC

Building parameters

Building parameters

TKO Project_Biogas_Expand_240320\Parameters

Tab	Group	Field	Value	Units
In-building release	Ventilation	Ventilation type	Natural ventilation	
		Air changes	3	/hr
		Vent location		
		Exhaust diameter		m
		Vent flowrate		m3/hr
	Indoor explosion model	Indoor explosion model	NFPA 68 (2007)	
		Internal obstacle to building area ratio		
		Vent panel height		m
		Vent panel location		
Indoor toxic modelling	Building data	Building exchange rate	4	/hr
		Tail time	1800	s
		Wind speed dependent	From Building	
Building wake	Chimney	Chimney diameter	2.5	m
		Chimney height	60	m

Event tree parameters

Event tree parameters

TKO Project_Biogas_Expand_240320\Parameters

Tab	Group	Field	Value	Units
Standalones	Standalones	Probability of a fireball	1	fraction
		Probability of a jet fire - see "Cont. - no rainout"		
		Probability of a pool fire	1	fraction
		Toxic probability	1	fraction
Explosion probability	Volume based	Volume based explosion probabilities	No	
		Low - medium boundary	0.45	m/s
		Medium - high boundary	0.75	m/s
		Number of volume definitions	3	
		Obstructed cloud volume	200, 3000, 6000	m3
		Low flame speed probability	0, 0.3, 0.6	fraction
		Medium flame speed probability	0.3, 0.6, 0.9	fraction
		High flame speed probability	0.6, 0.9, 1	fraction
	Detonation probability [used only when detonation model is selected under Explosion parameters/BST and ME (3D options)]	Probability of detonation for delayed ignitions	1	fraction
Continuous - no rainout	Immediate ignition	Immediate ignition	0.3	fraction
	Immediate ignition short duration effects	Fraction for effects	1	fraction
		Fireball	1	fraction
		Flash fire	0	fraction
		Explosion with flash fire	0	fraction
	Immediate ignition long duration effects	Horizontal fraction	0.6	fraction

	Immediate ignition long duration effects and standalone jet fires	Horizontal jet fire effects	1	fraction
		Vertical jet fire effects	1	fraction
	Delayed ignition	Flash fire	1	fraction
		Explosion with flash fire	0	fraction
Continuous - rainout	Immediate ignition	Immediate ignition	0.3	fraction
	Immediate ignition short duration effects	Fraction for effects	1	fraction
		Fireball with pool fire	1	fraction
		Fireball alone	0	fraction
		Flash fire with pool fire	0	fraction
		Flash fire alone	0	fraction
		Explosion with flash fire and pool fire	0	fraction
		Explosion with flash fire	0	fraction
		Pool fire alone	0	fraction
	Immediate ignition long duration effects	Horizontal fraction	0.6	fraction
		Horizontal jet fire alone	0	fraction
		Horizontal release pool fire effects	0	fraction
		Horizontal jet fire with pool fire	1	fraction
		Vertical release pool fire effects	0	fraction
		Vertical jet fire alone	0	fraction
		Vertical jet fire with pool fire	1	fraction
	Delayed ignition of cloud	Residual pool fire	0.15	fraction
		Flash fire with/without pool fire	1	fraction

		Explosion with flash fire and with/without pool fire	0	fraction
Instantaneous - no rainout	Immediate ignition	Immediate ignition	0.3	fraction
	Immediate ignition short duration effects	Fireball alone	1	fraction
		Flash fire	0	fraction
		Explosion with flash fire	0	fraction
	Delayed ignition	Flash fire	1	fraction
		Explosion with flash fire	0	fraction
Instantaneous - rainout	Immediate ignition	Immediate ignition	0.3	fraction
	Immediate ignition short duration effects	Fireball with pool fire	1	fraction
		Fireball alone	0	fraction
		Flash fire with pool fire	0	fraction
		Flash fire alone	0	fraction
		Explosion with flash fire and pool fire	0	fraction
		Explosion with flash fire	0	fraction
		Pool fire alone	0	fraction
	Delayed ignition of cloud	Residual pool fire	0.15	fraction
		Flash fire with/without pool fire	1	fraction
		Explosion with flash fire and with/without pool fire	0	fraction

Grid parameters

Grid parameters

TKO Project_Biogas_Expand_240320\Parameters

Tab	Group	Field	Value	Units
Effects grid	Grid	Grid calculation method	Number of cells	
		Grid cell size	10	m
		Maximum number of cells	160000	
		Grid sizing	Calculated	
	Grid bounds	Grid bounds minimum x	-0.4581	m
		Grid bounds maximum x	115.4	m
		Grid bounds minimum y	-26.59	m
		Grid bounds maximum y	75.83	m

