5 HAZARD TO HUMAN LIFE ASSESSMENT

5.1 INTRODUCTION

This section presents the findings of the hazard assessment undertaken for the Project. The hazard assessment includes an evaluation of the risk to off-site population of the Project due to the transport and use of natural gas, and also an evaluation of the risk during construction and operation phases of the Project due to the transport, storage, and use of other non-fuel dangerous goods.

5.2 LEGISLATION REQUIREMENT AND EVALUATION CRITERIA OVERVIEW

5.2.1 Overview

The key legislation and guidelines that are considered relevant to the development of the Project are as follows:

- *EIA Study Brief* (*ESB-286/2015*), Section 3.4.4 and Appendix B;
- *Environmental Impact Assessment Ordinance* (*EIAO*), *Cap. 499*;
- *Technical Memorandum on EIA Process* (*EIAO-TM*);
- *Hong Kong Planning Standards and Guidelines* (*HKPSG*), *Chapter 12*;
- *Gas Safety Ordinance*, *Cap. 51*; and
- *Dangerous Goods Ordinance*, *Cap. 295*.

5.2.2 Risk Criteria

Section 2 of Annex 4 of *EIAO-TM* specifies the individual risk guidelines and societal risk guidelines.

Individual risk is the predicted increase in the chance of fatality per year to a hypothetical individual who remains 100% of the time at a given stationary point. The individual risk guidelines require that the maximum level of off-site individual risk associated with a hazardous installation should not exceed 1 in 100,000 per year, i.e. 1×10^{-5} per year.

Societal risk expresses the risks to the population in the vicinity of the hazardous installations. The societal risk guidelines for acceptable risk levels are presented graphically in *Figure 5.1*. It is expressed in terms of lines plotting the frequency (F) of N or more deaths in the population from incidents at the installation. Two FN risk lines are used in the Hong Kong Government Risk Guidelines (HKRG) to demark "Acceptable" or "Unacceptable" regions. In order to avoid major disasters resulting in more than 1,000 deaths, 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 mitigation measures which can reduce risks will be considered.

5.3 STUDY OBJECTIVE

The objective of this hazard to human life assessment is to assess the risk to life of the off-site population from the Project during construction and operation phases. The detailed objectives of the assessment are:

- To identify all credible hazardous scenarios associated with transport and use of natural gas, and transport, storage and use of other non-fuel gas dangerous goods, with a view to determining a set of relevant scenarios to be included in a quantitative risk assessment (QRA);
- To execute a QRA of the set of relevant hazardous scenarios, expressing population risks in both individual and societal terms;
- To compare individual risk and societal risk with the criteria for evaluating hazard to life stipulated in Section 2 of Annex 4 of *EIAO-TM*; and
- To identify and assess practicable and cost-effective risk mitigation measures, if required.

5.4 STUDY METHODOLOGY

5.4.1 Overview

The methodology adopted in this QRA study is consistent with the approved studies, including both safety case and EIA studies, listed in the following:

- DNV, *Safety Case Report for Black Point Gas Supply Project, Report No. PP019678*, Revision No. 2 (1) ;
- ERM, EIA for *Black Point Gas Supply Project*, Revision 3 (2);
- ERM, EIA for *Liquefied Natural Gas (LNG) Receiving Terminal and Associated Facilities* (3);
- ERM, EIA for *1,800 MW Gas-fired Power Station at Lamma Extension* (4);

(1) DNV, *Safety Case Report for Black Point Gas Supply Project, Report No.: PP019678*, Revision No.2, August 2013.

(2) ERM, EIA for *Black Point Gas Supply Project* (Register No.: AEIAR-150/2010), February 2010.

(3) ERM, EIA for *Liquefied Natural Gas (LNG) Receiving Terminal and Associated Facilities* (Register No.: AEIAR-106/2007), December 2006.

(4) ERM, EIA for *1,800 MW Gas-fired Power Station at Lamma Extension* (Register No.: AEIAR-010/1999), February 1999.

- ERM/ BV, EIA for *Desalination Plant at Tseung Kwan O – Feasibility Study* [1];
- ERM, EIA for *In-situ Reprovisioning of Sha Tin Water Treatment Works – South Works – Designs and Construction – Hazard to Life Assessment* [2];
- ERM, *Lamma Power Station Extension: QRA for Gas Facilities* [3];
- ERM, EIA for *South Island Line (East) – Hazard to Life Assessment* [4]; and
- ERM, EIA for *Development of a Biodiesel Plant at Tseung Kwan O Industrial Estate* [5].

5.4.2 QRA Study Approach

The elements of this QRA study are depicted in *Figure 5.2*, and each of the elements is described as below.

Data Collection and Review

Relevant data on the Project and existing facilities such as their layout drawings, design basis, etc. are provided by CLP. Weather data and population data in the vicinity of BPPS are collected and reviewed.

Section 5.5 presents detailed information about the surrounding land, road traffic and marine vessel populations, project time frame, proposed assessment years and meteorological data. *Section 5.6* describes the Project facilities while *Section 5.7* describes the existing BPPS facilities.

Hazard Identification

A Hazard Identification (HAZID) Study including a HAZID Workshop has been conducted to identify all potential hazards, including both generic and site specific for the Project. A review of literature and incident/ accident database was also conducted. These form the basis for identifying all potential hazardous scenarios, which were included in this QRA study.

Section 5.8 presents the details of the HAZID.

(1) ERM/ BV, EIA for *Desalination Plant at Tseung Kwan O – Feasibility Study* (Register No.: AEIAR-192/2015), November 2015.

(2) ERM, EIA for *In-situ Reprovisioning of Sha Tin Water Treatment Works – South Works – Hazard to Life Assessment* (Register No.: AEIAR-187/2015), January 2015.

(3) ERM, *Lamma Power Station Extension: QRA for Gas Facilities*, 2003.

(4) ERM, EIA for *South Island Line (East) – Hazard to Life Assessment* (Register No.: AEIAR-155/2010), Report No.: 248137/51/F, August 2010.

(5) ERM, EIA for *Development of a Biodiesel Plant at Tseung Kwan O Industrial Estate* (Register No.: AEIAR-131/2009), February 2009.

Frequency Analysis

The frequencies, or the likelihood, of the various hazardous scenarios resulting from a natural gas or non-fuel gas dangerous goods release scenario have been derived from historical database and, where necessary, are modified to take into account local factors.

Section 5.9 presents the details of the frequency analysis.

Consequence Analysis

Flammable hydrocarbon and hydrogen, and toxic gas releases were modelled using the PHAST consequence modelling package developed by DNV.

Fragment range analysis for a carbon dioxide (CO_2) boiling liquid expanding vapour explosion (BLEVE) was conducted based on the similar approach adopted in the approved EIA study (1).

Section 5.10 presents the details of the consequence analysis.

Cumulative Risk Assessment

The consequence and frequency data together with weather and population data were subsequently combined using ERM's proprietary software, Riskplot™, which is in line with the previous QRA studies (1) (2) (3), (4) approved by EPD, and EMSD respectively. The software has been independently validated by United Kingdom Health and Safety Executive (UK HSE) to produce the required risk calculations.

The results from the cumulative risk assessment were compared with the risk criteria in Section 2 of Annex 4 of *EIAO-TM*.

Section 5.11 presents the results for the cumulative risk assessment including both individual risk and societal risk.

5.5 DESCRIPTION OF SURROUNDINGS AND STUDY BASIS

5.5.1 Surrounding Population

The BPPS area is generally remote with very low population density in the vicinity. All surrounding population, including land, road traffic and marine vessel population was considered in the analysis, for the following proposed assessment years:

(1) ERM, EIA for *South Island Line (East) – Hazard to Life Assessment* (Register No.: AEIAR-155/2010), Report No.: 248137/51/F, August 2010.

(2) ERM, EIA for *Black Point Gas Supply Project* (Register No.: AEIAR-150/2010), February 2010.

(3) ERM, EIA for *Liquefied Natural Gas (LNG) Receiving Terminal and Associated Facilities* (Register No.: AEIAR-106/2007), December 2006.

(4) ERM, *Lamma Power Station Extension: QRA for Gas Facilities*, 2003.

- Case 0: 2016 as the baseline condition year;
- Case 1a: 2019 as the expected peak impact (in HtLA context) construction year of the 1st CCGT unit;
- Case 1b: 2020 as the expected year of operation of the 1st CCGT unit;
- Case 2a: 2034 as the assumed peak impact (in HtLA context) construction year of the 2nd CCGT unit; and
- Case 2b: 2035 as the assumed year of operation of the 2nd CCGT unit (for worst-case assessment purpose).

The current plan for implementation of the 1st additional CCGT unit is from 2016 to 2019; the implementation of the 2nd additional CCGT unit is expected to be after 2019.

From the Hazard to Life Assessment (HtLA) point of view, there is an expectation of increase in surrounding population in the vicinity of the BPPS; therefore the resulting F-N curve will be on the conservative side should the assessment year for each scenario be further away from 2016.

Therefore, the assessment year of 2019 is considered as the expected peak impact construction year of the 1st CCGT unit from the HtLA point of view; the societal risk impact is expected to be the most conservative among the construction period of the 1st CCGT unit.

The operation year of the 2nd additional CCGT unit is assumed as 2035, 15 years from the operation year of the 1st additional CCGT unit, 2020. This is considered as a reasonably worst-case scenario for the purpose of the HtLA. In the same manner as the assumption for the 1st CCGT unit, the assessment year of 2034 is considered as the expected peak impact construction year of the 2nd CCGT unit from the HtLA point of view.

The safety management measures described in *Section 5.6* shall be implemented as requirements to protect construction workers of the Project from the risks associated with the existing BPPS facilities. With the safety management measures in place, the potential risks to construction workers are expected to be low. The construction workers are not considered as off-site population and are not taken into account in this QRA study.

The assumptions of population estimation are summarised in *Annex 5A*.

Surrounding Land Population Estimation

Based on a review of aerial maps, there is no land based population (building development) in the vicinity of BPPS. The nearest industrial facilities in Lung Kwu Sheung Tan are about 1.4 km away and the nearest proposed residential development in Lung Kwu Tan reclamation area is about 800 m from the site boundary of BPPS. With reference to the detailed consequence analysis, all potential hazardous consequences are not able to reach any land

based population (building development) in the vicinity to BPPS. Therefore, land based population (building development) will not affect the societal risk levels of the Project and therefore not considered in this QRA study.

Surrounding Road Traffic Population Estimation

Access to BPPS is via Lung Kwu Tan Road and this is the only road providing access to villages and industrial sites in this western region of the New Territories.

The population estimation for Lung Kwu Tan Road is based on 2014 Annual Traffic Census, which is the latest available road traffic data. The Annual Average Daily Traffic (AADT) value is 4,170 vehicles per day for station number 5481 from Lung Fai Street to Tsang Kok. With an assumed average speed of 50 km hr^{-1} and an average of three (3) persons per vehicle, the number of persons on the road was estimated as:

No. of persons = (4,170 × Vehicle Occupancy / 24 / Vehicle Speed)
= 4,170 × 3 / 24 / 50
= 10.4 persons km^{-1}

As a conservative approach, it was assumed the annual traffic growth at Lung Kwu Tan Road as one (1) % from 2014 to the proposed operation phase year of 2nd CCGT unit in 2035.

The traffic flow of Yung Long Road was assumed as 10% of day-time traffic flow from Lung Kwu Tan Road, and 10% of day-time traffic flow was assumed during the night-time in this QRA study.

Surrounding Marine Vessel Population Estimation

Black Point is situated near Deep Bay. The marine traffic in the vicinity includes passenger ferries, container ships and river trade vessels going to Guangzhou and other Pearl River ports. Small fishing vessels and leisure crafts also contribute to the marine traffic in the Black Point region.

Marine Vessel Population

The marine vessel population used in this QRA study are as given in *Table 5.1*. The figures are based on BMT's Marine Impact Assessment report (1) except those for fast ferries. The maximum population of fast ferries is assumed to be 450, based on the maximum capacity of the largest ferry operating in the area. However, the average load factors for fast ferries to Macau and Pearl River ports are 62% and 47% respectively (2). Hence, a distribution in ferry population was assumed as indicated in *Table 5.1*. This distribution gives an

(1) BMT Asia Pacific Ltd, *Marine Impact Assessment for Black Point & Soko Islands LNG Receiving Terminal & Associated Facilities*, Pipeline Issues, Working Paper #3, Issue 6, May 2006.

(2) *Passenger Arrivals/Departures and Passenger Load Factors at Cross-Boundary Ferry Terminals*, January to December 2014, Marine Department, Hong Kong SAR.

overall load factor of about 58% which is conservative and covers any future increase in vessel population. There is an additional category in the traffic volume data called "Others". These are assumed to be small vessels with a population of 5.

Table 5.1 Marine Vessel Population

Type of Marine Vessel	Average Population per Vessel		% of Trips
Ocean-Going Vessel	21		
Rivertrade Coastal Vessel	5		
Fast Ferries	450	(largest ferries with max population)	3.75
	350	(typical ferry with max population)	3.75
	280	(typical ferry at 80% capacity)	22.50
	175	(typical ferry at 50% capacity)	52.50
	105	(typical ferry at 30% capacity)	12.50
	35	(typical ferry at 10% capacity)	5.00
Tug and Tow	5		
Others	5		

Marine Vessel Protection Factors

The population on marine vessels is assumed to be provided with some protection from the vessel structure. The degree of protection offered depends on factors such as:

- Size of vessel;
- Construction material and likelihood of secondary fires;
- Speed of vessel and hence its exposure time to the flammable cloud;
- The proportion of passengers likely to be on deck or in the interior of the vessel; and
- The ability of gas to penetrate into the interior of the vessel and achieve a flammable mixture.

Small vessels such as fishing boats provide little protection but larger vessels such as ocean-going vessels provide greater protection. Fast ferries are air conditioned and have a limited rate of air exchange with the outside. Based on these considerations, the fatality probabilities assumed for each type of marine vessel are as given in *Table 5.2*.

Table 5.2 Population at Risk

Marine Vessel Type	Population	Fatality Probability	Population at Risk
Ocean-Going Vessel	21	0.1	2
Rivertrade Coastal Vessel	5	0.3	2
Fast Ferries	450	0.3	135
	350	0.3	105
	280	0.3	84
	175	0.3	53
	105	0.3	32

Marine Vessel Type	Population	Fatality Probability	Population at Risk
	35	0.3	11
Tug and Tow	5	0.9	5
Others	5	0.9	5

Methodology

In this QRA study, the marine traffic population in the vicinity of BPPS has been considered as both point receptors and average density values. The population of all marine vessels is treated as an area average density except for fast ferries which are treated as point receptors.

The marine area around Black Point was divided into 12.67 km^2 grid cells, each grid being approximately 3.6 km × 3.6 km. The transit time for a marine vessel to traverse a grid is calculated based on the travel distance divided by the marine vessel's average speed. The average speed (1) and transit time for different vessel types are presented in *Table 5.3*.

Table 5.3 Average Speed and Transit Time of Different Marine Vessel Type

Marine Vessel Type	Assumed Speed (m s^{-1})	Transit Time (min)
Ocean-Going Vessel	6.0	9.9
Rivertrade Coastal Vessel	6.0	9.9
Fast Ferries	15.0	4.0
Tug and Tow	2.5	23.7
Others	6.0	9.9

The number of marine vessels traversing each grid daily was provided by the marine study (1). These are given in *Table 5.4*, where the grid cell reference numbers are defined according to *Figure 5.3*. The marine study was based on 2003 data, extrapolated to years 2011 and 2021, which were used to estimate the marine traffic population at years 2016, 2019, 2020, 2034 and 2035.

The number of marine vessels present within each grid cell at any instant in time is then calculated from:

$$\textit{Number of vessels} = \textit{No. of vessels per day} \times \textit{Grid length} / 86{,}400 / \textit{Speed} \quad \text{(Equation 1)}$$

This was calculated for each type of marine vessel, for each grid and for years 2011 and 2021. The values obtained represent the number of marine vessels present within a grid cell at any instant in time. Values of less than one are interpreted as the probability of a vessel being present.

(1) BMT Asia Pacific Ltd., personal communication, 2006.

Table 5.4 Number of Marine Vessels per Day

Grid No.	Average Number of Marine Vessel per Day									
	2011					2021				
	OG	RT	TT	FF(*)	OTH	OG	RT	TT	FF(*)	OTH
1	19	788	368	44	567	23	863	403	52	621
2	0	0	21	0	84	0	0	23	0	92
3	19	557	263	77	294	23	610	288	91	322
4	0	368	168	11	294	0	403	184	13	322

OG: Ocean-Going Vessel
RT: Rivertrade Costal Vessel
TT: Tug & Tow Vessels
FF: Fast Ferries
OTH: Others
(*): Fast ferries are treated separately

Average Density Approach

The average marine population for each grid was calculated by combining the number of marine vessels in each grid as per *Equation 1* with the population at risk for each marine vessel *Table 5.2*. The population for the estimated marine populations for the assessment years is summarised in *Table 5.5*. This grid population is assumed to apply to all time periods.

Table 5.5 Estimated Marine Populations for the Assessment Years

Year	2016	2019	2020	2034	2035
Grid No. 1	93.8	96.5	97.3	111.5	115.1
Grid No. 2	5.4	5.6	5.6	6.4	6.6
Grid No. 3	63.2	65.1	65.7	75.4	77.9
Grid No. 4	43.0	44.2	44.6	50.9	52.4

It is noted however that fast ferries are excluded since ferries are treated separately in the analysis (see below).

When simulating a possible release scenario, the impact area is calculated from dispersion modelling. In general, only a fraction of the grid area is affected and hence the number of fatalities within a grid is calculated from:

$$Number\ of\ Fatality = Grid\ Population \times Impact\ Area / Grid\ Area \quad \text{(Equation 2)}$$

Point Receptor Approach

The average density approach, described above, effectively dilutes the population over the area of the grid. Given that ferries have a much higher population than other classes of vessel, combined with a relatively low presence factor due to their higher speed, the average density approach would not adequately highlight the impact of fast ferries on the FN curves. Fast ferries are therefore treated differently in this QRA study.

In reality, if a fast ferry is affected by an accident scenario, the whole ferry will likely be affected. The likelihood that the ferry is affected, however, depends

on the size of the hazard area and the density of ferry vessels. To model this, the population is treated as a concentrated point receptor, i.e. the entire population of the ferry is assumed to remain focused at the ferry location. The ferry density is calculated the same way as described above (*Equation 1*), giving the number of ferries per grid at any instant in time, or equivalent a "presence factor". A hazard scenario, however, will not affect a whole grid, but some fraction determined by the area ratio of the hazard footprint area and the grid area. The presence factor, corrected by this area ratio is then used to modify the frequency of the hazard scenario.

Probability that ferry is affected = Presence Factor × Impact Area / Grid Area
(Equation 3)

The fast ferry population distribution adopted was described in *Table 5.1*. Information from the main ferry operators suggested that 25% of ferry trips take place at night time (between 7 pm and 7 am), while 75% occur during daytime. Day and night ferries are therefore assessed separately in the analysis. The distribution assumed is given in *Table 5.6*.

Table 5.6 Fast Ferry Population Distribution for Day and Night Time Period

Population	Population at Risk	% of Day Trip	% of Night Trip	% of All Trips (=0.75 × day+0.25 × night)
450	135	5	-	3.75
350	105	5	-	3.75
280	84	30	-	22.50
175	53	60	30	52.50
105	32	-	50	12.50
35	11	-	20	5.00

The ferry presence factor (*Equation 1*) and probability that a ferry is affected by a release scenario (*Equation 2*) are calculated for each ferry occupancy category and each time period.

Stationary Marine Population

Other stationary marine vessel population such as that for the Urmston Road Anchorage area are more than 1,000 m from BPPS, with reference to the detailed consequence analysis, all potential hazardous consequences cannot reach other stationary marine vessel population. Therefore, no other stationary marine population is taken into account in this QRA study.

5.5.2 Project Time Frame and Proposed Assessment Years

Project Time Frame

The indicative project programme is that the construction of the Project would be implemented in stages commencing from the second half of 2016, with commercial operation of the first unit anticipated by the end of 2019. The second unit would be constructed and operated after 2019.

Proposed Assessment Years

Five assessment years were proposed to assess the risks from the Project and associated facilities, and the existing BPPS facilities within the site boundary for this QRA study, and are listed below:

- 2016 as the baseline condition year;
- 2019 as the expected peak impact (in HtLA context) construction year of the 1st CCGT unit;
- 2020 as the expected year of operation of the 1st CCGT unit;
- 2034 as the assumed peak impact (in HtLA context) construction year of the 2nd CCGT unit; and
- 2035 as the assumed year of operation of the 2nd CCGT unit.

5.5.3 Meteorological Data

Data on local meteorological conditions such as wind speed, wind direction, atmospheric stability class, temperature, and relative humidity were obtained from the Hong Kong Observatory.

The annual average temperature and relative humidity have been taken to be 23.3 °C and 78% respectively according to the *1981-2010 Normals for Hong Kong* (1).

The location of weather station in the vicinity of BPPS is Sha Chau weather station. Data from the Sha Chau weather station were adopted for this QRA study as this weather station is closest to BPPS and also the most relevant based on the topography. The meteorological data used in this QRA study are based on the data recorded by the Sha Chau weather station over a five-year period from 2010 to 2014.

The raw data from the Hong Kong Observatory are a series of readings taken hourly over the five-year period. These data were rationalised into four combinations of wind speed and atmospheric stability class, denoted as 2.5B, 3.0D, 7.0D and 2.0F where 2.0F for example refers to a wind speed of 2.0 m s^{-1} and atmospheric stability class F. The data were then further sorted in twelve (12) wind directions. This sorting of meteorological data was performed for the two time periods, day time and night time respectively.

The fraction of occurrence for each combination of wind direction, speed and atmospheric stability for each time period is summarised in *Table 5.7*.

(1) Hong Kong Observatory.

Wind directions, such as 90°, refer to the direction of the prevailing wind. For example, 90° refers to an easterly wind, 0° is northerly, 180° is southerly and 270° is westerly.

Table 5.7 Data from Sha Chau Weather Station (2010 – 2014)

	Day				Night			
Wind speed (m s^{-1})	**2.5**	**3.0**	**7.0**	**2.0**	**2.5**	**3.0**	**7.0**	**2.0**
Atmospheric stability	**B**	**D**	**D**	**F**	**B**	**D**	**D**	**F**
Wind direction								
0°	0.076	0.006	0.135	0.002	0.000	0.006	0.120	0.010
30°	0.011	0.004	0.058	0.002	0.000	0.006	0.098	0.009
60°	0.008	0.005	0.010	0.002	0.000	0.006	0.029	0.010
90°	0.045	0.010	0.053	0.005	0.000	0.014	0.124	0.028
120°	0.073	0.007	0.146	0.004	0.000	0.008	0.247	0.023
150°	0.016	0.003	0.027	0.002	0.000	0.003	0.045	0.011
180°	0.032	0.003	0.035	0.002	0.000	0.002	0.048	0.011
210°	0.079	0.006	0.066	0.004	0.000	0.003	0.093	0.014
240°	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.001
270°	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
300°	0.003	0.000	0.000	0.000	0.000	0.000	0.000	0.001
330°	0.030	0.003	0.025	0.002	0.000	0.003	0.022	0.005

The Pasquill-Gifford atmosphere stability classes range from A through F.

A: Turbulent
B: Very unstable
C: Unstable
D: Neutral
E: Stable
F: Very stable

Wind speed and solar radiation interact to determine the level of atmospheric stability, which in turn suppresses or enhances the vertical element of turbulent motion. The latter is a function of the vertical temperature profile in the atmosphere; the greater the rate of decrease in temperature with height, the greater the level of turbulence.

Class A represents extremely unstable conditions, which typically occur under conditions of strong daytime insolation. Class D is neutral and neither enhances nor suppresses atmospheric turbulence. Class F on the other hand represents stable conditions, which typically arise on clear nights with little wind.

5.6 DESCRIPTION OF THE PROJECT FACILITIES

5.6.1 Project Facilities Description

The Project comprises the following key new facilities:

- Turbine hall building, housing the following major equipment;

  - Combined cycle gas turbine;
  - Generator;
  - Steam turbine;
  - Condenser; and
  - Associated facilities for compressed air, oil systems, service water.

- Electrical annex (connected to the turbine hall building);
  - Control room building; and
  - Equipment building.

- Two further buildings will be added outside of the turbine hall building and electrical annex; and
  - Water treatment plant building; and
  - Electro-chlorination plant building.

- The following equipment and installations will be required to support the additional CCGT units but not located in buildings.
  - Heat Recovery Steam Generator (HRSG);
  - Generator step-up transformers;
  - Main and auxiliary transformers;
  - Exhaust stack;
  - Fuel gas compressors/ fuel gas conditioning and metering stations;
  - Air intake;
  - Auxiliary boiler;
  - Electrical and electronic control compartment;
  - Effluent handling plants;
  - Fuel oil filters/ transfer pumps; and
  - Water treatment/ chemical sampling plant.

The new proposed units will utilise a tie-in to the existing natural gas pipelines which serve CCGT units 1-8. Natural gas will be used as the primary fuel in combustion turbines which drive generators to produce electricity. The hot exhaust gas from the gas turbine combustion process is sent through an HRSG in order to extract the remaining energy out of the combustion exhaust and create steam. The energy stored in the steam is then extracted via a steam turbine which is also driving the same generator to produce additional power output.

Fuel gas (natural gas) is piped from the existing fuel gas headers to new fuel gas conditioning and metering stations located adjacent to each HRSG. From there the fuel gas pressure and quality are controlled to meet the required gas turbine parameters set by the gas turbine supplier. New work as part of the Project includes tie-ins with two existing fuel gas headers. It is anticipated that there will be new fuel gas compressors to raise the gas pressure for efficient combustion, as well as a metering station and filters.

The new gas turbines are also capable of burning fuel oil (distillate oil) from the existing fuel oil storage facility as a secondary fuel in the case that natural gas is not available. New work as part of the Project includes new fuel oil

filters, transfer pumps and piping up to the gas turbines from the existing fuel oil storage tanks.

The new generators will utilise hydrogen as a cooling medium during operation. The new units will tap into the existing bulk hydrogen supply and there will not be any hot tapping operations during the installation of new CCGT units. When the generators are not producing electricity, CO_2 will be used to purge them of leftover hydrogen to eliminate the potential explosive atmosphere during maintenance or outages. The frequency of purging is expected to be less than once a year. New work as part of the Project includes piping from the existing bulk hydrogen supply up to the generator hydrogen control systems.

Cooling water extracted from the seawater cooling process will be run through an electrochlorination system in order to produce sodium hypochlorite (NaOCl) which is used to treat the seawater before it passes through the cooling water system. This process is continuous and does not rely on any stored chlorine gas or hypochlorite brought from off-site. New work as part of this system will be new electrochlorination modules, dosing pumps, and piping as required to inject NaOCl into the cooling water system.

Urea is transported to BPPS and ammonia is generated on-site by a urea-to-ammonia system to avoid the hazards of ammonia transportation, transfer and storage. The generated ammonia is fed to the selective catalytic reaction system to control the level of nitrogen oxide and nitrogen dioxide to be released to atmosphere.

5.6.2 Project Facilities Layout

The layout of the Project facilities is depicted at *Figure 3.2*.

5.6.3 Safety Management Measures Implemented during Construction Phase

To minimise the potential risks to construction workers on-site during the construction phase of the Project, construction safety plan will be developed before commencement of construction and the following key safety management measures will be implemented.

- All construction workers shall comply with CLP's safety policy and requirements;
- Method statements and risk assessments shall be prepared and safety control measures shall be in place before commencement of work;
- All work procedures shall be complied with the operating plant procedures or guidelines and regulatory requirements;
- Work permit system, on-site pre-work risk assessment and emergency response procedure shall be in place before commencement of work;

- All construction workers shall equip with appropriate personal protective equipment (PPE) when working at the Project Site;
- Safety training and briefings shall be provided to all construction workers;
- All construction workers shall be under close site supervision; and
- Regular site safety inspections shall be conducted during the construction phase of the Project.

With the implementation of the above safety management measures, the potential risks to construction workers on site are expected to be insignificant. The construction workers are not considered as off-site population and therefore are not taken into account in this QRA study.

5.7 DESCRIPTION OF THE EXISTING BPPS FACILITIES

5.7.1 Overview

The existing BPPS facilities include following facilities, and the respective detailed description for each facility is presented in the following sections.

- Gas receiving station (GRS) for submarine pipeline from Yacheng Field 13-1 & 13-4 (Yacheng);
- GRS for submarine pipeline from Dachan Launching Station in Shenzhen;
- Fuel gas facilities including 400 m pipeline from GRS to the existing eight (8) CCGTs and the associated fuel gas systems;
- Interconnecting pipeline between BPPS and Castle Peak Power Station (CPPS);
- Hydrogen facilities;
- CO_2 facilities;
- Distillate oil facilities; and
- NaOCl facilities.

5.7.2 Gas Receiving Stations

GRS for Submarine Pipeline from Yacheng Field

The inlet emergency shutdown valve (ESDV) defines the transition between the submarine pipeline and the GRS. The inlet shutdown valve (SDV) is a primary shutdown in the event of a problem within GRS or gas facilities at BPPS. The valve closes within five (5) seconds from activation following an emergency shutdown (ESD) or pressure shutdown (PSD) condition.

A pig receiver receives maintenance and inspection pigs from the Yacheng pipeline. A pig receiver opening interlock (keyed valve) system is included to minimise the potential for opening the receiver while under pressure. Redundant pig signals verify pig arrival.

Motorised valves on the receiver piping will close in the event of fire detection to complete isolation. It is unusual and undesirable for liquids to enter the pipeline and pigging to clean the line is not routine. The pig receiver is designed for normal brush pigs, as well as instrumented smart pigs. Special connections were used during pipeline hydro-testing, dewatering and commissioning.

A slug catcher intercepts liquids from the pipeline for holding, handling and disposal, although in fact no liquids are expected. If any do occur, they will be collected in a slop receiver and disposed of by tank truck. The liquids would be condensate hydrocarbons. It is assumed that no liquids occur under normal operation for this QRA study. The slug catcher is small at 200 bbl. Liquids recovered in the slug catcher, if any, will be disposed of by tank truck.

Two parallel inlet gas filter separators remove traces of liquid mist and solid particles in the incoming gas. There are vertical cylinder type separators. Minimal quantities of collected condensate are anticipated. These separators use replaceable high efficiency coalescing cartridges for removal of 99% of particles over three (3) microns in size. Mist carryover and solids collected by the brush pig are captured. Filter flow is from the inside of the cartridge to outside with a liquid dump to the slop system. The same cartridges are used in the outlet filter/ separators.

Seven (7) water bath gas heaters warm the natural gas to counteract the temperature drop which occurs on pressure reduction (Joule-Thompson cooling), and maintain the sale gas at least 28 °C above hydrocarbon dew point. The heaters are horizontal cylinders of 4 m diameter and 13 m in length. Five (5) heaters are required for full capacity. Gas flow through individual heaters is controlled by open/ close inlet block valves. As the sale gas demand increases, inlet block valves to the heaters are opened in sequence.

Two (2) parallel pressure reduction stations are available to adjust the delivery pressure to 35 - 41 barg. Each station comprises two (2) 350 mm trains in parallel for peak flow delivery and one (1) 100 mm train for low flow. Each station provides 100% capacity, in order to ensure high reliability, and both are normally kept pressurised to act as back-up in case of valve failure in the operating train. Each train consists of a primary pressure control valve, followed by a 14" monitoring (tracking) valve and a 20" SDV. Individual 18" SDVs are installed to prevent overpressure by their fast closure times of under one (1) second, instead of a single 28" valve with slower closure times, in each train. In addition, low flow self-contained pressure regulators provide the water bath with stand-by fuel.

Two (2) parallel outlet gas filter separators remove any liquid formed in the pressure let-down. No liquids should form if the heating system is operating properly. There are 3-micron thick coalescing filter elements which are identical to those in the inlet filter/ separators.

Metering and sales facilities consist of six (6) parallel meter runs. Five (5) are required for maximum flow and one (1) is spare. All meter streams are normally kept pressurised. The meter runs are opened in sequence as the gas flow is increased. Flow is totalled on two (2) independent metering computers with redundant transmitters. Flow signals are transmitted to the control room at BPPS. A composite sampler gathers samples for gas chromatography testing in an independent laboratory.

The outlet SDV defines the transition between the GRS and the downstream BPPS facilities.

A pig launcher for the interconnecting pipeline to CPPS was taken for this QRA study as part of the GRS facilities.

Both open and closed drain systems are installed in the GRS. The open drain collects waste water from limited areas under the process equipment and drains it to the open drain sump. Waste is transferred to BPPS open drain system by the way of lift pumps and is primarily for rain water discharge. The closed drain system collects high pressure hydrocarbons wastes and drains to the closed drain sump. Liquids are pumped from the sump to the slop receiver by pump for storage and disposal by way of tank truck. Vapours are vented to atmosphere through a flame arrestor.

An elevated vent stack safely disposes of process blowdown gas, pressure safety valve releases and blowdown gas from the pipeline. The stack is 180 feet high and 28" in diameter. A CO_2 snuffing system is installed to extinguish fires in cases where the vent stack is struck by lightning, static electricity or other causes. The system is designed for full pipeline gas flow during the three (3) seconds closing time of the SDVs. The height limits radiation from an accidental ignition to a person on the ground to 3,000 BTU per hour-square foot to under five (5) seconds. As aforementioned, the existing vent stack will provide a common vent for all two GRSs to allow depressurisation of equipment.

GRS for Submarine Pipeline from Dachan Launching Station in Shenzhen

Gas is received via the Dachan Pipeline and the first major piece of equipment in the station is an ESDV, which can be closed by means of the station ESD system in the event of an emergency, isolating the station from the source of natural gas.

Downstream of the ESDVs is the pig receiver. This enables the running of cleaning and inspection pigs in the pipeline. Following the pig receiver are the inlet filter units, metering runs, heaters and pressure letdown section where the pressure is reduced to about 40 barg. The natural gas is then sent

out to distribution headers to supply all CCGT units at BPPS. The headers from two GRSs are combined at the mixing station.

The existing vent stack provides a common vent for both GRSs to allow depressurisation of equipment in an emergency.

5.7.3 BPPS Gas Facilities

The maximum gas flow rate at the manifold is 507,000 m^3 hr^{-1}, while the nominal gas flow to each existing gas turbine is 63,000 m^3 hr^{-1}.

Typical operating conditions are approximately 38 barg and 41 °C.

According to operating experience over the past years, the variations in these are slight. The designed variation in delivery pressure is 34 – 41 barg. The gas conditions remain broadly constant throughout the fuel gas system. The equipment is designed for 50 barg.

5.7.4 Interconnecting Gas Pipeline between BPPS and CPPS

The interconnecting pipeline is part of the gas transmission system linking the GRS at BPPS and the Intermediate Pressure Reduction Station (IPRS) at Castle Peak Power Station (CPPS). The pipeline runs mainly underground along the Yung Long Road, Lung Kwu Tan Road, Lung Fai Street and through the CPPS site. It starts at the outlet ESDV from the BPPS facilities, and ends at the inlet ESDV to the IPRS.

Only the section of the interconnecting gas pipeline within the site boundary of BPPS was included in this QRA study for the purpose of cumulative risk assessment.

5.7.5 Hydrogen Facilities

The hydrogen facilities are used to unload hydrogen tube trailers/ pallets charged up from an external supplier. The charged tube trailers/ pallets provide a storage and supply of hydrogen to the generator gas control system where it is used as a cooling medium in the generator cooling circuit via the hydrogen distribution system.

Hydrogen is delivered in tube trailer/ pallets at a maximum pressure of 200 barg and connected to the station supply manifold using a flexible hose. Replacement of fully-filled hydrogen tube trailer/ pallet is required before hydrogen is used up.

The current delivery frequency of hydrogen road trailers to BPPS by an external supplier is about once per two weeks, depending on the consumption rate of hydrogen at BPPS. It is expected that an additional 20% hydrogen delivery is required for each of the proposed CCGT units.

Hydrogen Trailer Unloading/ Storage Bay

The hydrogen trailer bay is designed and constructed in line with NFPA 50A. It is an open structure enclosed by a security fence and lockable gates. Concrete kerbs and guard stop are provided to prevent the trailer damaging any part of the installation during trailer reversing or unloading.

Hydrogen Tube Trailer

Each tube trailer consists of trailer chassis, container frame, hydrogen cylinders and interconnection pipework. The chassis is designed in compliance with the relevant transportation regulations in Hong Kong. The trailer will have the relevant licences governing its use before it is put into service.

Each chassis has rigid side guards and rear guards to protect against traffic collision, and is also equipped with an anti-towaway system.

The trailers have a container frame, which will accommodate multiple cylinders occupying a total of 11.1 m^3 water capacity or 2,115 m^3 gas capacity at 200 barg storage pressure.

Hydrogen Distribution System

The hydrogen distribution system is designed to supply hydrogen from hydrogen trailer(s) and distribute it to the generator gas control system of each CCGT unit, where it is used as the rotor cooling medium.

The system supplies the generator gas control systems with hydrogen for filling of the generators prior to returning them to services after a generator overhaul/ shutdown which required purging the generator of hydrogen with CO_2/ air.

The system also provides hydrogen to the generator control system during normal operation at 4 barg to make up for leakage from the generator units.

The system operates at a normal working pressure of 6.9 barg.

Off-site Transport

For off-site transport of hydrogen via trailers, only the road section from the junction of Nim Wan Road/ Yung Long Road to BPPS, approximately 1 km, was included in this QRA study for the purpose of cumulative risk assessment. This is selected as Yung Long Road is dedicated for access to BPPS, and 1 km is an indicative distance comparable to other approved EIAs where the Consultation Zone boundary of the Potentially Hazardous Installation was taken into consideration.

5.7.6 CO_2 Facilities at BPPS

The CO_2 storage and distribution system is used to purge the generator of each CCGT unit during hydrogen filling and emptying operations, and for continuous purging of the generator gas dryer control cabinets. In addition, the system also provides CO_2 for purging the fuel gas distribution pipework.

The current delivery frequency of CO_2 road tankers to BPPS by an external supplier is about once per month, depending on the consumption rate of CO_2 at BPPS. It is expected that an additional 20% CO_2 delivery is required for each of the proposed CCGT units.

Storage Tank Refrigeration System

The CO_2 storage equipment is located outdoors in a compound with easy access to the storage tank to enable filling from a road tanker. The equipment is skid mounted for ease of installation.

The CO_2 is stored in a storage tank as a liquid. The storage tank is provided with 2 × 100% duty refrigeration units.

Vaporisation and Distribution System

One (1) of the two (2) main vaporisation units is selected for duty by the operators at the storage system local control panel. When large quantities of CO_2 are required for purging, the station operators command the duty vaporiser to start from the local control panel or from the distributed control system (DCS). This command will cause the vaporiser to be powered up and the inlet isolation valve to open admitting liquid CO_2 to the vaporiser. When the CO_2 is no longer required the station operators command the vaporiser to shutdown from the local control panel or from the DCS.

Off-site Transport

For off-site transport of carbon dioxide via road tankers, only the road section from the junction of Nim Wan Road/ Yung Long Road to BPPS, approximately 1 km, was included in this QRA study for the purpose of cumulative risk assessment. This is selected as Yung Long Road is dedicated for access to BPPS, and 1 km is an indicative distance comparable to other approved EIAs where the Consultation Zone boundary of the Potentially Hazardous Installation was taken into consideration.