General risk parameters

General risk parameters

TKO Project_Biogas_Expand_240320\Parameters

Tab	Group	Field	Value	Units
General risk	General risk	Maximum number of subdivisions per square	1	
		Maximum number of subsquares across ellipse	10	
		Aversion index	1.2	
		Method for handling indoor / outdoor risk	Indoor and outdoor risk calculations	
	Risk Level Lower Limit	Minimum case frequency	1E-12	/ AvgeYear
		Minimum event probability	1E-12	
	Toxic risk	Factor for toxic F-N spread	2	
	Explosions	Optimise explosions	No optimisation	
		Number of explosion steps	100	
		Tolerance for distance to overpressure thresholds	1E-06	
	Outdoor risk	Fraction of population indoors for societal risk	0.9	fraction
		Fraction of population indoors for individual risk	0	fraction
IRISK	Run control	IRISK run mode	Use IRISK	
	Parallelization control	CPU / GPU Parallelization mode	Asynchronous (multi-threaded)	
		Asynchronous parallelization mode	MT-Single-Precision (GPU-CUDA)	
	Effect zone modelling control	Specify number of radiation X steps?	No	
		Specify number of flash fire X steps?	No	
		Specify number of explosion X steps?	No	
		Number of X steps per radiation ellipse	21	
		Number of X steps per explosion source	21	
		Number of X steps per flash fire envelope	21	
	Multi-grids	Use multi-grid?	Partial multi-grid	

		Number of zoom levels	12	
		Constant zoom level multiplier	2	
		Target number of grid cells spanning effect zone	300	
		Multi-grid parallelization options	Optimized structured grid	
Ignition	Ignition source shut down	Active shut down	No shut down	
		Shut down time		s
		Cooling time		s

Outdoor vulnerability

Outdoor vulnerability

TKO Project_Biogas_Expand_240320\Parameters\General risk parameters

Tab	Group	Field	Value
Enable	Enable	Info	Can be made editable on the Workspace dialog 'Editing' tab

Indoor vulnerability

Indoor vulnerability

TKO Project_Biogas_Expand_240320\Parameters\General risk parameters

Tab	Group	Field	Value
Enable	Enable	Info	Can be made editable on the Workspace dialog 'Editing' tab

Surface parameters

Surface parameters

TKO Project_Biogas_Expand_240320\Parameters

Tab	Group	Field	Value	Units
Dispersing surface	Properties	Surface over which the dispersion occurs	Land	
		Surface roughness length	User-defined	
		User-defined length	183.2	mm
Surface for pools	Type of surface for pools	Type of surface for pools	Concrete	
	User defined surface properties	Pool minimum thickness	5	mm
		Surface thermal diffusivity	9.48E-07	m2/s
		Surface roughness factor	2.634	
		Surface thermal conductivity	0.00221	kJ/ m.s.degK
Bund properties	Dimensions	Bund height	0	m
		Bund area (internal)	0	m2
		Bund diameter (internal)	0	m
	Whether the bund can overflow	Bund area multiplier for catastrophic rupture	1.5	

Annex C

Consequence Data

Section Tag	Description	Hole Size	Maximum Downwind Impact Distance (m)			
			FB	JF	FF	LFL
01	Anaerobic Digester	Cat	76.7	-	23.6	23.3
		10mm	-	1.8	0.5	-
		25mm	-	4	1.4	-
		Rup	-	12.6	4.7	-
02	H2S Removal	Cat	21.8	-	6.0	5.7
		10mm	-	1.8	0.5	-
		25mm	-	4	1.4	-
		Rup	-	12.6	4.7	-
03	Biogas Holder	Cat	64.7	-	19.5	19.4
		10mm	-	1.8	0.6	-
		25mm	-	4	1.4	-
		Rup	-	12.6	4.5	-
04	Biogas Booster	10mm	-	1.8	0.6	-
		25mm	-	4	1.4	-
		Rup	-	12.6	4.5	-
05	Biogas Transfer Pump	10mm	-	1.8	0.6	-
		25mm	-	4	1.4	-
		Rup	-	12.6	4.5	-

Annex D

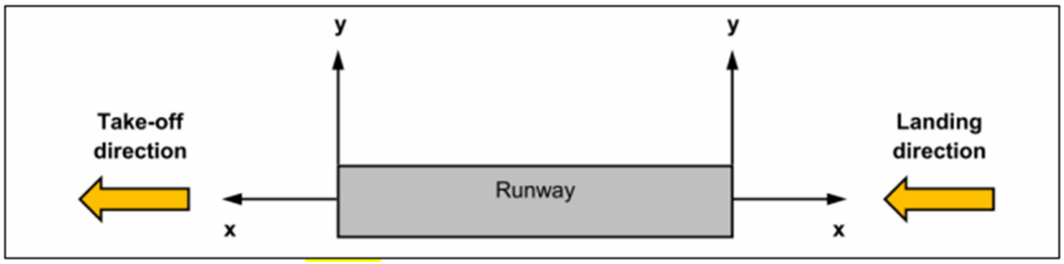
External Hazard Review

Aircraft Crash

The Project site is located approximately 37 km east of the Hong Kong International Airport. The HSE [24] method has been used to estimate the frequency of aircraft crash per year as below.