5.7.7 Distillate Oil Facilities at BPPS

BPPS is a dual fuel combined cycle power plant, and the primary fuel is natural gas while the secondary fuel is distillate oil.

Distillate Oil Unloading and Storage System

The current distillate oil bunkering and auxiliaries at the Oil Unloading and Heavy Load Berths have a capacity to facilitate the operation of double berthing.

The distillate oil unloading system receives distillate oil unloading from oil barge. There are two (2) marine unloading arms associated with the distillate oil unloading system, each marine unloading arm is sized to deliver at a flow rate of 1,000 m^3 hr^{-1}. The first one is located at the Oil Unloading Berth while the second one is located at the Heavy Load Berth.

The existing distillate oil unloading system, distillate oil bunkering and auxiliaries at oil unloading facilities are operated only during the distillate oil unloading operation with frequency of about once every two years.

For each unloading operation, about 500 to 1,000 tonnes distillate oil is unloaded at either the Oil Unloading Berth or Heavy Load Berth to distillate oil storage tanks though fuel oil bunkering line and fuel oil strainer. The unloaded distillate oil is to replenish the use of distillate oil at BPPS. Bund wall and oil spill kits are provided to minimise the risk due to accidental leakage of distillate oil.

There are three (3) distillate oil storage tanks in the tank farm nearby the Oil Unloading and Heavy Load Berths. Each of them has a 22,000 m^3 capacity which is sufficient for approximately 100 hours continuous firing of the existing eight (8) CCGT units. This tank farm is surrounded by a bund wall which can retain any oil leaks within the tank farm area.

Distillate Oil Transfer System

The distillate oil transfer system downstream of the storage tanks consists of pumping equipment and three (3) forwarding streams.

There are two (2) identical CCGT forwarding streams, each supplies distillate oil to one half of BPPS (four (4) CCGT unit liquid fuel modules).

The third (3^{rd}) stream supplies the essential services diesel generators service tanks and the auxiliary boiler day tank.

The piping and valve arrangement around the tanks allows the streams to draw distillate oil from any one of tanks.

The distillate oil storage tanks and auxiliary boiler day tank bunds are provided with instruments to detect the presence of liquid in the bunds.

5.7.8 NaOCl Facilities at BPPS

Cooling water extracted from the seawater cooling process will run through an electrochlorination system in order to produce NaOCl which is used to treat the seawater before it passes through the cooling water system. This

process is continuous and does not rely on any stored chlorine gas or hypochlorite brought from off-site.

Chlorinated seawater, together with the entrained hydrogen gas, which is a byproduct of the electrolysis reaction, flows to one of the two hydrogen disentrainment tanks. Due to the instability of seawater/ NaOCl, the residence time in the disentrainment tank is restricted to approximately one (1) hour. At the inlet to these open topped tanks, the NaOCl solution weirs over into the tank, causing separation of the entrained hydrogen gas, which discharges to atmosphere by natural ventilation.

The limited hydrogen byproduct is generated from the electrochlorination reaction, it is dispersed through the open tank top without additional pressure. Currently, lightning protection system is provided for the NaOCl solution storage tanks from which hydrogen is vented to atmosphere. As there is no heat source in the vicinity of the NaOCl solution storage tanks, there is no chance that the small amount of hydrogen can be ignited and any risk impact will only be localised. Considering the points above, NaOCl facilities in BPPS have not been modelled in this QRA study.

5.7.9 Safety Philosophy and Safety Equipment at BPPS

The safety philosophy is to ensure containment of hazardous materials used on-site by incorporating various safety features, maintenance and operation philosophies to minimise any potential escalation from an accident.

The safety equipment implemented at BPPS to mitigate against the effect of any accident can be summarised in the following categories:

- Emergency shutdown facilities;
- Blowdown facilities;
- Overpressure protection facilities;
- Leak detection facilities; and
- Fire detection and protection facilities.

GRS

Emergency Shutdown Facilities

The inlet ESDV provides isolation from the submarine pipeline in the event of an operating problem in the GRS or CLP facilities, including both BPPS and CPPS.

Another ESDV is located downstream of the pig launcher for the interconnecting pipeline to CPPS. It is closed by a push-button from the GRS control room.

Process SDVs, located immediately downstream of the pressure control valves, provide protection of the downstream facilities from overpressure in the event of pressure control valve failure.

Unit SDVs are located upstream and downstream of the main units in the GRS, including on the outlet line to both BPPS and CPPS. They are closed by a push-button from the GRS control room.

Plant ESD is initiated automatically if high or low pressure is detected by two (2) out of three (3) pressure sensors downstream of the pressure reduction stations. It may also be initiated manually from the GRS control room or externally on the plant by means of ESD push-buttons.

ESD automatically activates the inlet ESDV, the interconnecting pipeline ESDV, the process SDVs and the unit SDVs.

Isolation of the pig receiver is by motorised valves, which close in the event of fire detection.

Blowdown Facilities

In the event of overpressure which is not contained by the process SDVs, the system is designed to vent automatically from a point downstream of the pressure reduction station.

In the event of an ESD, each unit on the plant may be blown down to the vent. This is initiated manually from the GRS control room. The performance of the blowdown system is assumed to be a reduction of the pressure in each unit to 7 barg within fifteen (15) minutes after initiation.

Blowdown, vent and pressure relief valve (PRV) released gas is disposed at a vent stack. A CO_2 snuffing system is installed to extinguish the vent if the gas is ignited by lightning or other causes.

Overpressure Protection Facilities

Overpressure protection on the downstream piping is provided by:

- Primary pressure control valve;
- Secondary pressure control valve;
- The fast-closing process SDVs;
- Vent to atmosphere; and
- PRVs.

Leak Detection

IR point/ open path flammable gas detectors are installed at GRS area to provide flammable gas leak detection capability.

Fire Detection and Protection Facilities

A 300 mm fire water ring main for the site is supplied from BPPS. There are seven (7) fire water monitors, eight (8) street fire hydrants and twenty-two (22) hose reels on-site. There are also UV/ IR flame detectors, manual fire alarm system with audio alarm and nine (9) kg portable powder fire extinguishers.

For the satellite instrument enclosure (SIE) Room, there are automatic and manual fire alarm and protection system including very early smoke detection & alarm (VESDA) system, conventional smoke detectors, heat detectors and manual call points as well as total gas flooding system (NOVEC 1230). Portable 5 kg CO_2 and 9 litre foam fire extinguishers are also provided.

Gas Facilities at BPPS

Emergency Shutdown Facilities

Emergency isolation of the supply pipeline can be achieved by means of:

- Outlet SDV on the GRS; and
- ESDVs located downstream of the eight (8) filter separators.

Isolation valves are also provided on the inlet and the eight (8) outlets of the manifold, but these are not ESDVs and could only be closed on independent actuation by the operator.

The ESDVs will be closed automatically on fire detection.

Blowdown Facilities

It is necessary that natural gas can be safely vented at a high level from any section of the system prior to maintenance on that section. It is also necessary that all sections can be adequately purged and that a positive check of the effectiveness of the purging can be performed.

The complete fuel gas supply (FGS) system is provided with vent and purge points to enable the system to be purged with a CO_2 supply for maintenance. All vent points are suitably earthed to prevent any danger of electrostatic sparks.

The whole piping system is electrically trace heated and thermally insulated. This maintains the stagnant fuel gas at the correct temperature during shutdown ready for restart of the gas turbine.

Any section of the system on which work is to be carried out must be physically isolated from any section that is live with natural gas by a double block and bleed system, or equivalent.

The removal of blanks and opening of normally closed tested/ purge valves is controlled by written procedures.

Each gas turbine is contained in an acoustically-lined steel enclosure. The enclosure also serves as containment for the turbine ventilation and fire protection systems and protects the turbine from external impact.

The fuel gas module is also covered by an enclosure. The ventilation system is designed such that under permanent operations a negative pressure of 5 mm WG is maintained with the enclosure.

Overpressure Protection Facilities

Overpressure protection on the downstream piping is provided by:

- The primary pressure control valve;
- The secondary pressure control valve;
- The fast-closing process SDVs;
- Vent to atmosphere; and
- PRVs.

Leak Detection Facilities

The gas leak detector is normally installed along the flammable gas path above the potential flammable gas leak sources or inside the exhaust vent ducts to provide flammable gas leak detection capability.

Fire Detection and Protection Facilities

The gas turbine modules are fitted with CO_2 fire extinguishing systems.

Fire detectors are provided in different zones within the gas turbine modules. On alarm by two (2) out of three (3) fire detector loops in a zone, the turbine and its ventilation are tripped and CO_2 is released automatically. Alarms are indicated on the fire panel in the central control room. The fire protection system can also be activated from manual call points beside the gas turbine enclosures.

Hydrogen Facilities at BPPS

Emergency Shutdown Facility

Hydrogen supply to the generator gas control system will be suspended in case of emergency by the following provision:

- ESDVs;
- Pipe rupture safety valves; and
- Manual SDVs.

Operation of the ESDV will be initiated automatically on receiving signals from the following scenarios:

- Hydrogen leakage detection in trailer bay;
- Fire detection in trailer bay;
- Manifold pressure low;
- Hydrogen purity low;
- Oxygen concentration high in hydrogen gas supply; and
- Manual triggering.

Each hydrogen manifold is equipped with two pipe rupture safety valves arranged in parallel. The two valves will be shutdown automatically when the supply gas exceeds the design flow rates of 250 $Nm^3\ hr^{-1}$ (for generator charging operation) and 10 $Nm^3\ hr^{-1}$ (for normal generator make-up) respectively. This is to prevent uncontrolled continuous escape of hydrogen in case of sudden pipe rupture in the distribution manifolds.

In case of malfunction of the ESDVs during an emergency, hydrogen supply can be isolated by the manually operated SDV on the manifolds located outside the trailer bay at the boundary fence.

Leak Detection Facility

Hydrogen detectors are installed strategically inside the hydrogen trailer bay compound to detect signs of hydrogen leakage. On detection of hydrogen with a concentration of 25% lower flammable limit (LFL), flashing and audible alarm will be initiated at entrance to the area being monitored. The alarms will also trigger the ESDV and fire protection water spray system.

Low pressure alarms at hydrogen distribution system also provide leak detection capability.

Distillate Oil Facilities at BPPS

Fire Detection and Protection Facilities

Fire is the primary risk during the distillate oil unloading process. Special precautions, therefore, have to be taken to avoid this from happening. Smoking or naked light are forbidden in the Oil Unloading and Heavy Load Berths and fire-fighting equipment should be ready and in good condition. Proper connection of the marine unloading arm to the oil barge and constant watch during unloading is required.

Distillate oil off-loading hose connections are ready for the compressed service air. Floodlighting for 24-hour operation and closed circuit television (CCTV) system are ready to provide clear vision. It is for monitoring the bunkering/

fire-fighting operation at the locations around each marine unloading arm in front of its pair of foam monitors, and the foam monitor house respectively.

5.8 HAZARD IDENTIFICATION

5.8.1 Overview

Hazards associated with the Project facilities have been identified based on a detailed review of known incident records worldwide and experience gained from operations at similar facilities. In addition, a systematic HAZID process including a HAZID Workshop has been conducted to identify any local or site specific factors.

The major hazards arising from the Project facilities are mainly related to the loss of containment of flammable hydrocarbons and hydrogen, and the release of toxic gas such as CO_2.

This section includes the following subsections:

- Review of hazardous materials;
- Review of the potential major accidental events;
- Review of industry incidents relevant to identified hazardous materials;
- Review of potential initiating events leading to major accidental events;
- HAZID Workshop for the Project facilities; and
- Development of hazardous sections.

5.8.2 Review of Hazardous Materials

Natural Gas

Natural gas is supplied from Yacheng Field and Dachan Launching Station in Shenzhen, and it is a primary fuel in combustion turbines which drive generators.

Natural gas is composed of primary methane gas with other fossil fuels such as ethane, propane, butane and pentane, etc. Natural gas is extremely flammable when mixed with appropriate concentration of air or oxygen in the presence of an ignition source.

The compositions of natural gas supplied from Yacheng pipeline is summarised at *Table 5.8*. The average gas molecular weight is 19.84 and its hydrogen sulphide content is less than 50 ppm by volume.

The composition of natural gas supplied from Dachan Pipeline is given at *Table 5.9* and the total hydrogen sulphide content in the natural gas is less than 20 mg m^{-3} (about 15 ppm).

Not only is the maximum surface emissive power of pure methane higher, but also are the consequence distances for both flash fire and jet fire hazardous scenarios associated with pure methane larger than that of natural gas. Therefore, pure methane has been conservatively selected as a representative material for natural gas in the consequence modelling conducted by PHAST.

The major hazards arising from loss of containment of natural gas may lead to hazardous scenarios, including jet fire, flash fire, fireball, and vapour cloud explosion (VCE).

Table 5.8 The Composition of Natural Gas Supplied from Yacheng Field

Composition	Molar Percentage (%)
Methane	84.683
Ethane	2.706
Propane	0.935
Butane	0.458
Pentane	0.151
C_6 - C_{13}	0.108
Nitrogen	0.796
CO_2	10.163

Table 5.9 The Composition of Natural Gas Supplied from Dachan Launching Station

Composition	Maximum Molar Percentage (%)	Minimum Molar Percentage (%)
Methane	N.A.	85.0
Ethane	10.0	N.A.
Propane	4.0	N.A.
Butane	2.0	N.A.
Pentanes +	0.5	N.A.
Nitrogen	3.0	N.A.
CO_2	3.0	N.A.

Dangerous Goods Related to the Project

The details of each of dangerous goods related to the Project are analysed as below and summarised at *Table 5.10.*

Hydrogen

CAS number of hydrogen is 1333-74-0, and hydrogen is a colourless and odourless gas at ambient temperature and pressure. It has a boiling point of -253 °C at 1 bar, a critical temperature of -240 °C and a critical pressure of 13 bara.

Hydrogen is extremely flammable in oxygen and air, and has the widest range of flammable concentrations in air among all common gaseous hydrocarbons. This range is between the lower limit of 4% to an upper limit of 75% by volume. Because of this wide range, a given volume of hydrogen release will present a large flammable volume, thus increasing the probability of ignition.

Also, when diluted with inert gas, hydrogen can still burn with only 5% oxygen. It can be ignited by low energy sources; hence it is easily ignited by static electricity.

The major hazards arising from loss of containment of hydrogen may lead to hazardous scenarios, including jet fire, flash fire, fireball, and VCE.

Distillate Oil

Distillate oil is an ultra-low sulphur diesel and it is a clear oily liquid. Distillate oil has a relatively high flash point (> 66 °C), which is above ambient temperature, and a high boiling point. Thus, evaporation from a liquid pool is expected to be minimal.

The major hazards arising from distillate oil are therefore considered to be pool fire, or even flash fire.

Carbon Dioxide

CAS number of CO_2 is 124-38-9, and CO_2 is a colourless and odourless gas at ambient temperature and pressure. In high concentration, a sharp smell may become apparent. It has a melting point of -56.6 °C at 1 bar, a critical temperature of 30 °C and a critical pressure of 74 bara.

When liquid CO_2 under pressure is released to atmosphere, the discharge consists of gaseous and solid CO_2 only. When solid CO_2 is in direct contact with skin will cause acute cold damage, "cold burn".

High concentrations of CO_2 may cause asphyxiation. Symptoms may include loss of mobility/ consciousness, victim may not be aware of asphyxiation. Low concentrations of CO_2 can also cause increased respiration and headache.

As per DNV's *CO2RISKMAN* 2013 (1), a CO_2 BLEVE occurs when a very rapid depressurisation of a pressurised liquid of CO_2 due to a vessel rupture creates a superheated liquid phase that suddenly vaporises in an explosive manner. This may give a transient overpressure peak inside the remaining vessel that further bursts the vessel creating a shockwave and projectiles.

The major hazards arising from CO_2 are therefore considered to be toxicity effect, and projectile effect from a CO_2 BLEVE, which is explained in *Section 5.8.3*.

Sodium Hypochlorite

CAS number of NaOCl is 7681-52-9, and NaOCl solution is a corrosive liquid with the appearance of colourless to yellowish, and with a chlorine-like odour. NaOCl is not flammable, but it can decompose and release corrosive chorine

(1) DNV's CO2RISKMAN, "*Guidance on CCS CO2 Safety and Environment Major Accident Hazard Risk Management*", DNV Report No. 13IJLJW-2, 30th January 2013, Rev. 1.

gas when it is in contact with acids. NaOCl is produced by an electrochlorination system at BPPS. This process is continuous and does not rely on any stored chlorine gas or hypochlorite brought from off-site.

The major hazard associated with NaOCl is the possibility of giving off toxic chlorine gas under the decomposition of the solution. However, once generated on-site, NaOCl is consumed immediately for treatment of seawater before it passes through the cooling water system. Hence, an accidental mixing of NaOCl with incompatible chemicals such as acids leading to a toxic chlorine gas release is not expected to occur, and it is not foreseen to have risk impact from NaOCl solution generated on-site on off-site population. Therefore, NaOCl is not taken into account in this QRA study.

Ammonia

CAS number of ammonia is 7664-41-7, and ammonia is a corrosive alkaline solution and can react with body tissues. In case of an accidental exposure, it can severely damage tissues of the mucous membranes and upper respiratory tract. Symptoms include burning sensation, coughing, wheezing, laryngitis, shortness of breath, headaches and vomiting. In case of inhalation of high concentration ammonia, it may cause fatality due to spasm inflammation and edema of the larynx and bronchi, chemical pneumonitis and pulmonary edema.

Nevertheless, ammonia is barely able to cause any flammable incidents due to its high auto-ignition temperature at 651 °C and the limited flammable range, from 16 to 25%, by volume of air.

The major hazard related to ammonia is its toxicity characteristic, instead of flammability; however, once generated on-site, ammonia is consumed immediately to treat the exhaust gas from the Project through selective catalytic reduction system. Hence, it is not foreseen to have risk impact from ammonia generated on-site on off-site population. Nevertheless; ammonia detector and monitor system will be in place as safeguard measures, therefore, ammonia is not taken into account in this QRA study.

Urea

CAS number of urea is 57-13-6, but urea is not classified as dangerous goods based on "*Fire Protection Notice No.4, Dangerous Goods General*" by Fire Services Department (1); therefore, urea is not taken into account in this QRA study.

Dangerous Goods Delivery Routes

The existing dangerous goods delivery routes, depicted in *Figure 5.4*, are through the Central Road, which is adjacent to the Project Site.

(1) *Fire Protection Notice No. 4, Dangerous Goods General*, Fire Services Department.

During the construction phases of the Project, alternative routes, either through the Workshop Road or the Transformer Road, can be used for dangerous goods delivery. Alternative routes for dangerous goods delivery are depicted in *Figure 5.5*.

The alternative dangerous goods delivery routes are kept separated from the Project Site to minimise the impacts from the construction activities within the Project Site to the dangerous goods during the delivery, and vice versa, during the construction phases of the Project.

Table 5.10 Dangerous Goods Related associated with the Project

Chemical	Dangerous Goods Classification*	Exempt Quantity	Location	Storage Quantity	Maximum Storage Quantity	Storage Temperature (°C)	Storage Pressure (barg)
Hydrogen	Category 2	1 Cylinder	Hydrogen trailer bay	2 x 64 Cylinders	128 Cylinders#	25	200.0
Distillate oil	Category 5	20 L	Distillate oil tank #1	2.2 x 10^7 L (22,000 m^3)	2.2 x 10^7 L (22,000 m^3)	25	0.0
Distillate oil	Category 5	20 L	Distillate oil tank #2	2.2 x 10^7 L (22,000 m^3)	2.2 x 10^7 L (22,000 m^3)	25	0.0
Distillate oil	Category 5	20 L	Distillate oil tank #3	2.2 x 10^7 L (22,000 m^3)	2.2 x 10^7 L (22,000 m^3)	25	0.0
CO_2	Category 2	1 Cylinder	Station liquid CO_2 storage tank	6 tonnes (tank capacity)	6 tonnes (tank capacity)	-18	20.7
NaOCl	Category 4	250 L	On-site generation at electrochlorination plant	-	-	-	-
Ammonia	Category 2	1 Cylinder	On-site generation at the Project Site	-	-	-	-

Note

*: The dangerous goods category is classified based on "*Fire Protection Notice No.4, Dangerous Goods General*" by Fire Services Department (1).

#: The maximum cylinder capacity is 26,784 L.

(1) *Fire Protection Notice No. 4, Dangerous Goods General*, Fire Services Department.

5.8.3 Review of Potential Major Accidental Events

Leakage or rupture scenarios of process equipment, pipeline or pipework handling flammable gas such as natural gas or hydrogen can result in a flammable gas cloud, which may be ignited if it encounters an ignition source while its concentration lies within the flammable range. In some cases, static discharge may also cause immediate ignition of flammable gas release.

Distillate oil is heavier than air and can also form a flammable mixture with air, an ignition of distillate oil spillage from storage tanks or associated pipework can result in pool fire or even flash fire depending on circumstances.

In addition, CO_2 facilities contain a large amount of pure CO_2; leakage or rupture scenarios from these facilities could result in a toxicity effect, or even projectile effect from a CO_2 BLEVE.

Hazardous scenarios evaluated in this QRA study include:

- Jet fire;
- Flash fire;
- Pool fire;
- Fireball;
- Vapour cloud explosion;
- Boiling liquid expanding vapour explosion; and
- Toxicity effect.

The characteristic of the hazardous scenarios are described separately below:

Jet Fire

A jet fire results from an ignited release of pressurised flammable gas such as natural gas or hydrogen. The momentum of the release carries the flammable material forward in a jet, entraining air to give a flammable mixture, an ignition of which results in a jet flame.

Flash Fire

Following the release of flammable liquid or gas, if there is no immediate ignition, the vapour will disperse and be diluted as a result of air entrainment. The dispersing vapour cloud may subsequently come into contact with an ignition source and burn rapidly with a sudden flash.

If the source of flammable material which created the cloud is still present, then the fire may flash back to the source giving a jet fire or pool fire. Direct contact with the burning vapour of a flash fire may cause fatalities but the

short duration of the flash fire means that thermal radiation effect is not significant outside the flammable gas cloud and thus no fatalities are expected outside of the flash fire envelope.

Pool Fire

A pool fire occurs when a flammable liquid, such as distillate oil, is split onto the ground and ignited. The pool formed from the release initially spread due to the gravitational and surface tension forces acting on it. As the pool spreads, it absorbs thermal energy from its surrounding causing evaporation from the pool surface, resulting in a flash fire if this vapour encounters an ignition source.

Fireball

Immediate ignition of flammable gas release from a full bore rupture of natural gas manifold, or a catastrophic rupture of a hydrogen road trailer/ a hydrogen trailer at hydrogen trailer bay, may give rise to a fireball. Persons caught in the open area within the fireball diameter are assumed to be 100% fatality.

Vapour Cloud Explosion

Flash fire is the most likely outcome upon an ignition of a dispersing vapour cloud from a flammable hydrocarbon or hydrogen release. However, if the vapour cloud accumulates in an area with significant congestion from surrounding equipment, buildings/ structures, damaging overpressure from a VCE may result upon an ignition.

Flammable gas cloud concentration is also one of the important factors to determine whether an explosion can occur. An explosion with the maximum loading is expected if the flammable material is sufficiently mixed with air at its stoichiometric concentration.

Boiling Liquid Expanding Vapour Explosion

A CO_2 BLEVE due to a catastrophic rupture of a CO_2 road tanker or a CO_2 storage tank was taken into account in this QRA study.

CO_2 BLEVE

As per DNV's *CO2RISKMAN* 2013 (1), a CO_2 BLEVE occurs when a very rapid depressurisation of a pressurised liquid of CO_2 due to a vessel rupture creates a superheated liquid phase that suddenly vaporises in an explosive manner. This may give a transient overpressure peak inside the remaining vessel that further bursts the vessel creating a shockwave and projectiles.

(1) DNV's CO2RISKMAN, "*Guidance on CCS CO2 Safety and Environment Major Accident Hazard Risk Management*", DNV Report No. 13IJLJW-2, 30th January 2013, Rev. 1.

Toxicity Effect

Toxicity effect for a CO_2 release is due to a scenario of depleting oxygen in air following a large amount release of CO_2. The ability of the toxic gas cloud to disperse below dangerous concentrations strongly depends on wind speed and stability. The toxic gas cloud will mix and disperse faster in neutral and unstable wind conditions. Conversely in stable wind conditions, the toxic gas cloud will remain dense and travel a further distance.

5.8.4 Review of Industry Incidents Relevant to Identified Hazardous Materials

To investigate further the possible hazards from the Project facilities, a worldwide review of past industry incidents at similar facilities was conducted based on following incident/ accident databases:

MHIDAS database (MHIDAS is a Major Hazard Incident Data Service developed by the Safety and Reliability Directorate of the UK Atomic Energy Authority. MHIDAS contains incidents from over 95 countries particularly the UK, U.S., Canada, Germany, France and India. The database allows access to many other important sources of accident data, such as the Loss Prevention Bulletin, and is continuously updated) (1);

eMARS, which contains reports of chemical accidents and near misses provided to the Major Accident and Hazards Bureau (MAHB) of the European Commission's Join Research Centre from EU, OCED and UNECE countries (2);

ARIA, operated by the French Ministry of Ecology, Sustainable Development and Energy, lists the accidental events, which have or could have damaged health or public safety nature or the environment (3);

EGIG 1970 to 2013, which is a European gas pipeline incident database since 1970, and a valuable and reliable source of information that is used to establish causes of failure and failure frequencies in the gas transmission pipeline system (4);

- Energy Institute;
- Global Congress on Process Safety 2013; and
- US Gas Pipeline Incident Database, 1984 to 2013 (5).

(1) UK AEA, Major Hazard Incident Database (MHIDAS) Silver Platter.

(2) Major Accident Hazards Bureau (MAHB), https://emars.jrc.ec.europa.eu/?id=4.

(3) ARIA (Analysis, Research and Information on Accidents) Database, http://www.aria.developpement-durable.gouv.fr/about-us/the-aria-database/?lang=en.

(4) European Gas Pipeline Incident Data Group, *9th EGIG Report*, 1970 – 2013.

(5) PRC International, *America Gas Association, Analysis of DOT Reportable Incidents for Gas Transmission and Gathering Pipelines*, January 1984 to December 2013.

The review of past incidents/ accidents for similar facilities are summarised in *Annex 5B*.

5.8.5 Review of Potential Initiating Events Leading to Major Accidental Events

The potential hazardous incidents arising from the Project and the existing facilities are mainly associated with a loss of containment of flammable hydrocarbons and hydrogen, or a toxic gas release. An initiating event is defined as a significant accidental release of hazardous materials beyond its normal barriers. This could occur as a result of failure of a major piece of process equipment, pipeline, or pipework. The various failure modes of different facilities that could result in a loss of containment are discussed below.

Natural Gas Facilities

Natural gas facilities include additional CCGT units and associated pipework from the Project facilities, the existing CCGT units, GRSs, and associated natural gas manifolds and pipework. The major causes for a loss of containment from natural gas facilities are:

- Corrosion, both internal and external;
- Third party interference due to work in adjoining areas, etc.;
- Material defect;
- Construction defect;
- Operator errors during operation and maintenance;
- Defect caused by pressure cycling; and
- External effects.

Hydrogen Facilities

Hydrogen facilities include hydrogen road trailers, hydrogen trailers at hydrogen trailer bay, associated hydrogen manifold and pipework, and generator gas control systems at each of both additional and existing CCGT units. The major causes for a loss of containment from hydrogen facilities are:

- Corrosion, both internal and external;
- Material defect;
- Construction defect;
- Operator errors during operation and maintenance;
- Traffic accidents; and

- External effects.

CO_2 Facilities

CO_2 facilities include CO_2 road tankers, a CO_2 storage tank, vaporiser, and associated CO_2 manifold and pipework to CCGT units. The major causes for a loss of containment from CO_2 facilities are:

- Overfilling;
- Corrosion, both internal and external;
- Material defect;
- Construction defect;
- Operator errors during operation and maintenance;
- Traffic accidents; and
- External effects.

Distillate Oil Facilities

Distillate oil facilities include a distillate oil unloading system, three distillate oil storage tanks, an auxiliary boiler day tank, associated pumps and pipework. The major causes for a loss of containment from distillate oil facilities are:

- Overfilling;
- Corrosion, both internal and external;
- Material defect;
- Construction defect;
- Operator errors during operation and maintenance; and
- External effects.

External Hazards

This section outlines these hazards that are outside the control of BPPS, but could still pose a risk on the Project and the existing BPPS facilities. Such hazards are termed as "external hazards" because they are independent of the process operations on-site but still can lead to major hazard accidents. These external hazard events include the following:

- Earthquake;
- Subsidence;

- Lightning;
- Hill fire;
- Storm surge and flooding;
- Tsunami;
- Aircraft crash; and
- Helicopter crash.

Since these events are independent of the operations, protection against them needs to be incorporated in the system design. Design criteria for the protection of hazardous facilities against such events are well established, and are generally dependent on the geographical locations of the facilities. Additional criteria could also be imposed (for instance development of hazardous facilities is subject to stricter planning regulations in areas of high seismic activity).

Each of these external hazard events is further analysed in the following section.

Earthquake

An earthquake has the potential to cause damage to process equipment and pipework. Damage to pipework could be due to ground movement/ vibration, with guillotine failure of pipework.

Studies by the Geotechnical Engineering Office (1) and Civil Engineering Development Department (2) conducted in the last decades indicate that Hong Kong Special Administrative Region is a region of low 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. (3). As Hong Kong is a region of low seismicity, an earthquake is an unlikely event. The generic failure frequencies adopted in this QRA study 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. There is no need to address earthquakes separately as they should be already included in the generic failure rates in *Section 5.9*.

(1) GEO Publication No. 1/2012, *Review of Earthquake Data for the Hong Kong Region*, Geotechnical Engineering Office, Civil Engineering and Development Department, The Government of the Hong Kong Special Administrative Region, September 2012.

(2) GCO, *Review of Earthquake Data for the Hong Kong Region*, GCO Publication No. 1/91, Civil Engineering Services Department, Hong Kong Government, 1991.

(3) 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.

Subsidence

For subsidence which would result in failure of process equipment or pipework, the ground movement must be relatively sudden and severe. Normal subsidence events occur gradually over a period of months and thus appropriate mitigation action can be taken to prevent failures. In the worst cases, the BPPS plant could be shutdown and the relevant equipment isolated and depressurised. The Project and the existing facilities are built on coastal land with solid foundation. No undue risk from subsidence is therefore foreseen and failures due to this should deemed to be included in generic failure frequencies in *Section 5.9*.

Lightning

Lightning strikes have led to a number of major accidents worldwide. For example, a contributory cause towards the major fire at the Texaco refinery in the UK in 1994 was thought to be an initial lightning strike on process pipework.

The Project and the existing facilities will be protected with lightning conductors to safety earth direct lightning strikes. The grounding will be inspected regularly. The potential for a lightning strike to hit the Project and the existing facilities and cause a release event is therefore deemed to be unlikely. Failures due to lightning strikes should be covered by generic frequencies in *Section 5.9*.

Hill Fire

Hill fires are relatively common in Hong Kong, and could potentially occur near the BPPS site. Recent statistics for these fires in Hong Kong country parks have been reviewed. Although the BPPS site is not actually located in a country park, some of the surrounding terrain and vegetation is similar to those typically found in country parks. According to Agriculture, Fisheries and Conservation Department (AFCD) statistics, the average number of hill fires is 32.4 per year during the five years 2008-2012 (range: 16 to 49). The area affected by fire each year is available from AFCD annual reports for 2009-2013 at the following table. These are compared to the total area of country parks in Hong Kong of 44,004 – 44,239 Ha.

Averaging the data for the 5-year period suggests that 1% of vegetation areas are affected by fire each year, or equivalently, the frequency of a hill fire affected a specific site is 0.01 per year.

Table 5.11 Hill Fire Data for Hong Kong

Year	Area Affected (Ha)	Country Park Area (Ha)	% of Total Country Park Affected
2012	79	44,239	0.18
2011	27	44,239	0.06
2010	897	44,239	2.03
2009	275	44,004	0.62
2008	501	44,004	1.14

BPPS site is protected from external fires (e.g. hill fire) by a firebreak line in BPPS Landscape Plan and regular inspection to ensure the firebreak line is properly maintained. Also, BPPS and the route between BPPS and CPPS are patrolled by station security, who will report to Fire Services Department and BPPS/ CPPS central control room immediately in case of hill fires.

Also, there is no incident record of any hill fire in the vicinity of the BPPS site. Taking into account the low frequency of hill fire near BPPS and safety management measures are implemented in placed in BPPS, hill fire leading to impact at BPPS site is considered unlikely and thus is not taken into account in this QRA study.

Storm Surges and Flooding

If the pipework becomes submerged under water, it is possible for buoyancy forces to lift the pipework/storage tanks, causing damage and possible a loss of containment.

Flooding from heavy rainfall is not possible due to the coastal location of BPPS including the Project Site. The slopes of the natural terrain will channel water to the sea. The primary hazard from typhoons is the storm surge. Winds, and to a lesser extent pressure, cause a rise in sea level in coastal areas. In general, storm surges are limited to several metres.

The Project and existing BPPS facilities, located at +6 mPD above sea level, are therefore protected against any risk from storm surges, waves and other causes of flooding.

As a result, storm surges and flooding are not taken into account in this QRA study.

Tsunami

Similar to storm surges, the main hazard from tsunamis is the rise in sea level and possible floatation of process equipment and pipework. The highest rise in sea level ever recorded in Hong Kong due to a tsunami was 0.3 m [(1)], and occurred as a result of the 1960 earthquake in Chile, the largest earthquake ever recorded in history at magnitude 9.5 on the Richter scale. The Project and the existing BPPS facilities are approximately at +6 mPD. The effect of a tsunami on BPPS including the Project Site is therefore considered negligible.

The reason for the low impact of tsunamis on Hong Kong may be explained by the extended continental shelf in the South China Sea which effectively dissipates the energy of a tsunami. Also, the presence of the Philippine Islands and Taiwan acts as an effective barrier against seismic activity in the

(1) Hong Kong Observatory.

Pacific (1). Secondary waves that pass through the Luzon Strait diffract and lose energy as they traverse the South China Sea.

Seismic activity with the South China Sea area may also produce tsunamis. Earthquakes on the western coast of Luzon in the Philippines have produced localised tsunamis but there is no record of any observable effects in Hong Kong. Also, with the shelter effects offered by Lantau Island and Hong Kong Island, tsunami comes from South East of Hong Kong cannot affect the BPPS.

As a result, tsunami is not taken into account in this QRA study.

Summary of natural hazards

The Project Site and design of the existing BPPS facilities are such that there will be no special risks from natural hazards. Natural hazards are therefore not treated separately in the analysis but should be included in the generic failure frequencies in *Section 5.9*.

Aircraft Crash

The BPPS site does not lie within the flight path of Chek Lap Kok (depicted at *Figure 5.6*), being about 10 km from the nearest runway.

The frequency of aircraft crash was estimated using the methodology of the HSE (2). The model takes into account specific factors such as the target area of the proposed hazard site and its longitudinal (x) and perpendicular (y) distances from the runway threshold (*Figure 5.7*). The crash frequency per unit ground area (per km^2) is calculated as:

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

(Equation 4)

where:

N is the number of runway movements per year

R is the probability of an accident per movement (landing or take-off)

$F(x,y)$ gives the spatial distribution of crashes and is given by:

Landings

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

(Equation 5)

for $x > -3.275$ km

(1) Lee, B. Y., *Report of Hong Kong in the International Tsunami Seminar in the Western Pacific Region*, International Tsunami Seminar in the Western Pacific Region, Tokyo, Japan, 7-12 March 1988.

(2) Byrne, J. P., *The Calculation of Aircraft Crash Risk in the UK*, HSE\R150, 1997.

Take-off

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

(Equation 6)

for $x > -0.6$ km

Equations 5 and *Equations 6* are valid only for the specified range of x values. If x lies outside this range, the impact probability is zero.

NTSB data (1) for fatal accidents in the U.S. involving scheduled airline flights during the period 1986-2005 are given in *Table 5.12*. The 10-year moving average suggests a downward trend with recent years showing a rate of about 2×10^{-7} per flight. However, only 13.5% of accidents are associated with the approach to landing, 15.8% are associated with take-off and 4.2% are related to the climb phase of the flight (2). The accident frequency for the approach to landings hence becomes 2.7×10^{-8} per flight and for take-off/climb 4.0×10^{-8} per flight. The number of flights at Chek Lap Kok in 2014 was about 390,000. The number of flights at Chek Lap Kok in 2035 (the operation phase of 2nd CCGT unit) was estimated as 685,000 (assumed as linear growth of a period from 1999 to 2014), which is in the same order of magnitude with the estimated number of flights as 620,000 in 2032 from the approved EIA study for *Expansion of Hong Kong International Airport into a Three-Runway System* (3).

Table 5.12 U.S. Scheduled Airline Accident Rate

Year	Accident rate per 1,000,000 flights for accidents involving fatalities	10-year moving average accident rate per 1,000,000 flights
1986	0.14	-
1987	0.41	-
1988	0.27	-
1989	1.10	-
1990	0.77	-
1991	0.53	-
1992	0.53	-
1993	0.13	-
1994	0.51	-
1995	0.12	0.451
1996	0.38	0.475
1997	0.30	0.464
1998	0.09	0.446
1999	0.18	0.354
2000	0.18	0.295
2001	0.19	0.261
2002	0.00	0.208
2003	0.20	0.215

(1) www.ntsb.gov/aviation/Table6.htm.

(2) *Annual Review of Aircraft Accident Data: U.S. General Aviation, Calendar Year 2001*, National Transport Safety Board.

(3) Mott MacDonald, EIA for *Expansion of Hong Kong International Airport into a Three-Runway System*, (Register No.: AEIAR-185/2014), November 2014.

Year	Accident rate per 1,000,000 flights for accidents involving fatalities	10-year moving average accident rate per 1,000,000 flights
2004	0.09	0.173
2005	0.27	0.188

Considering landings on runway 25L for example, the values for x and y to the Project Site according to *Figure 5.6* are 1.4 km and 11.7 km respectively. Applying *Equation 5* gives $F_L = 5.2\times10^{-5}$ km^{-2}. Substituting this into *Equation 4* gives:

$$g(x,y) = NRF(x,y) = 685{,}000 / 8 \times 2.7 \times 10^{-8} \times 5.2 \times 10^{-5} = 1.2 \times 10^{-7} \text{ per km}^2\text{-year}$$

The number of plane movements has been divided by eight (8) to take into account the 8 flight routes in the approved EIA study for *Expansion of Hong Kong International Airport into a Three-Runway System* (1). This effectively assumes that each runway is used equally and the wind blows in each direction with equal probability.

The target area is estimated at 40,000 m^2 (0.04 km^2). This gives a frequency for crashes into the Project Site associated with landings on runway 25L as 4.8×10^{-9} per year. Repeating the calculation for landings and take-offs from all runways gives the results shown in *Table 5.13.*

Table 5.13 Aircraft Crash Frequency onto the Project Site

Runway	Landing (per year)	Take-off (per year)
07R	-	2.4×10^{-11}
07C	-	1.3×10^{-10}
07L	-	No take off at 07L*
25L	4.8×10^{-9}	-
25C	No landing at 25C*	-
25R	6.8×10^{-9}	-
Total	1.2×10^{-8}	1.6×10^{-10}

*: The preferred operation mode is referred to the approved EIA study (1).

The combined frequency of all take-off and landing crashes onto the Project Site from activities on all runways is 1.2×10^{-8} per year, which has been taken into account in this QRA study.