The crash frequency model considers the parameters of the target area, including the longitudinal (x) and perpendicular (y) distances from the runway threshold.

Exhibit D1 Aircraft Crash Coordinate System



The crash frequency per unit ground area (per km²) is calculated as:

$$g(x,y) = NRF(x,y)$$

where N is the number of aircraft movements per year, R is the possibility of an aviation accident per movement, and F(x,y) is the spatial distribution of crashes. The distribution is divided into two scenarios: Landings and Take-off. The formulas are given by:

Landings

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

where $x > -3.275km$

Take-off

$$F_T(x,y) = \frac{(x+0.6)}{1.44} e^{\frac{-(x+0.65)}{12}} \left[\frac{46.25}{\sqrt{2\pi}} e^{-0.5(125y)^2} + 0.9635 e^{-4.1|y|} + 0.08 e^{-|y|}\right]$$

where $x > -0.6km$

The two equations for the spatial distribution are valid only under a specific range of x values. Otherwise, the possibility of the impact would be zero. The two equations can be applied to 25R, 25L runways for aircraft arrivals and 07R, 07L runways for aircraft departures.

The possibility of an aviation accident per movement R is obtained from the NTSB database for fatal accidents in U.S. involving scheduled airline flights during the period 1986 – 2010 (NTSB). Taking average of the 10-year period, it is suggested that the possibility of an aviation accident is at a rate of 2 x 10^{-7} per flight. There are 13.5% of accidents associated with landing, 15.8% associated with take-off. Hence, it can be estimated that the possibility of aviation accident for the landing is 2.7x10^{-8} per flight and take-off is

4.0×10^{-8} per flight, in line with previous QRA [8]. The number of aircraft movements per year N is obtained from the Hong Kong International Airport (HKIA) database from 2010 to 2023.

Table D1 Hong Kong International Airport Civil International Air Transport Movements of Aircraft

Year	Landing	Take-off	Total
2009	139,715	139,686	279,401
2010	153,279	153,260	306,539
2011	166,919	166,887	333,806
2012	175,861	175,823	351,684
2013	186,048	186,032	372,080
2014	195,520	195,488	391,008
2015	203,043	203,005	406,048
2016	205,793	205,773	411,566
2017	210,339	210,320	420,659
2018	213,899	213,867	427,766
2019	209,904	209,891	419,795
2020	80,330	80,336	160,666
2021	72,403	72,407	144,810
2022	69,352	69,377	138,729
2023	138,054	138,056	276,110

Due to COVID, the number of aircraft movements has been significantly reduced between 2020 and 2022. The movement recovered in 2023 but is still only 65% as compared to 2019. The growth rate between 2009 and 2019 is estimated to be 4.21%. If the same growth rate is applied to the period between 2020 and 2041(operational phase of EPP), the number of aircraft movement will be about 1,039,835. The movement number for both landing and take-off adopted in the calculation has been divided into 8, assuming that aircraft are using the runways equally.

In the future, 3RS system would be applied on aircraft landing and take-off. For the aircraft using runways 07R or 07L, are arriving from south-west. The longitudinal distance from the runway is hence around -35km, which is much smaller than the minimum value of -3.275km. For aircraft using runways 25L or 25C for departures, they are taking-off toward south-west and have similar situation with runways 07R and 07L for landing. Hence, they have no potential impact to the proposed area, or other sites in the vicinity.