Helicopter Crash

The BPPS site is provided with a helicopter landing pad although the frequency of use is expected to be low with perhaps one landing/take-off per week. The approach, landing and take-off stages of an aircraft flight are associated with the highest risk and therefore the possible impact of helicopter crashes on the Project facilities were assessed.

(1) Mott MacDonald, EIA for *Expansion of Hong Kong International Airport into a Three-Runway System*, (Register No.: AEIAR-185/2014), November 2014.

The frequency of helicopter crash was estimated using the methodology of the HSE (1). The model takes into account specific factors such as the target area of the proposed hazard site. The crash frequency per unit ground area (per km^2) is calculated as:

$$C_{HEL} = NR_HF \text{ (per } km^2\text{-year)}$$

(Equation 7)

where:

N is annual number of helicopter movements

R_H is helicopter landing/ take-off reliability (2.4×10^{-6} crashes per movement)

F is 29.6 (0 – 100 m) or 0.74 (100 – 200 m)

Considering one flight per week using the helipad and within 100 m from the helipad, the values for N and F are 52 and 29.6 respectively. Applying *Equation 7* gives $C_{HEL} = 3.69\text{x}10^{-3}$ per km^2-year.

Only accidents involving fatalities were therefore taken into account in this QRA study. 4% of incidents resulted in one or more fatalities and so the frequency of uncontrolled crashes was calculated as $3.69\times10^{-3} \times 0.04 = 1.48\times10^{-4}$ per km^2-year. Similar approach was applied to the impact range between 100 m and 200 m from the helipad.

The target areas within 100 m and between 100 m and 200 m from the helipad were identified and estimated based on plot plan to calculate the helicopter crash frequency.

Regarding passing helicopters, there are no helicopter flight paths in the vicinity of BPPS. The possibility of a passing helicopter crashing into the Project facilities is therefore much smaller than the generic failure frequencies used in this QRA study. Helicopter crashes are therefore not considered separately but are deemed to be included in the generic failure frequencies in *Section 5.9*.

5.8.6 HAZID Workshop for the Project Facilities

A HAZID Workshop for the Project facilities was conducted at BPPS on 8 September 2015 to identify the potential hazards from the Project facilities based on HAZID Workshop team's specialist opinion, past incidents/ accidents, lessons learned and checklists.

A systematic approach was adopted, whereby the Project facilities were divided into a number of "subsystems" based on the layout and the hazards/ keywords from the checklist applied to each subsystem as relevant.

The key findings from HAZID Workshop were summarised at *Table 5.14*.

(1) Byrne, J. P., *The Calculation of Aircraft Crash Risk in the UK*, HSE\R150, 1997.

Table 5.14 HAZID Workshop Worksheets for the Project Facilities

System: 1. CCGT Units
Subsystem: 1. Process hazards

Hazards/ Keywords	Description/ Causes	Consequences	Safeguards	Recommendations
1. Natural gas leak within additional CCGT units	1. Corrosion	1. Potential loss of containment	1. Gas and fire detection	
	2. Mechanical failure	2. Leaks reaching the ignition sources, leading to fire and potential explosion	2. Shutdown system	
	3. Mal-operation leading to process deviations		3. Operating and maintenance procedures	
			4. Hazardous area classification	
2. Natural gas leak from gas header extension	1. Corrosion	1. Potential loss of containment	1. Operating and maintenance procedures	
	2. Mechanical failure	2. Leaks reaching the ignition sources, leading to fire and potential explosion	2. Routine plant patrol	
	3. Mal-operation leading to process deviations	3. Potential domino effect on additional CCGT units	3. Shutdown system	
3. Ignition of natural gas from vent during normal operation and system purging	1. Due to lightning	1. Fire and / or explosion	1. Hazardous area classification	
	2. Sparks / statics / smoking	2. Potential thermal radiation effects on adjoining equipment	2. Vent location will consider separation distance from adjoining electrical equipment	
			3. Operating procedures	
4. Distillate oil leak from piping	1. Corrosion	1. Potential loss of containment	1. Operating procedures	
	2. Mechanical failure	2. Leaks reaching the ignition sources, leading to fire	2. Routine plant patrol	
	3. Mal-operation leading to process deviations	3. Oil spillage	3. Drain to oil interceptor in additional CCGT units area or contained in pipe trench	
5. Hydrogen for generator	1. Leaks from seals / valves	1. Potential loss of containment	1. Hydrogen pressure monitoring system	
		2. Ignition, fire and potential explosion	2. Routine plant patrol and test	
			3. Hazardous area classification	
6. CO_2 purging for generator and gas pipeline	1. Leaks from seals / valves	1. No major concern	1. Operating procedures	
7. Electrochlorination system	1. Sodium Hypochlorite is	1. Small amount of hydrogen	1. Lightning protection available	

System: 1. CCGT Units
Subsystem: 1. Process hazards

Hazards/ Keywords	Description/ Causes	Consequences	Safeguards	Recommendations
	generated on-site	release to atmosphere, maybe ignited by lightning leading to potential fire and explosion		
8. Usage of urea/ ammonia (Selective Catalytic Reduction System)	1. Ammonia is generated on-site, non-reacted ammonia will be released to atmosphere via stack	1. Ammonia release in exceeded regulatory limit	1. Ammonia detector at stack and monitoring system	
9. Chemical dosing system (acid/ alkali)	1. Leakage from chemical dosing system	1. Potential injury to operator	1. Operating procedures 2. Bund wall available	
10. Transformer oil leak	1. Leakage of oil from transformer	1. Oil spillage	1. Bund wall available	
11. Commissioning	1. Unplanned events	1. Fire	1. Commissioning procedures 2. Toolbox / Briefings	

System: 1. CCGT Units
Subsystem: 2. Natural hazards

Hazards/ Keywords	Description/ Causes	Consequences	Safeguards	Recommendations
1. Earthquake	1. Damage to piping and equipment	1. Fire and / or explosion	1. Area of low seismic activity 2. Plant with seismic design	
2. Tsunami	1. Waves higher than predicted	1. Possible damage to structures / facilities due to high wave and associated flooding	1. Black Point not susceptible to tsunami 2. Site at +6 mPD 3. Storm water drainage system available	
3. Storm / flooding	1. Damage to piping and equipment	1. Possible damage to structures / facilities	1. Storm water drainage system available 2. Site at +6 mPD	
4. High wind - typhoon	1. Damage to piping and equipment	1. Possible damage to structures / facilities	1. Plant designed to withstand super typhoon	
5. Subsidence / ground movement	1. No issue			

System: 1. CCGT Units
Subsystem: 2. Natural hazards

Hazards/ Keywords	Description/ Causes	Consequences	Safeguards	Recommendations
6. Extreme weather - temperature	1. No issue			
7. Lightning	1. Ignition of vent gas, refer to 1.2	1. Ignition of fugitive emission	1. Lightning protection available	
	2. Damage to piping and equipment	2. Fire and / or explosion		
		3. Damage to equipment		
8. Landslide	1. Damage to piping and equipment	1. Possible damage to structures / facilities	1. Sufficient separation distance at site boundary	
9. Hill fire	1. Hill fire	1. Potential operation interruption, no major issue	1. Firebreak line in BPPS Landscape Plan	
			2. BPPS emergency response plans	
			3. Sufficient separation distance at site boundary	

System: 1. CCGT Units
Subsystem: 3. External hazards

Hazards/ Keywords	Description/ Causes	Consequences	Safeguards	Recommendations
1. Fuel oil tank on fire or fuel oil tank rupture at BPPS	1. Fuel oil stored as secondary fuel for gas turbine units	1. Facility is about 15 m away and hence potential impact due to fire	1. Bund wall available	
			2. Fire-fighting system available for fuel oil storage tank area	
2. Hydrogen fire/ explosion at BPPS	1. Hydrogen stored at BPPS for generator cooling, rupture of hydrogen trailer at hydrogen trailer bay	1. Potential for projectiles causing damage to the facility	1. Trailer bay located in a concrete compound with ventilation system, leak/fire detection system available	
			2. Trailer house more than 300 m from proposed CCGT units	
3. Projectiles from turbine accidents at BPPS	1. Mechanical failure of turbine or lube oil failure	1. Potential for projectiles causing damage to the facility	1. Sufficient separation distance and workshop building between existing and additional CCGT units	
			2. Periodic inspection of the	

System: 1. CCGT Units
Subsystem: 3. External hazards

Hazards/ Keywords	Description/ Causes	Consequences	Safeguards	Recommendations
			turbine	
			3. Turbine located in a housing and turbine housing is within a structure	
4. Gas leaks at BPPS	1. Leak in the open area or in the gas turbine enclosure	1. Potential fire or explosion leading to potential damage on additional CCGT units	1. Gas leak detection and isolation system at different sections in BPPS	
			2. Sufficient separation distance and workshop building between existing and additional CCGT units	
5. Boiler explosion	1. Potential overpressure in boiler	1. Potential for projectiles causing damage to the facility	1. Boiler controls/ inspection and maintenance	
			2. Sufficient separation distance and workshop building between existing and additional CCGT units	
6. Aircraft crash	1. During take-off/ landing / approach	1. Damage to the facility and fire	1. BPPS is not in the flight path for aircrafts; it is about 20 km away from Hong Kong airport	
7. Helicopter crash	1. Helipad at BPPS and at the radar station	1. Damage to the facility and fire	1. Helipad about 50 m away from the additional CCGT units	
			2. Administration procedure for use of helipad at BPPS	
			3. Helipad at the radar station near BPPS used for specific purpose and not frequent	
8. Vehicle crash	1. Vehicle impacts onto process equipment	1. Damage to the facility and fire	1. Vehicle limit speed sign within BPPS	
			2. Crash barriers adjacent to gas header	
9. Transformer fire	1. Transformer fire	1. Potential domino effect on gas turbine/ pipeline within	1. Sufficient separation distance between transformer and gas	

System: 1. CCGT Units
Subsystem: 3. External hazards

Hazards/ Keywords	Description/ Causes	Consequences	Safeguards	Recommendations
		additional CCGT units	turbine/ pipeline	
10. Dropped objects	1. Lifting of objects over operational equipment	1. Damage to existing equipment leading to potential fire and explosion hazards	1. Lifting plans need to comply with operating plant procedures and guidelines (e.g. weight limits for lifting over operational plant)	
11. Sabotage/ Security	1. Intentional acts	1. Damage to facilities	1. Security system and perimeter fence available	

System: 1. CCGT Units
Subsystem: 4. Material hazards

Hazards/ Keywords	Description/ Causes	Consequences	Safeguards	Recommendations
1. Pressurised air	1. Generated on-site for process and instrument requirements	1. Pressure system hazards	1. Design procedures 2. Operating and safety procedures	
2. CO_2 for fire-fighting system	1. Used for fire-fighting	1. Potential asphyxiation to personnel	1. Operating and safety procedures	

System: 1. CCGT Units
Subsystem: 5. Loss of utilities

Hazards/ Keywords	Description/ Causes	Consequences	Safeguards	Recommendations
1. Loss of power supply	1. Loss of power supply to control system	1. Additional CCGT units will shutdown in safe mode	1. UPS for safety critical systems including lighting, controls etc. 2. Backup power supply available	
2. Loss of instrument air supply	1. Loss of instrument air supply to control system	1. Additional CCGT units will shutdown in safe mode	1. Interconnection to BPA compressed air system	

System: 1. CCGT Units
Subsystem: 6. Layout hazards

Hazards/ Keywords	Description/ Causes	Consequences	Safeguards	Recommendations
1. Layout	1. Preliminary layout review			

System: 1. CCGT Units
Subsystem: 6. Layout hazards

Hazards/ Keywords	Description/ Causes	Consequences	Safeguards	Recommendations
	has been carried out and will be reviewed to address separation distances, access and emergency egress issue			
2. Movement of dangerous goods	1. Additional consumption of hydrogen and CO_2 leading to increase dangerous goods delivery to BPPS	1. Possible injury to personnel	1. Operating procedures 2. Licensed contractors for hydrogen and CO_2 delivery	

System: 1. CCGT Units
Subsystem: 7. Interface with existing facility

Hazards/ Keywords	Description/ Causes	Consequences	Safeguards	Recommendations
1. Tie-ins	1. Tie-in procedures not followed	1. Loss of containment; fire and explosion	1. Safety management system in place to ensure tie-in procedure are followed	

System: 1. CCGT Units
Subsystem: 8. Construction phase

Hazards/ Keywords	Description/ Causes	Consequences	Safeguards	Recommendations
1. Access for installation / construction	1. Possible interference with existing equipment	1. Damage to existing equipment. Potential leaks and fire	1. Constructability study to be conducted	
2. Dropped objects	1. Lifting of objects over operational equipment	1. Damage to existing equipment. Potential leaks and fire	1. Lifting plans need to comply with operating plant procedures and guidelines (e.g. weight limits for lifting over operational plant)	
3. Vehicle movement	1. Vehicle impacting onto process equipment	1. Accidents leading to potential piping or equipment damage	1. Vehicle limit speed sign within BPPS 2. Constructability study to be conducted 3. Contractor management system	

System: 1. CCGT Units
Subsystem: 8. Construction phase

Hazards/ Keywords	Description/ Causes	Consequences	Safeguards	Recommendations
4. Escape and evacuation for construction team	1. Emergency events at BPPS	1. Emergency evacuation	1. Emergency response plan available	
			2. Constructability study to be conducted	
			3. Contractor management system	
5. General construction hazards	1. Hot work, excavation, confined space, work at height, etc.	1. Possible damage to operational equipment and personnel injuries	1. Permit to work	
			2. Construction safety plan (PPE, safety training, briefings, etc.)	

5.8.7 External Hazards of Construction Activities

Construction activities of the Project, which may cause potential external hazards on the existing BPPS facilities and discussed during the HAZID session, are summarised as follows:

- Movement of large equipment/ construction vehicles within BPPS to the Project Site;
- Dropped object from crane operation;
- General construction hazards such as hot work, drilling, etc.; and
- Tie-in works onto existing BPPS facilities.

Each of the construction activities is discussed below:

Movement of Large Equipment/ Construction Vehicles

One of the hazards identified from the Project construction activities to existing BPPS facilities is the movement of large equipment/ construction vehicles due to Project works leading to potential damage of BPPS equipment nearby the Project Site.

Based on the layout plan, the Project Site (for each phase) is well segregated from existing BPPS equipment. Also, during the construction phases, a dedicated access route will be used for construction vehicles. Therefore, the chance of vehicle crash impact on the existing CCGT units is negligible during construction phases.

As for other existing equipment (e.g. distillate oil pumping house for construction phase of first new unit, first new CCGT unit for construction phase of second new unit), the chances of construction vehicle crash impact can be minimised by ensuring speed limit enforcement being specified in the contractor's method statement to limit speed. Speed checks will be conducted to ensure enforcement of speed limits. A procedure will be developed to ensure adequate site access control. Also, lifting plans, with detailed risk assessment, will be prepared and endorsed for heavy lift of large equipment.

Moreover, the construction vehicle impact can be mitigated by providing vehicle crash barrier, which is designed for the specific limited speed between the construction site and the distillate oil facilities during 1st CCGT unit construction phase. A crash barrier will also be provided between the construction site and the operating 1st CCGT unit facilities during 2nd CCGT unit construction phase.

With the implementation of the above mitigation measures in place during the construction phases, the construction vehicle crash hazards can be minimised and managed. The failure due to construction vehicles should be covered by the generic failure frequencies in *Section 5.9.*

However, as a conservative approach, external construction vehicle impact on the distillate oil pumping house facilities during the construction phase of 1st CCGT unit, and on the operating 1st CCGT unit facilities during the construction phase of 2nd CCGT unit, are taken into account in this QRA study. The worst case scenario approach for construction vehicle impact was considered, by conservatively assuming one hundred (100) vehicle movements per day and a running distance of one (1) kilometre for each vehicle movement within the Project Site.

The fault tree analysis of the construction vehicles impact for Construction of 1st CCGT unit and 2nd CCGT unit is summarised in *Annex 5C*.

Dropped Object from Crane Operation

Any lifting operation near or over live equipment may cause damage to the existing BPPS facilities during the construction phases.

However, the lifting equipment operation procedure will be specified in the contractor's method statement to ensure that any lifting operation near or over live equipment should be strictly minimized. If such lifting operation cannot be avoided, lifting activities will be assessed, controlled, and closely supervised by contractors and operation staff. Also, adequate protection covers will be provided on the existing BPPS facilities in case the operation of lifting equipment has a potential to impact live equipment at the BPPS. Process isolation will be achieved in case that live equipment protection becomes impractical.

A Job Safety Analysis will be conducted for construction activities of the Project during the construction phases, to identify and analyse hazards associated with the construction activities. Also, risk from the Project and existing facilities will be minimised through the contractor's method statement, work permit system, strict supervision and adequate protection covers on live equipment. The potential for a dropped object to cause damage on the Project and the existing facilities and cause a release event is therefore considered included in the generic leak frequency in *Section 5.9*.

General Construction Activities Such as Hot Works, Drilling, etc.

General construction activities such as hot works within the Project Site will increase the number of ignition sources.

The ignition sources potentially present at the Project Site during the construction phases can be managed through a hazardous area classification study and updated hazardous area maps before the start of the construction activities to control ignition sources during construction phases. Also, work permit system for hot work activities within the Project Site will be specified in the contractor's method statement.

However, as a conservative approach, the ignition sources potentially present at the Project Site during the construction phases are taken into account in this

QRA study and all delayed events are considered to be ignited when the consequence of the cloud can reach the Project Site (in modelling terms, the delayed ignition events from scenarios when the wind is blowing from northeast, are conservatively modelled with 100% ignition probability as a worst case scenario).

Tie-in Work onto the Existing BPPS Facilities

During the tie-in works (connection of pipework), the potential hazard is the same as an increased number of ignition sources on the Project Site, which has been discussed in the paragraph above. During the commissioning works (start-up of new CCGT unit), the potential hazards are the same as those associated with any start-up operations, whose frequency of occurrence has been included in the generic failure frequencies suggested in *Section 5.9*.

To follow industrial best practices for construction works, the procedure for tie-in works onto existing BPPS equipment network should be reviewed by authorized personnel as appropriate, and then strictly followed during construction phases via a work permit system.

5.8.8 Development of Hazardous Sections

The Project and the existing BPPS facilities were divided into numbers of hazardous sections for the detailed analysis in this QRA study, based on following consideration:

- ***Isolation valves***: Sections are delimited by ESDVs/ SDVs where applicable. These ESDVs/ SDVs will ensure that the inventory released from a potential leak is limited to one section; and

- Process conditions, such as operating temperature, operating pressure, etc.

The hazardous section lists for the Project and the existing BPPS facilities are summarised in *Table 5.15* and *Table 5.16*.

Table 5.15 Hazardous Section List for the Project Facilities

Code	Plant Section Description	Potential Hazardous Scenarios	No. of items	Pipe Diameter (mm)	Length of Section	Operating Temperature (°C)	Operating Pressure (barg)
FG_01	Manifold extending from Yacheng fuel gas manifold to blending station	Jet fire, flash fire, fireball, VCE	1	700	120	41	38.0
FG_02	Manifold extending from Dachan fuel gas manifold to blending station	Jet fire, flash fire, fireball, VCE	1	700	120	41	38.0
FG_03	Manifold from blending station for 1st CCGT Unit	Jet fire, flash fire, fireball, VCE	1	700	10	41	38.0
FG_04	Piping from manifold to 1st CCGT unit	Jet fire, flash fire, VCE	1	200	120	41	38.0
FG_05	1st CCGT unit gas filter separator	Jet fire, flash fire, VCE	1	200	100	41	38.0
FG_06	1st CCGT unit fuel gas module	Jet fire, flash fire, VCE	1	200	5	41	38.0
FG_07	Manifold for 2nd CCGT	Jet fire, flash fire, fireball, VCE	1	700	95	41	38.0
FG_08	Piping from manifold to 2nd CCGT unit	Jet fire, flash fire, VCE	1	200	120	41	38.0
FG_09	2nd CCGT unit gas filter separator	Jet fire, flash fire, VCE	1	200	100	41	38.0
FG_10	2nd CCGT unit fuel gas module	Jet fire, flash fire, VCE	1	200	5	41	38.0
HY_01	Additional hydrogen road trailer for 1st CCGT unit (on-site and off-site transport)	Jet fire, flash fire, fireball, VCE	1	-	-	25	200.0
HY_02	Hydrogen manifold for 1st CCGT	Jet fire, flash fire, VCE	2	25	295	25	6.9
HY_03	Piping from hydrogen manifold to 1st CCGT unit	Jet fire, flash fire, VCE	1	25	115	25	6.9
HY_04	Additional hydrogen road trailer for 2nd CCGT unit (on-site and off-site transport)	Jet fire, flash fire, fireball, VCE	1	-	-	25	200.0
HY_05	Hydrogen manifold for 2nd CCGT	Jet fire, flash fire, VCE	2	25	95	25	6.9
HY_06	Piping from hydrogen manifold to 2nd CCGT unit	Jet fire, flash fire, VCE	1	25	115	25	6.9
DO_01	Distillate oil manifold for 1st CCGT	Pool fire, flash fire	1	350	45	25	3.5
DO_02	Piping from distillate oil manifold to 1st CCGT unit	Pool fire, flash fire	1	200	125	25	3.5
DO_03	Distillate oil manifold for 2nd CCGT	Pool fire, flash fire	1	350	95	25	3.5
DO_04	Piping from distillate oil manifold to 2nd CCGT unit	Pool fire, flash fire	1	200	125	25	3.5
CD_01	Additional CO_2 road tanker to 1st CCGT unit (on-site and off-site transport)	CO_2 BLEVE, toxicity effect	1	-	-	-18	20.7

Code	Plant Section Description	Potential Hazardous Scenarios	No. of items	Pipe Diameter (mm)	Length of Section	Operating Temperature (°C)	Operating Pressure (barg)
CD_02	CO_2 manifold for 1st CCGT	Toxicity effect	1	25	300	30	10.0
CD_03	Piping from CO_2 manifold to 1st CCGT unit	Toxicity effect	1	25	125	30	10.0
CD_04	Additional CO_2 road tanker to 2nd CCGT unit (on-site and off-site transport)	CO_2 BLEVE, toxicity effect	1	-	-	-18	20.7
CD_05	CO_2 manifold for 2nd CCGT	Toxicity effect	1	25	95	30	10.0
CD_06	Piping from CO_2 manifold to 2nd CCGT unit	Toxicity effect	1	25	125	30	10.0

Table 5.16 Hazardous Section List for the Existing BPPS Facilities

Code	Plant Section Description	Potential Hazardous Scenarios	No. of items	Pipe Diameter (mm)	Length of Section	Operating Temperature (°C)	Operating Pressure (barg)
GRS_01	Above ground piping from shore end to pig receiver of Yacheng GRS	Jet fire, flash fire, fireball, VCE	1	700	160.0	21.0	150.0
GRS_02	Piping from receiver to slug catcher of Yacheng GRS	Jet fire, flash fire, fireball, VCE	1	700	35.0	21.0	150.0
GRS_03	Piping from slug catcher to inlet gas filter separators of Yacheng GRS	Jet fire, flash fire, fireball, VCE	2	700	40.0	21.0	150.0
GRS_04	Piping from inlet gas filter separator to gas heater of Yacheng GRS	Jet fire, flash fire, fireball, VCE	7	700	105.0	21.0	150.0
GRS_05	Piping from gas heaters to pressure reduction station, including PRS of Yacheng GRS	Jet fire, flash fire, fireball, VCE	1	700	95.0	21.0	150.0
GRS_06	Piping from pressure reduction station to outlet gas filter separator of Yacheng GRS	Jet fire, flash fire, fireball, VCE	2	700	20.0	21.0	150.0
GRS_07	Piping from outlet gas filter separator to manifold, including sales gas meter unit of Yacheng GRS	Jet fire, flash fire, fireball, VCE	1	700	45.0	21.0	38.0
GRS_08	Pig receiver of Yacheng GRS	Jet fire, flash fire, fireball, VCE	1	700	8.7	21.0	150.0
GRS_11	Above ground piping from shore end to pig receiver of Dachan GRS	Jet fire, flash fire, fireball, VCE	1	700	70.0	19.7	54.8

Code	Plant Section Description	Potential Hazardous Scenarios	No. of items	Pipe Diameter (mm)	Length of Section	Operating Temperature (°C)	Operating Pressure (barg)
GRS_12	Piping from receiver to gas filter of Dachan GRS	Jet fire, flash fire, fireball, VCE	1	700	95.0	19.7	54.8
GRS_13	Filter & inlet/outlet piping of Dachan GRS	Jet fire, flash fire, fireball, VCE	3	400	15.0	19.7	54.8
GRS_14	Piping from filter to metering station of Dachan GRS	Jet fire, flash fire, fireball, VCE	1	700	45.0	19.7	54.8
GRS_15	Piping from metering station to heaters, including metering runs of Dachan GRS	Jet fire, flash fire, fireball, VCE	1	700	80.0	19.7	54.8
GRS_16	Heater Piping of Dachan GRS	Jet fire, flash fire, fireball, VCE	7	350	40.0	19.7	54.8
GRS_17	Piping from heater to PRS, including PRS of Dachan GRS	Jet fire, flash fire, fireball, VCE	1	700	35.0	19.7	54.8
GRS_18	Piping from PRS to manifold, including HIPPS of Dachan GRS	Jet fire, flash fire, fireball, VCE	1	700	265.0	41.0	38.0
GRS_19	Pig receiver of Dachan GRS	Jet fire, flash fire, fireball, VCE	1	800	8.7	19.7	54.8
FG_101	Yacheng manifold	Jet fire, flash fire, fireball, VCE	1	700	200.0	41.0	38.0
FG_102	Dachan manifold	Jet fire, flash fire, fireball, VCE	1	600	200.0	41.0	38.0
FG_103	Piping from manifold to Unit 1	Jet fire, flash fire, VCE	1	200	100.0	41.0	38.0
FG_104	Unit 1 gas filter separator	Jet fire, flash fire, VCE	1	200	60.0	41.0	38.0
FG_105	Unit 1 fuel gas module	Jet fire, flash fire, VCE	1	200	5.0	41.0	38.0
FG_106	Piping from manifold to Unit 2	Jet fire, flash fire, VCE	1	200	100.0	41.0	38.0
FG_107	Unit 2 gas filter separator	Jet fire, flash fire, VCE	1	200	60.0	41.0	38.0
FG_108	Unit 2 fuel gas module	Jet fire, flash fire, VCE	1	200	5.0	41.0	38.0
FG_109	Piping from manifold to Unit 3	Jet fire, flash fire, VCE	1	200	100.0	41.0	38.0
FG_110	Unit 3 gas filter separator	Jet fire, flash fire, VCE	1	200	70.0	41.0	38.0
FG_111	Unit 3 fuel gas module	Jet fire, flash fire, VCE	1	200	5.0	41.0	38.0
FG_112	Piping from manifold to Unit 4	Jet fire, flash fire, VCE	1	200	100.0	41.0	38.0
FG_113	Unit 4 gas filter separator	Jet fire, flash fire, VCE	1	200	70.0	41.0	38.0
FG_114	Unit 4 fuel gas module	Jet fire, flash fire, VCE	1	200	5.0	41.0	38.0
FG_115	Piping from manifold to Unit 5	Jet fire, flash fire, VCE	1	200	100.0	41.0	38.0
FG_116	Unit 5 gas filter separator	Jet fire, flash fire, VCE	1	200	60.0	41.0	38.0
FG_117	Unit 5 fuel gas module	Jet fire, flash fire, VCE	1	200	5.0	41.0	38.0
FG_118	Piping from manifold to Unit 6	Jet fire, flash fire, VCE	1	200	100.0	41.0	38.0
FG_119	Unit 6 gas filter separator	Jet fire, flash fire, VCE	1	200	60.0	41.0	38.0
FG_120	Unit 6 fuel gas module	Jet fire, flash fire, VCE	1	200	5.0	41.0	38.0

Code	Plant Section Description	Potential Hazardous Scenarios	No. of items	Pipe Diameter (mm)	Length of Section	Operating Temperature (°C)	Operating Pressure (barg)
FG_121	Piping from manifold to Unit 7	Jet fire, flash fire, VCE	1	200	100.0	41.0	38.0
FG_122	Unit 7 gas filter separator	Jet fire, flash fire, VCE	1	200	60.0	41.0	38.0
FG_123	Unit 7 fuel gas module	Jet fire, flash fire, VCE	1	200	5.0	41.0	38.0
FG_124	Piping from manifold to Unit 8	Jet fire, flash fire, VCE	1	200	100.0	41.0	38.0
FG_125	Unit 8 gas filter separator	Jet fire, flash fire, VCE	1	200	60.0	41.0	38.0
FG_126	Unit 8 fuel gas module	Jet fire, flash fire, VCE	1	200	5.0	41.0	38.0
FG_127	Interconnecting gas pipeline from BPPS to CPPS	Jet fire, flash fire, fireball, VCE	1	600	950.0	41.0	40.0
HY_11	Hydrogen road trailer for existing gas facilities (on-site and off-site transport)	Jet fire, flash fire, fireball, VCE	1	-	-	25.0	200.0
HY_12	Hydrogen trailer at hydrogen trailer bay	Jet fire, flash fire, fireball, VCE	2	-	-	25.0	200.0
HY_13	Trailer to high pressure piping	Jet fire, flash fire, VCE	2	25	20.0	25.0	200.0
HY_14	Trailer to low pressure piping	Jet fire, flash fire, VCE	2	25	20.0	25.0	6.9
HY_15	Hydrogen manifold	Jet fire, flash fire, VCE	2	25	496.0	25.0	6.9
HY_16	Piping from main supply to Unit 1	Jet fire, flash fire, VCE	1	25	32.0	25.0	6.9
HY_17	Piping from main supply to Unit 2	Jet fire, flash fire, VCE	1	25	31.0	25.0	6.9
HY_18	Piping from main supply to Unit 3	Jet fire, flash fire, VCE	1	25	43.0	25.0	6.9
HY_19	Piping from main supply to Unit 4	Jet fire, flash fire, VCE	1	25	35.0	25.0	6.9
HY_20	Piping from main supply to Unit 5	Jet fire, flash fire, VCE	1	25	36.0	25.0	6.9
HY_21	Piping from main supply to Unit 6	Jet fire, flash fire, VCE	1	25	36.0	25.0	6.9
HY_22	Piping from main supply to Unit 7	Jet fire, flash fire, VCE	1	25	44.0	25.0	6.9
HY_23	Piping from main supply to Unit 8	Jet fire, flash fire, VCE	1	25	36.0	25.0	6.9
DO_11	Distillate oil tank #1	Pool fire, flash fire	1	-	-	25.0	Atmospheric pressure
DO_12	Distillate oil tank #2	Pool fire, flash fire	1	-	-	25.0	Atmospheric pressure
DO_13	Distillate oil tank #3	Pool fire, flash fire	1	-	-	25.0	Atmospheric pressure
DO_14	Distillate oil pumping house	Pool fire, flash fire	8	350	35.0	25.0	3.5
DO_15	Distillate oil manifold section 1	Pool fire, flash fire	1	450	10.0	25.0	3.5
DO_16	Distillate oil manifold section 2	Pool fire, flash fire	1	350	25.0	25.0	3.5
DO_17	Distillate oil manifold section 3	Pool fire, flash fire	1	250	435.0	25.0	3.5
DO_18	Piping from distillate oil manifold to Unit 1	Pool fire, flash fire	1	200	75.0	25.0	3.5

Code	Plant Section Description	Potential Hazardous Scenarios	No. of items	Pipe Diameter (mm)	Length of Section	Operating Temperature (°C)	Operating Pressure (barg)
DO_19	Piping from distillate oil manifold to Unit 2	Pool fire, flash fire	1	200	75.0	25.0	3.5
DO_20	Piping from distillate oil manifold to Unit 3	Pool fire, flash fire	1	200	75.0	25.0	3.5
DO_21	Piping from distillate oil manifold to Unit 4	Pool fire, flash fire	1	200	75.0	25.0	3.5
DO_22	Piping from distillate oil manifold to Unit 5	Pool fire, flash fire	1	200	75.0	25.0	3.5
DO_23	Piping from distillate oil manifold to Unit 6	Pool fire, flash fire	1	200	75.0	25.0	3.5
DO_24	Piping from distillate oil manifold to Unit 7	Pool fire, flash fire	1	200	75.0	25.0	3.5
DO_25	Piping from distillate oil manifold to Unit 8	Pool fire, flash fire	1	200	75.0	25.0	3.5
DO_26	Unloading arm at oil unloading berth/ heavy load berth	Pool fire, flash fire	1	200	20.0	25.0	3.5
DO_27	Fuel oil bunkering line from unloading arm to distillate oil tanks through fuel oil strainer	Pool fire, flash fire	1	300	100.0	25.0	3.5
CD_11	CO_2 road tanker to the existing facilities (on-site and off-site transport)	CO_2 BLEVE, toxicity effect	1	-	-	-18.0	20.7
CD_12	CO_2 storage tank	CO_2 BLEVE, toxicity effect	1	-	-	-18.0	20.7
CD_13	CO_2 manifold section 1	Toxicity effect	1	25	20.0	30.0	10.0
CD_14	CO_2 manifold section 2	Toxicity effect	1	25	275.0	30.0	10.0
CD_15	Piping from CO_2 manifold to Unit 1	Toxicity effect	1	25	30.0	30.0	10.0
CD_16	Piping from CO_2 manifold to Unit 2	Toxicity effect	1	25	30.0	30.0	10.0
CD_17	Piping from CO_2 manifold to Unit 3	Toxicity effect	1	25	45.0	30.0	10.0
CD_18	Piping from CO_2 manifold to Unit 4	Toxicity effect	1	25	35.0	30.0	10.0
CD_19	Piping from CO_2 manifold to Unit 5	Toxicity effect	1	25	35.0	30.0	10.0
CD_20	Piping from CO_2 manifold to Unit 6	Toxicity effect	1	25	35.0	30.0	10.0
CD_21	Piping from CO_2 manifold to Unit 7	Toxicity effect	1	25	45.0	30.0	10.0
CD_22	Piping from CO_2 manifold to Unit 8	Toxicity effect	1	25	35.0	30.0	10.0

5.9 FREQUENCY ANALYSIS

A number of references and the approved EIA studies (1) (2) (3) have been reviewed for the frequency analysis. The likelihood or the frequency of outcome events resulting in a flammable or toxic gas release from process equipment or pipework, and the subsequent potential hazardous scenarios such as fire, explosion or toxic gas dispersion scenarios was estimated in this QRA study.

Failure frequencies for various hazard sources/ equipment were adopted from historical databases in line with the approved EIA studies, summarised in *Table 5.17*. In addition, fault tree analysis was applied to analyse the failure frequencies associated with hydrogen road trailers and CO_2 road tankers, to take into account the combination of spontaneous failures from trailer/ tanker and external road traffic accident failures. Release scenarios including a range of hole sizes from a small leak to a full bore rupture or a catastrophic rupture were assessed in this QRA study.

Table 5.17 Release Event Frequencies

Equipment	Release Scenario	Release Phase	Release Frequency	Unit	Reference
Pipe size 600 mm to 750 mm	i) 10 & 25 mm hole	Liquid/ Gas	1.00E-07	per meter-year	Hawksley
	ii) 50 & 100 mm hole	Liquid/ Gas	7.00E-08	per meter-year	Hawksley
	iii) Full bore rupture	Liquid/ Gas	3.00E-08	per meter-year	Hawksley
Pipe size 150 mm to 500 mm	i) 10 & 25 mm hole	Liquid/ Gas	3.00E-07	per meter-year	Hawksley
	ii) 50 & 100 mm hole	Liquid/ Gas	1.00E-07	per meter-year	Hawksley
	iii) Full bore rupture	Liquid/ Gas	5.00E-08	per meter-year	Hawksley
Storage Tank (Single-containment tank)	i) 10 mm hole	Liquid	1.00E-04	per tank-year	Purple Book
	ii) Catastrophic	Liquid	5.00E-06	per tank-year	Purple Book
Storage Tank (Double-containment tank)	i) Catastrophic	Liquid	1.25E-08	per tank-year	Purple Book
	ii) Partial failure*	Liquid	1.25E-08	per tank-year	Purple Book
Pressure Vessel	i) 10 mm hole	Liquid/ Gas	1.00E-05	per vessel-year	Purple Book
	ii) Catastrophic	Liquid/ Gas	5.00E-07	per vessel-year	Purple Book

(1) ERM, EIA for *Black Point Gas Supply Project* (Register No.: AEIAR-150/2010), February 2010.

(2) ERM, EIA for *Liquefied Natural Gas (LNG) Receiving Terminal and Associated Facilities* (Register No.: AEIAR-106/2007), December 2006.

(3) ERM/ BV, EIA for *Desalination Plant at Tseung Kwan O – Feasibility Study* (Register No.: AEIAR-192/2015), November 2015.

Equipment	Release Scenario	Release Phase	Release Frequency	Unit	Reference
Cylinder	i) Catastrophic	Gas	1.00E-06	per cylinder-year	Purple Book
	ii) Partial failure*	Gas	2.60E-06	per cylinder-year	Journal of hazardous material (1)
Road Tanker	i) Catastrophic	Liquid/ Gas	5.00E-07	per road tanker-year	Purple Book
	ii) Leak#	Liquid/ Gas	5.00E-07	per road tanker-year	Purple Book
Pumps	i) Leak	Liquid	1.00E-04	per year	COVO Study
	ii) Full bore rupture	Liquid	1.00E-05	per year	COVO Study
Frequency of spontaneous truck fire	-	-	4.00E-09	per truck-km	Refer to PHI QRA (2)
Truck rollover frequency	-	-	1.90E-07	per truck-km	Refer to PHI QRA
Truck impact frequency	-	-	4.00E-07	per truck-km	Refer to PHI QRA
Conditional probability of vessel rupture in traffic accident	-	-	4.25E-03	-	DNV QRA Report (3)
Conditional probability of large leak on vessel in traffic accident	-	-	4.00E-03	-	DNV QRA Report
Conditional probability of small leak (all sizes including pipe, valve etc.) in traffic accident	-	-	1.50E-01		DNV QRA Report
Driver fails to put out the fire with vehicle fire extinguisher	-	-	5.00E-01	per demand	Fire services fail to prevent BLEVE (4)
Unloading Arm	i) Leak^	Liquid/ Gas	4.05E-03	per year	COVO Study
	ii) Full bore rupture	Liquid/ Gas	4.05E-05	per year	COVO Study
Truck accident frequency (for construction vehicle impact)	-	-	5.90E-07	per truck-km	Refer to PHI QRA

Note:
*: 10 mm and 25 mm hole releases are assumed as the representative hole size releases for the partial failure of the storage tank with double containment tank design and cylinder.
#: 25 mm hole release is assumed as a representative hole size release for the continuous release from a hole the size of the largest connection.

(1) Ames S. and Crowhurst D, *Domestic explosion hazards from small LPG containers*, Journal of hazardous materials, 1988.

(2) ERM, EIA for *In-situ Reprovisioning of Sha Tin Water Treatment Works – South Works – Hazard to Life Assessment* (Register No.: AEIAR-187/2015), January 2015.

(3) DNV Technica, *Project Summary Project for the Risk Assessment of the Transport of Non Fuel Dangerous Goods in Hong Kong*, 1996.

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

^: 10 mm, 25 mm, 50 mm and 100 mm hole releases are assumed as the representative hole size releases for the leak hole size of the unloading arm.