Table D2 Calculation for Aircraft Crash Frequency

Runway	x (km)	y (km)	F(x,y)	N (per year)	R (per flight)	Crash frequency (per unit area)	Target area (km2)	Crash Frequency (per year)
25R Landing	30	18.5	1.2E-11	129,979	2.7E-08	2.1E-14	2.85E-02	1.2E-15
25L Landing	30	17	1.6E-11	129,979	2.7E-08	2.9E-14	2.85E-02	1.6E-15
07R Landing	-34.5	17	0.0E+00	129,979	2.7E-08	0.0E+00	2.85E-02	0.0E+00
07L Landing	-34.5	18.5	0.0E+00	129,979	2.7E-08	0.0E+00	2.85E-02	0.0E+00
25C Landing	No Landings at 25C							0.0E+00
07C Landing	No Landings at 07C							0.0E+00
07L Take-off	No Take-off at 07L							0.0E+00
25R Take-off	No Take-off at 25R							0.0E+00
07C Take-off	30	22.2	2.9E-11	129,979	4.0E-08	7.9E-14	2.85E-02	4.5E-15
07R Take-off	30	17	5.5E-09	129,979	4.0E-08	1.5E-11	2.85E-02	8.2E-13
25L Take-off	-34.5	17	0.0E+00	129,979	4.0E-08	0.0E+00	2.85E-02	0.0E+00
25C Take-off	-34.5	22.2	0.0E+00	129,979	4.0E-08	0.0E+00	2.85E-02	0.0E+00

According to Table G2, the total crash frequency is 8.3E-13 per year, which is much smaller than 1.0E-9 per year. The risk of aircraft crash at the proposed site area could therefore not consider for further assessment.

Earthquake

As per QRA Methodology for LPG Installation [10], it was concluded that external events including earthquakes are to be considered but not quantified in the assessment of risks from LPG installations. The methodology for external events is considered also applicable to biogas plant. There are also recent studies conducted by the Geotechnical Engineering Office [11][12] that classified Hong Kong as a region of low to moderate seismicity. The seismicity in the vicinity of Hong Kong is considered similar to that of the areas of Central Europe and the Eastern areas of the U.S. [13] and much lower than places like Japan, Taiwan and the western USA [11]. As such, an earthquake can be considered an unlikely event in Hong Kong. An earthquake has the potential to cause damage to the facilities inside proposed EPP due to ground movement and vibration. It is noted that the generic failure frequencies adopted in this QRA Study [14] are based on historical incidents that included earthquakes as one of the potential causes of failure.

External Fire

Vegetation in the East side of EPP is observed. However, it is too far to affect major equipment such as Anaerobic Digesters and Biogas Holders. Therefore, hazard due to external fire is not further considered in this assessment.

Landslide

A slope is located in the East side of EPP. However, major equipment such as Anaerobic Digesters and Biogas Holders are too far to be affected from landslide. Thus, landslide causing damage is not considered further in this assessment.

Vehicle Impact

Only authorized vehicles will be permitted to enter the proposed EPP, and speed will be restricted for vehicle movements within the site. Safety Markings and marked crash barriers will be provided to the above ground piping, digesters and gasholders near the internal road. According to information provided from Proposed EPP, an estimation of 9 waste truck per day would be visiting the EPP. The Road Traffic Accident Statistic published by Hong Kong Transport Department is used to estimate the likehood of vehicle impact. Based on the data published between 2006 and 2020, the average medium and high impact accident involvement rate are 0.14 and 0.02 per million vehicle km respectively. Based on the length of internal road and taking credit of the provision of crash barrier with frequency reduction factor of 0.1, the frequencies of leak and rupture to the Anaerobic Digesters and Biogas Holders are provided below:

Table D3 Event Frequency by Vehicle Impact

Equipment	Leak	Rupture
Anaerobic Digesters	9.22E-07	1.02E-07
Biogas Holders	8.64E-07	9.61E-08

The event frequency of hazards causing by vehicle impact to Anaerobic Digesters and Biogas Holders is estimated to be in the range of 10^{-7}/yr or less. This is at least 2 orders of magnitudes lower than the frequencies provided in Table 5.2 . Thus, vehicle impact can be concluded to pose insignificant risk to the overall facility and not required to be further assessed.

Subsidence

Subsidence is usually slow in movement and such movement can be observed and remedial action can be taken in time. Therefore, the probabilities of severe environmental events and subsidence are very small or negligible so these external events are not further considered in the study.

Severe Environmental Event

Loss of containment as a result of a severe environmental event such as a typhoon or tsunami (i.e. a large wave following an earthquake) is assumed to be an insignificant contributor to the risk levels at this site. Storm surge has been known to occur in Hong Kong during a typhoon, causing flooding in low lying areas.

However, proposed EPP is located at +10mPD ground elevation and it is unlikely that the facilities would be subject to such phenomena.

Lightning

The proposed EPP will be equipped with lightning protection system to protect the equipment from ignition. The installations will be protected with lightning conductors to safely earth direct lightning strikes. The double grounding system will be inspected regularly. With sufficient protection system, the effect of lightning strike is not further considered in this assessment.

Third Party Damage

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 EPP would be surrounded by fence wall with typical height of 3 m to avoid illegal entrance of third party. Thus, third party damage is not further considered in this assessment.