5.9.1 Discussion on Failure Frequencies

Natural Gas Facilities

The failure frequencies for natural gas facilities were selected from Hawksley (1), who presents his own derived data for both above and below ground pipework in 1984. This historical database was also suggested in the approved EIA studies (2) (3) for natural gas facilities.

The failure database adopted in the Safety Case Report for Black Point Gas Supply Project (Safety Case Report) is the generic leak frequencies developed by DNV based on the Hydrocarbon Release Database (HCRD) from UK HSE. The database is based on approximately 4,000 recorded leaks recorded between October 1992 and March 2010 from the UK sector of the North Sea which has been collected by the UK HSE. In general, the database for offshore facilities gives higher leak frequencies than most of the onshore sources of data.

The natural gas facilities at BPPS mainly consist of both above and underground pipework; therefore, it is more applicable to adopt failure frequencies suggested by Hawksley (1) in this QRA study.

Moreover, the failure rates from Hawksley (1) are also compared with that suggested by UK HSE (4), which was established by the Hazardous Installations Directorate (HID) C15 of the UK HSE in 2012. The UK HSE failure rates (4)are intended for use on Land Use Planning cases and have been in use for several years. After review, it is found that the failure rates for pipework from Hawksley (1) and UK HSE (4) are in the same order of magnitude.

Other Dangerous Goods Facilities

The majority of the failure frequencies were selected from the data suggested by the approved EIA studies, including, Purple Book (5), COVO Study (6), as these international databases were developed for risk assessments for the use, handling, transport and storage of dangerous substances.

(1) Hawksley, J.L., *Some Social, Technical and Economic Aspects of the Risks of Large Plants*, CHEMRAWN III, 1984.

(2) ERM, EIA for *Black Point Gas Supply Project* (Register No.: AEIAR-150/2010), February 2010.

(3) ERM, EIA for *Liquefied Natural Gas (LNG) Receiving Terminal and Associated Facilities* (Register No.: AEIAR-106/2007), December 2006.

(4) UK HSE, *Failure Rate and Event Data for use within Risk Assessments*, 28 July 2012.

(5) *Guidelines for Quantitative Risk Assessment*, "Purple Book", 2005.

(6) Rijnmond Public Authority, A *Risk Analysis of Six Potentially Hazardous Industrial Objects in the Rijnmond Area – A Pilot Study*, COVO, D. Reidel Publishing Co., Dordrecht,1982.

These databases are based on failure data collected from a variety of onshore facilities including refineries, LPG storage, etc., and other dangerous substances installations such as chlorine and ammonia storage tanks with professional judgment applied as appropriate.

The following subsections provide the discussion on the frequency of other failure events such as overtopping and bund overflowing.

Bund Overtopping

The possibility of bund overtopping is considered for tank catastrophic rupture scenarios. The proportion of tank contents that overtop the bund depends on the geometry, specifically the hydrostatic head of liquid, and the height of the bund wall and the distance of the bund from the tank.

For the distillate oil storage site, the likelihood of bund overtopping was therefore estimated based on the orientation of a release in relation to the nearest bund wall. Directions are considered in quadrants (see *Figure 5.8*). The probability of a release being directed towards the nearest bund wall is taken to be 0.25, while the probability of a leak being directed towards the inner regions of the impoundment area is taken as 0.75. For tanks located in the corner of the bund area, the probability of overtopping is taken as 0.5.

Bund Overflowing

It would, in theory, be possible to release the contents of more than one tank into a bund at the same time. A tank fire leading to a subsequent escalation to other tanks is calculated below:

The frequency of a bund fire from all causes, including an escalation, can be taken as 1.2×10^{-5} (1). The risk at the BPPS site is further reduced because:

- Bunds are equipped with fire detection and protection measures such as CCTV connected to foam monitor house and a manually operated foam system;

- Bunds can be drained to remove flammable/combustible material. This will limit the duration of a bund fire; and

- Tank failure below the liquid level is normally not to be expected during an external fire, because of the cooling effect from the liquid.

The maximum duration of a bund fire incident resulting from a tank catastrophic rupture can be estimated as follows. The worst case of distillate oil tank rupturing and spilling its entire contents of distillate oil into the bund

(1) *Bund effectiveness in preventing escalation of tank farm fires*, T Davies, A B Harding, I P McKay, R G J Robinson, A Wilkinson, Process Safety and Environmental protection, 74, Part B, 88-93, May 1996. (Note: the authors of this paper are listed alpha

with surface area of 9,147 m^2 has been considered; the distillate oil then is ignited and burns without any mitigation measures.

With reference to PHAST (1), the value of burning rate for fuel oil (distillate oil) is 0.035 kg per m^2-s. The maximum volume of distillate oil in the bund is *A* m^3, corresponding to *B* kg. Thus the burning time t_B can be estimated as:

t_B = *'B' / (0.035 × 9,147) = 1.69 × 10^7 / (0.035 ×9,147) =52,800 seconds = 14.7 hours*

Thus, a bund fire incident can be expected to last only D (14.7 hours). The frequency of two (2) out of three (3) tanks within the bund randomly failing within a day may be estimated from:

$$3 \times 10^{-4} \times 2 \times 10^{-4} \times D / 8{,}760 \times 0.02 = 2.0 \times 10^{-12} \text{ per year}$$

where:
10^{-4} per year is the leak frequency of a tank
0.02 is the ignition probability

The resulting frequency of an overflowing pool fire was estimated as 2.0×10^{-12} per year, which is much lower than the risk criteria in Section 2 of Annex 4 of *EIAO-TM*, therefore it is not taken into account in this QRA study.

5.9.2 Flammable Gas Detection and Shutdown Probability

With reference to Purple Book (2), the effect of blocking valve system is determined by various factors, such as the position of gas detection monitors and the distribution thereof over the various wind directions, the direction limit of the detection system, the system reaction time and the intervention time of an operator. The probability of failure on demand for an automatic blocking system is 0.001 per demand while that for a hand-operated blocking system is 0.01 per demand.

However, only GRS and hydrogen trailer bay areas are protected by an automatic shutdown system, and the other natural gas facilities and hydrogen distribution system are protected by a hand-operated shutdown system.

As a conservative approach, the probability of failure on demand for all detection and shutdown system was assumed to be 1 in this QRA study.

5.9.3 Ignition Probability

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

(1) DNV, PHAST version 6.7.

(2) *Guidelines for Quantitative Risk Assessment*, "Purple Book", 2005.

Ignition Probability for Natural Gas

Table 5.18 summarises the ignition probabilities adopted in this QRA study for natural gas, which is consistent with the approved EIA studies (1) (2). The total ignition probability is 0.07 for small leaks (considered to be 10 mm and 25 mm leaks) and 0.32 for large leaks and ruptures. These ignition probabilities are consistent with the model of Cox, Lees and Ang (3).

The ignition probabilities are distributed between immediate ignition and delayed ignition. Delayed ignition is further divided between delayed ignition 1 and delayed ignition 2 to take into account that a dispersing gas cloud may be ignited at different points during its dispersion. Delayed ignition 1 results in a flash fire and takes into account the possibility that an ignition could occur within the plant area due to the presence of ignition sources on-site. Delayed ignition 2 gives a flash fire after the gas cloud has expanded to its maximum (steady state) extent.

If both delayed ignition 1 and 2 do not occur, the gas cloud disperses with no hazardous effect.

Table 5.18 Ignition Probability for Natural Gas

	Immediate Ignition	Delayed Ignition 1	Delayed Ignition 2	Delayed Ignition Probability	Total Ignition Probability
Small leak	0.02	0.045	0.005	0.05	0.07
Large leak/ rupture	0.10	0.200	0.020	0.22	0.32

For isolation failure scenarios, the delayed ignition probabilities given in *Table 5.18* are doubled. The longer duration and larger inventory release from a non-isolated release is assumed to make it more likely that an ignition takes place.

Ignition Probability for Distillate Oil

Table 5.19 summarises the ignition probabilities adopted in this QRA study for distillate oil. The total ignition probability is 0.03 for small leaks (considered to be 10 mm and 25 mm leaks) and 0.08 for large leaks and ruptures. These ignition probabilities are consistent with the model of Cox, Lees and Ang (3).

The ignition probabilities are distributed between immediate ignition and delayed ignition. If a delayed ignition does not occur, the gas cloud disperses with no hazardous effect.

(1) ERM, EIA for *Black Point Gas Supply Project* (Register No.: AEIAR-150/2010), February 2010.

(2) ERM, EIA for *Liquefied Natural Gas (LNG) Receiving Terminal and Associated Facilities* (Register No.: AEIAR-106/2007), December 2006.

(3) Cox, Lees and Ang, *Classification of Hazardous Locations*, IChemE.

Table 5.19 Ignition Probability for Distillate Oil

	Immediate Ignition	Delayed Ignition Probability	Total Ignition Probability
Small leak	0.01	0.02	0.03
Large leak/ rupture	0.02	0.06	0.08

For isolation failure scenarios, the delayed ignition probabilities given in *Table 5.19* are doubled. The longer duration and larger inventory release from a non-isolated release is assumed to make it more likely that an ignition takes place.

Ignition Probability for Hydrogen

Hydrogen has a higher probability of ignition; ignition energy required for hydrogen is one-tenth of natural gas. Therefore, the immediate ignition probability of hydrogen can be higher than the ignition probability of natural gas by a factor of 5.

The approach is consistent with Cadwallader and Herring (1) who give ignition probabilities for hydrogen fuel vehicles as 0.5 for small spills and 0.9 for large spills. Hydrogen is much lighter than air and therefore, if not immediately ignited, it will tend to quickly disperse vertically (as opposed to dense gases). Therefore, the hydrogen cloud is unlikely to find any ignition source. It should be nevertheless noted that the risk of static ignition will persist. This risk is however only relevant for a few minutes as the hydrogen will quickly disperse. The probability of delayed ignition is therefore conservatively taken as the same as the probability of immediate ignition.

The ignition probabilities selected for hydrogen in this QRA study are presented in *Table 5.20*.

Table 5.20 Ignition Probability for Hydrogen

Ignition Probability	Small Leak	Large Leak
Immediate Ignition	0.5	0.9
Delayed Ignition	0.5	0.9

5.9.4 VCE

The explosion probability given an ignition adopted in this QRA study was taken from Cox, Lees and Ang model (2), as shown in *Table 5.21*. VCE occurs upon a delayed ignition from a gas release at a congested area. Since a liquid release is contained in a potential explosion site (PES), it is conservative to

(1) Cadwallader and Herring, *Safety Issues with Hydrogen as a Vehicle Fuel*, Idaho National Engineering and Environmental Laboratory, Lockheed Martin, September 1999.

(2) Cox, Lees and Ang, *Classification of Hazardous Locations*, IChemE.

assume an unignited liquid release vapourises to produce a flammable vapour cloud, subsequently ignited to produce an explosion.

Table 5.21 Probability of Explosion

Leak Size (Release Rate)	Explosion Probability
Minor (< 1 kg s^{-1})	0.04
Major (1 – 50 kg s^{-1})	0.12
Massive (> 50 kg s^{-1})	0.30

5.9.5 Escalation

An initially small release may escalate into a larger, more serious event if a jet fire impinges on neighbouring equipment for an extended time (more than about ten (10) minutes). It is taken into account the modelling for the isolation fail branch of the event trees for natural gas facilities. If neighbouring piping is within range of the flame zone of a jet fire, an escalation probability of 1/6 is taken to conservatively estimate the directional probability and chance of impingement. Escalation is assumed to cause a full bore rupture of the affected pipeline/ piping only.

5.9.6 Event Tree Analysis

An event tree analysis was performed to model the development of each event from an initial release to a final hazardous scenario. The event tree analysis was considered whether there is immediate ignition, delayed ignition or no ignition. The possible hazardous scenarios include jet fire, flash fire, pool fire, toxicity effect, fireball and VCE.

The event tree analysis for natural gas, hydrogen, distillate oil and CO_2 facilities is depicted at *Figure 5.9*, *Figure 5.10*, *Figure 5.11* and *Figure 5.12* respectively.

5.9.7 Hazardous Scenarios Frequencies

A summary of hazardous scenarios frequencies considered in this QRA study are summarised in *Annex 5C*.

5.10 CONSEQUENCE ANALYSIS

This section summarises the approaches to model the major hazardous scenarios from the continuous and catastrophic releases considered in this QRA study. Consequence analysis comprises the following items:

- Source term modelling, which involves determining the release rate variation with time and thermodynamic properties of the released fluids;
- Physical effects modelling, which involves estimating the effect zone of the various hazardous scenarios; and

- Consequence end-point criteria, which involves assessing of the impact of hazardous scenarios on the exposed population during construction and operation phases of the Project.

5.10.1 Source Term Modelling

Source term modelling was carried out to determine the maximum (e.g. initial) release rate that may be expected should a loss of containment occur.

Release Rate Calculation

The release rate and release variation with time were estimated using PHAST. The release rate models used in PHAST are based on standard orifice type calculations, where the hole size and process conditions are used to determine the discharge rate. The release rate also depends on the physical properties of the material being released at the leak location, as well as the hole diameter.

For a guillotine failure of a pipe or a 100 mm hole size leak scenario, the release rate obtained from the discharge modelling is found to be more than the normal process flow rate or maximum pump outflow possible. For such a situation, the release rate was usually limited to 30% above the maximum pump throughput (end-of-curve) for a leak from the pipe downstream of a pump. To achieve this, the modelled pressure (i.e. system pressure at initial state) were reduced iteratively so that the desired release rate is achieved for the given process conditions.

Release Duration

With reference to Purple Book (1), the closing time of an automatic blocking system is two (2) minutes while that of a hand-operated blocking system is thirty (30) minutes.

The closing time of two (2) minutes for an automatic blocking system has been verified by CLP based on their solid operation experience and is deemed applicable to the existing BPPS facilities.

Detection and shutdown system may however fail due to some reasons, also as per Purple Book (1), the release duration is limited to a maximum of thirty (30) minutes. The release duration of thirty (30) minutes was conservatively assumed and adopted in this QRA study.

Release Direction

The orientation of a release can have some effects on the hazard footprint calculated by PHAST. The models take into account the momentum of the release, air entrainment, vaporisation rate and liquid rainout fraction.

(1) *Guidelines for Quantitative Risk Assessment*, "Purple Book", 2005.

For a horizontal, non-impinging release, momentum effects tend to dominate for most releases giving a jet fire as the most serious outcome. If a release is vertically upwards, the hazard footprint will be significantly less compared to a horizontal release. Also, if a release impinges on the ground or other obstacles, the momentum of the release and air entrainment is reduced, thereby reducing the hazard footprint but also increasing the liquid rainout fraction. In this scenario, a pool fire becomes more likely.

Therefore, for all pool fire scenarios, the release orientation was set to "*downward impinging release*" in order to obtain the worst case consequence pool fire; while "horizontal non-impinging" was selected for modelling other fire effects such as jet fire and flash fire, and toxicity effect, as a conservative approach.

5.10.2 Physical Effects Modelling

Flammable and Toxicity Effect Modelling

The physical effects modelling by PHAST assessed the effects zones for the following hazardous scenarios in this QRA study:

- Jet fire;
- Flash fire;
- Pool fire;
- Fireball;
- Vapour cloud explosion; and
- Toxicity effect.

Each of these events is further analysed in the following section.

Jet Fire

A jet fire results from an ignited release of the pressurised flammable gas. The momentum of the release carries the flammable materials forward in form of a long plume entraining air to give a flammable mixture. Combustion in a jet fire occurs in the form of a strong turbulent diffusion flame that is strongly influenced by the momentum of the release.

A jet fire was modelled for a pressurised flammable gas release. The default jet fire correlation model in PHAST was selected, and the release orientation was set as a horizontal non-impinging release.

Flash Fire

If there is no immediate ignition, the flammable gas such as natural gas and hydrogen may disperse before subsequently encountering an ignition source

giving a jet fire or pool fire. The vapour cloud will then burn with a flash back to the source of the leak. A flash fire is assumed to be fatal to anyone caught within the flash fire envelope, although the short duration of a flash fire means that radiation effects are negligible. The fatality probability is therefore zero for persons outside the flash fire envelope.

Dispersion modelling was conducted by PHAST to calculate the extent of the flammable vapour cloud. This takes into account both the direct vaporisation from the release, and also the vapour formed from evaporating pools. The extent of the flash fire was assumed to be the dispersion distance to LFL in this QRA study.

Pool Fire

In case of an early ignition of a liquid pool, an early pool fire will be formed and the maximum pool diameter can be obtained by matching the burning rate with the release rate. Under such a condition, the size of the pool fire will not increase further and will be steady. In case of a delay ignition, the maximum pool radius is reached when the pool thickness at the centre of the pool reaches the maximum thickness.

Fireball

Immediate ignition of release caused by a catastrophic rupture of process equipment or a full bore rupture of a pipeline may give rise to a fireball. The consequence analysis for a fireball scenario was conducted by Roberts (HSE) method (1) in PHAST as the calculation method.

The flammable mass for fireball modelling was conservatively estimated by the initial flow rate continuing for ten (10) seconds even though the initial release rate is decreasing rapidly in case of a full bore rupture scenario of a pipeline. This approach is consistent with the approved study, Safety Case Report (2).

Persons caught in the open area within the fireball diameter have been assumed to be 100% fatality.

Vapour Cloud Explosion

Explosions may only occur in areas of high congestion, or high confinement. Ignition in the open may only result in a flash fire or an unconfined VCE yielding relatively a lower damaging overpressure.

When a large amount of flammable gas is rapidly released, a vapour cloud forms and disperses in the surrounding air. The release can occur from natural gas manifold, GRS, etc. If this cloud is ignited before the cloud is

(1) DNV, PHAST version 6.7.

(2) DNV, *Safety Case Report for Black Point Gas Supply Project*, Report No.: PP019678, Revision No.2, August 2013.

diluted below its LFL, a VCE or flash fire will occur. The main consequence of a VCE is damage to buildings/ structures due to an overpressure while the main consequence of a flash fire is a direct flame contact. The resulting outcome, either a flash fire or a VCE depends on a number of parameters.

Pietersen and Huerta (1985) (1) has summarised some key features of 80 flash fires and AIChE/CCPS (2000) (1) provides an excellent summary of vapour cloud behaviour. They describe four features which must be present in order for a VCE to occur. First, the release material must be flammable. Second, a cloud of sufficient size must form prior to an ignition, with ignition delays of 1 to 5 minutes considered the most probable for generating VCEs. Lenoir and Davenport (1992) (1) analysed historical data on ignition delays, and found delay times from six (6) seconds to as long as sixty (60) minutes. Third, a sufficient amount of the cloud must be within the flammable range. Fourth, sufficient confinement or turbulent mixing of a portion of the vapour cloud must be present.

The blast effects produced depend on whether a deflagration or detonation results, with a deflagration being, by far, the most likely. A transition from deflagration to detonation is unlikely in the open air. The ability for an explosion to result in a detonation is also dependent on the energy of the ignition source, with larger ignition sources increasing the likelihood of a direct detonation.

In order to calculate the distances to given overpressures, the Baker-Strehlow-Tang (BST) model (2), which is a congestion based model, was adopted in this QRA study. The volume of flammable material in congested areas was estimated as well as the flame expansion characteristics, and then the BST model predicts the overpressures at a given distance. The BST model predicts the blast levels based on:

- Mass of flammable material involved in an explosion (determined based on dispersion modelling by PHAST);
- Reactivity of the flammable material (high, medium, or low)
- Degree of freedom for the flame expansion (1D, 2D, 2.5D or 3D); and
- Congestion level of a PES (high, medium, low).

To apply the BST model, the BPPS plant was divided into various PESs based on the equipment layout. A leak from each hazardous section of the Project and the existing BPPS facilities is then assumed to cause an explosion in the nearest PES.

(1) Center for Chemical Process Safety of the American Institute of Chemical Engineer, *Guidelines for Chemical Process Quantitative Risk Analysis*, Second Edition, 2000.

(2) Centre for Chemical Process Safety of the American Institute of Chemical Engineer, *Estimating the Flammable Mass of a Vapour Cloud*, John L. Woodward.

To calculate the overpressures from a VCE scenario, dispersion modelling was performed by PHAST to obtain the mass of flammable gas within the flammability limits. Then, the volume of the flammable vapour cloud from PHAST was compared with the volume of each of the PESs. If the vapour cloud is larger than the PES volume, the mass of material involved in the explosion was assumed to be limited by the PES volume. A stoichiometric mixture was assumed throughout the PES volume in this case. For each explosion at each of PESs, the explosion centre was taken as the centre of the PES area.

Similar to thermal radiation levels, overpressure levels, corresponding to specific fatality levels, were taken from the data published by Purple Book (1) for indoor/ outdoor population. The various overpressure levels considered in this QRA study are presented in *Section 5.10.3*.

Figure 5.13 depicts the identified ten (10) PESs based on a review of the BPPS plot plan, and *Table 5.22* lists the input parameters, such as level of congestion, reactivity of material, etc., to the BST model performed by PHAST.

(1) *Guidelines for Quantitative Risk Assessment*, "Purple Book", 2005.

Table 5.22 Identified PESs at BPPS

Tag	Facility Description	Reactivity of Material	Degree of Freedom for Flame Expansion	Level of Congestion	Length (m)	Width (m)	Height (m)	Estimated PES Volume (m^3)
PES 1	Fuel supply pipework under HRSG of Unit 1	Low	2D	Medium	47.4	29.9	3	4,252
PES 2	Fuel supply pipework under HRSG of Unit 2	Low	2D	Medium	47.4	29.9	3	4,252
PES 3	Fuel supply pipework under HRSG of Unit 3	Low	2D	Medium	47.4	29.9	3	4,252
PES 4	Fuel supply pipework under HRSG of Unit 4	Low	2D	Medium	47.4	29.9	3	4,252
PES 5	Fuel supply pipework under HRSG of Unit 5	Low	2D	Medium	47.4	29.9	3	4,252
PES 6	Fuel supply pipework under HRSG of Unit 6	Low	2D	Medium	47.4	29.9	3	4,252
PES 7	Fuel supply pipework under HRSG of Unit 7	Low	2D	Medium	47.4	29.9	3	4,252
PES 8	Fuel supply pipework under HRSG of Unit 8	Low	2D	Medium	47.4	29.9	3	4,252
PES 9	Fuel supply pipework under HRSG of 1st CCGT Unit	Low	2D	Medium	54.8	17.5	3	2,877
PES 10	Fuel supply pipework under HRSG of 2nd CCGT Unit	Low	2D	Medium	54.8	17.5	3	2,877

Toxicity Effect

Dispersion modelling was employed by PHAST to calculate the extent of the toxic gas cloud. This takes into account both the direct vapourisation from the release, and also the vapour formed from evaporating pools. In this QRA study, the extent of the toxic gas cloud was based on the dispersion distance to the various thresholds, corresponding to the different CO_2 toxicity levels described in the *Section 5.10.3*.

Fragment Effect Modelling - Projectile

As discussed in the approved EIA study [1], a catastrophic rupture of a CO_2 storage tank or a CO_2 road tanker, due to either a spontaneous failure or a CO_2 BLEVE, may produce fragments that can cause fatalities hundreds of metres away.

Fragment Range

The fragment range estimation approach is consistent with the approved EIA study [2]. The initial velocity of the fragment must be determined before estimating the range of the fragment. The fragment range can be estimated by solving equations for trajectory motions, allowing for the effects of drag.

Several models have been proposed to estimate the initial velocity of a fragment. The Brode and Baum models described by Lees (1996) [3] and the Centre for Chemical Process Safety (CCPS, 1999) [4] were proposed in this QRA study to estimate the fragment range associated with a CO_2 BLEVE.

Brode [5] assumed that a portion of the total internal energy of a storage vessel is translated into kinetic energy of the fragment:

$$v_i = \sqrt{\frac{2E_k}{M}}$$

$$E_k = \frac{kp_1V}{\gamma - 1}$$

(1) ERM/ BV, EIA for *Desalination Plant at Tseung Kwan O – Feasibility Study* (Register No.: AEIAR-192/2015), November 2015.

(2) ERM, EIA for *South Island Line (East) – Hazard to Life Assessment* (Register No.: AEIAR-155/2010), Report No.: 248137/51/F, August 2010.

(3) Birk, A.M., 1996, Hazards from Propane BLEVEs: An update and Proposal for Emergency Responders, Journal of Loss Prevention in Process Industries, Vol.9, No. 2, pp.173-181.

(4) Center for Chemical Process Safety of the American Institute of Chemical Engineer, *Guidelines for Evaluating the Characteristics of Vapor Cloud Explosions, Flash Fires, and BLEVEs*, 1999.

(5) Lees, F.P., *Loss Prevention in Process Industries*, 3rd Edition, Butterworth-Heinemann, Oxford, UK, 2005.

$$k = 1 - \left[\frac{p_o}{p_1}\right]^{(\gamma-1/\gamma)} + (\gamma - 1)\frac{p_o}{p_1}\left[1 - \left(\frac{p_o}{p_1}\right)^{(-1/\gamma)}\right]$$

where:

v_i is an initial fragment velocity (m s^{-1})

E_k is a kinetic energy (J)

M is the total mass of the empty cylinder (kg)

k is a fraction of internal energy converted to fragment kinetic energy

p_1 is an absolute pressure in cylinder (Pa)

p_o is an ambient pressure (Pa)

V is the volume of the vessel (m^3)

γ is a ratio of specific heats of the gas

The weakness of the Brode model (1) is that it does not take into account the fragment size.

Baum (2) developed empirical correlations for the initial velocity for an end cap breaking away from a cylindrical vessel, a cylindrical vessel breaking into two (2) parts, and disintegration of a spherical or cylindrical vessel into multiple fragments. As an example, the model for end cap breaking into two (2) parts is presented in the equations below. The model for a cylindrical vessel breaking into two (2) parts and disintegration of vessel into multiple fragments are similar.

$$F = \frac{(p_1 - p_o)Ar}{M_f a_o^2}$$

$$a_o = \sqrt{\frac{T\gamma R}{m}}$$

The correlation for the initial velocity:

$$v_i = 2a_o F^{0.5}$$

where:

F is a parameter for calculation of initial velocity

A is an area of the detached portion of the cylinder wall (m^2)

r is a radius of the vessel (m)

M_f is a mass of fragment (kg)

a_o is a speed of sound (m s^{-1})

T is a temperature of the gas inside cylinder at failure (K)

R is an ideal gas constant (J $kmol^{-1}$ K^{-1})

m is a molecular mass of cylinder contents (kg $kmol^{-1}$)

(1) Lees, F.P., *Loss Prevention in Process Industries*, 3rd Edition, Butterworth-Heinemann, Oxford, UK, 2005.

(2) Baum M. R., 1988, D*isruptive Failure of Pressure Vessels – Preliminary Design Guidelines for Fragment Velocity and the Extent of the Hazard Zone*, Journal of Pressure Vessel Technology – Trans ASME 1988:110:168-76.

However, the mass of fragment from a CO_2 BLEVE is not available from literature, the range of projectile is not possible to estimate based on the above equations.

Nevertheless, another study by Holden and Reeves (1) reviewed twenty seven (27) events involving cylindrical vessels (2). The events are classified into two (2) groups; vessels above 90 m^3 and vessels below 90 m^3. It was reported that 80% of the fragments travelled less than 200 m and the maximum range was identified to be 500 m for the vessels below 90 m^3. The study also reported that fragment ranges are much less than the maximum range from theoretical estimates.

Tasneem Abbasi *et al*. (3) reported two (2) events about fragment from cylinder vessels. The most relevant datum is for a cylindrical vessel containing 35,000 kg of liquid CO_2, which gives a maximum range of fragments of less than 300 m.

With reference to the above incident databases, the maximum fragment range for a CO_2 road tanker or a CO_2 storage tank at BPPS is conservatively assumed to be 500 m.

Shielding Factors

No shielding factor is conservatively applied to the road traffic population on Nim Wan Road and Yung Long Road, and the surrounding marine vessel population, which is in line with the approved EIA study (4).

Target Area

If a fragment strikes a critical part of the body such as head or torso, a fatality may result. Assuming a cylindrical shaped torso, about 1 m long and 12" diameter (the chest size for the average Chinese male is 35" circumference, Alvanon, 2008) (4), gives a target area of 0.3 m^2.

The probability of a road traffic vehicle or a marine vessel being hit is estimated by taking into account the exposure factors and the fraction of fragment that have sufficient range to reach the road traffic vehicle or marine vessel.

The probability of a person at a road traffic vehicle or a marine vessel being struck by a fragment is therefore calculated based on:

(1) Holden, P., Reeves, A., (1985). *Fragmentation Hazards from Failures of Pressurized Liquefied Gas Vessels. Assessment and Control of Major Hazards*. IChemE Symposium Series # 93 IChemE, Rugby, UK. 205-220.

(2) Lees, F.P., *Loss Prevention in Process Industries*, 3rd Edition, Butterworth-Heinemann, Oxford, UK, 2005.

(3) T. Abbasi, S.A. Abbasi, *The boiling liquid expanding vapour (BLEVE): Mechanism, consequence assessment, management*, Journal of Hazardous Materials 141 (2007) 489-519.

(4) ERM, EIA for *South Island Line (East) – Hazard to Life Assessment* (Register No.: AEIAR-155/2010), Report No.: 248137/51/F, August 2010.

- The probability that the road traffic vehicle or marine vessel will be hit, based on the fraction of fragment that have sufficient range to reach the road traffic vehicle or marine vessel;

- A road traffic vehicle target area of 8 m^2, the typical size of private vehicle;

- A marine vessel target area of 900 m^2, the typical size of Rivertrade Coastal Vessel; and

- A person target area of 0.3 m^2.

The number of road traffic vehicles within 500 m radius from a CO_2 road tanker at the junction of Nim Wan Road and Yung Long Road to BPPS is estimated as 34 in 2035, while the number of marine vessels within 500 m radius from a CO_2 storage tank at BPPS is estimated as 42 in 2035.

After taking into account these factors, the probability of hitting a road traffic vehicle or a marine vessel to cause one fatality was calculated as 7.8×10^{-13}, which is much lower than 1×10^{-9} per year, the lowest frequency considered as per risk criteria in Section 2 of Annex 4 of *EIAO-TM*. Therefore, it is not taken into account in this QRA study.

5.10.3 Consequence End-Point Criteria

The estimation of the fatality/ injury caused by a physical effect such as thermal radiation requires the use of probit equations, which describe the probability of fatality as a function of some physical effects. The probit equation takes the general form:

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

where:

Y	is the probit
a, b	are constants determined from experiments
V	is a measure of the physical effect such as thermal dose

The probit is an alternative way of expressing the probability of fatality and is derived from a statistical transformation of the probability of fatality.

Thermal Radiation

The following probit equation (1) is used to determine impacts of thermal radiation from a jet fire, pool fire or fireball to persons unprotected by clothing.

$$Y = -36.38 + 2.56\ ln\ (t\ I^{4/3})$$

(1) TNO, *Methods for the Determination of Possible Damage to People and Objects Resulting from Releases of Hazardous Materials (The Green Book)*, Report CPR 16E, The Netherlands Organisation of Applied Scientific Research, Voorburg, 1992.

where:

Y is the probit

I is the radiant thermal flux (W m^{-2})

t is duration of exposure (s)

This equation gives the thermal radiation levels presented in *Table 5.23*, assuming a 20-second exposure time. For areas lying between any two radiation flux contours, the equivalent fatality level is estimated as follows:

- For areas beyond the 50% fatality contour, the equivalent fatality is calculated using a 2/3 weighting towards the lower contour. For example, the equivalent fatality between the 1% and 50% contours is calculated as $2/3 \times 1 + 1/3 \times 50 = 17\%$; and

- For areas within the 50% contour, the equivalent fatality is calculated with a 2/3 weighting towards the upper contour. For example, the equivalent fatality between the 90% and 50% contours is calculated as $2/3 \times 90 + 1/3 \times 50 = 77\%$.

The different approach above and below the 50% fatality contour is due to the sigmoid shape of the probit function.

Table 5.23 Levels of Harm for 20-second Exposure Time to Heat Fluxes

Incident Thermal Flux (kWm^{-2})	Fatality Probability for 20-second Exposure Time	Equivalent Fatality Probability for Area between Radiation Flux Contours
9.8	1%	17%
19.5	50%	77%
28.3	90%	97%
35.5	99.9%	

Flash Fire

With regard to a flash fire, the criterion chosen is that a 100% fatality is assumed for any person outdoors within the flash fire envelope. The extent of the flash fire is assumed to be the dispersion to its LFL.

Overpressure

For an explosion, a relatively high overpressure is necessary to lead to significant fatalities for persons outdoors. Persons indoor have a high harm probability due to the risk of building collapse and flying debris such as breaking windows. *Table 5.24* presents the explosion overpressure levels suggested by Purple Book (1).

(1) *Guidelines for Quantitative Risk Assessment*, "Purple Book", 2005.

Table 5.24 Effect of Overpressure - Purple Book

Explosion Overpressure (barg)	Fraction of People Dying	
	Indoor	Outdoor
> 0.3	1.000	1
> 0.1 to 0.3	0.025	0

Toxicity Effect

Fatality rates due to a toxic exposure are determined by the probit function, as follows:

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

where:

Y	is the probit corresponding to the probability of death
a, b, n	are the constants describing the toxicity of a substance
C	is the concentration of the toxic material (ppm)
t	is duration of exposure (minutes)

As can be seen from the probit equation, the fatality due to a toxic exposure depends on the exposed duration and the toxicity of the materials. Similar to thermal radiation, toxic cloud contours corresponding to 90%, 50% and 1% fatality was obtained from PHAST. With reference to Purple Book (1), the exposure time was taken as thirty (30) minutes in this QRA study. If the scenario release duration is less than thirty (30) minutes, the actual concentrations corresponding to the certain fatality levels are calculated based on the release duration instead of thirty (30) minutes.

Persons indoors are expected to be offered some protection from the ingress of a toxic cloud in buildings, the fatality probability for indoor persons is therefore assumed to be one tenth of the outdoor fatality probability.

Carbon Dioxide

Toxicity of CO_2 is reviewed and values for the constants a, b and n is referred from available literature of the "HSE" (1). Based on the database, *a* is taken as -90.8, *b* is taken as 1.01 and *n* is taken as 8.

The concentrations corresponding to thirty (30) minutes exposure for 90%, 50% and 1% fatality for CO_2 are summarised in *Table 5.25*.

(1) HSE, "*Comparison of risks from carbon dioxide and natural gas pipelines*", RR749, 2009.

Table 5.25 CO_2 Toxic Concentration at various Fatality Levels

Fatality Level	Concentration (ppm)
90%	107,713
50%	91,933
1%	68,902

5.10.4 Consequence Results

The effect zones for the hazardous scenarios considered presents in the format in *Figure 5.14*.

- *d*: maximum downwind distance;
- *c*: maximum crosswind width;
- *s*: offset distance (distance between source and upwind end of effects zone). It is noted that a negative offset distance indicates that the upwind end of the effects zone is located upwind of the source, as would occur for thermal radiation and overpressure contours, for example; and
- *m*: distance between release source and location of maximum crosswind width.

All consequence results are summarised in *Annex 5D*.

5.11 CUMULATIVE RISK ASSESSMENT

The cumulative risks were calculated by summing the risks from the Project and the existing BPPS facilities, as follows. The details of cumulative risk assessment to consider the hazardous facilities at each of the assessment years are summarised in *Table 5.26*.

- Transport and use of natural gas; and
  - Natural gas facilities.
- Transport, storage and use of other non-fuel gas dangerous goods.
  - Hydrogen facilities;
  - CO_2 facilities; and
  - Distillate oil facilities.

Table 5.26 Details of Cumulative Risk Assessment

Potential Risks	2016	2019	2020	2034	2035
Existing Natural Gas Facilities	Yes	Yes	Yes	Yes	Yes
Existing Hydrogen Facilities, On-site and Off-site Transport of Hydrogen	Yes	Yes	Yes	Yes	Yes
Existing CO_2 Facilities, On-site and Off-site Transport of CO_2	Yes	Yes	Yes	Yes	Yes
Existing Distillate Oil Facilities	Yes	Yes	Yes	Yes	Yes

Potential Risks	2016	2019	2020	2034	2035
Construction activities for 1st CCGT Unit leading to potential impact on nearby BPPS equipment		Yes			
1st additional CCGT unit			Yes	Yes	Yes
Additional Hydrogen Distribution, On-site and Off-site Transport of Hydrogen for 1st CCGT unit			Yes	Yes	Yes
Additional CO_2 Distribution, On-site and Off-site Transport of CO_2 for 1st CCGT unit			Yes	Yes	Yes
Additional Distillate Oil Distribution for 1st CCGT unit			Yes	Yes	Yes
Construction activities for 2nd CCGT Unit leading to potential impact on nearby BPPS equipment				Yes	
2nd additional CCGT unit					Yes
Additional Hydrogen Distribution, On-site and Off-site Transport of Hydrogen for 2nd CCGT unit					Yes
Additional CO_2 Distribution, On-site and Off-site Transport of CO_2 for 2nd CCGT unit					Yes
Additional Distillate Oil Distribution for 2nd CCGT unit					Yes

5.11.1 Individual Risk

The cumulative individual risk contours from 1E-05 to 1E-09 per year of the following assessment years are depicted at *Figure 5.15* to *Figure 5.19*, and individual risk contours show that there is no off-site risk larger than 1E-05 per year and the all individual risk contour of 1E-09 per year does not reach any land population in the vicinity of BPPS.

- Case 0: 2016 as the baseline condition year (*Figure 5.15*);
- Case 1a: 2019 as the expected peak impact (in HtLA context) construction year of the 1st CCGT unit (*Figure 5.16*);
- Case 1b: 2020 as the expected year of operation of the 1st CCGT unit (*Figure 5.17*);
- Case 2a: 2034 as the assumed peak impact (in HtLA context) construction year of the 2nd CCGT unit (*Figure 5.18*); and
- Case 2b: 2035 as the assumed year of operation of the 2nd CCGT unit (*Figure 5.19*).

It is noted that the individual risk contours differ between Case 0 and Case 1a, and between Case 1b and Case 2a. The additional risk is due to the consideration of potential hazards due to Project construction activities (for each construction phase).

At the operation phases of 1st and 2nd additional CCGT units, the individual risk contours from 1E-06 to 1E-09 per year in the vicinity of the Project Site have been extended in south-westerly direction due to additional CCGT equipment considered (for each operation phase).

All individual risk results do not demonstrate off-site individual risk contour at 1E-05 per year, and are acceptable according to individual risk guideline as stipulated in Section 2 of Annex 4 of *EIAO-TM*.

5.11.2 Societal Risk

The potential loss of life (PLL) values for the natural gas and other non-fuel gas dangerous goods facilities at each assessment year are presented in *Table 5.27*. It can be observed that the major risk contributor is from natural gas facilities and the risks are the highest for the worst scenario (operation phase of 2nd CCGT unit in 2035) because of two additional CCGT units in operation and surrounding population growth (both road traffic and marine vessel population).

The detail breakdown of the main risk contributor to PLL for each of the assessment year is summarised in *Annex 5E*.

Table 5.27 PLL Breakdown

Type of Facilities	2016	2019	2020	2034	2035
Natural Gas	3.69E-06	3.92E-06	4.01E-06	4.66E-06	4.96E-06
Non-Fuel Gas Dangerous Goods	5.53E-08	1.56E-07	6.53E-08	6.71E-08	7.73E-08
Total	**3.74E-06**	**4.08E-06**	**4.08E-06**	**4.73E-06**	**5.03E-06**

The cumulative risk presented in FN curves for following assessment years are depicted at *Figure 5.20*, and all FN curves are within the "Acceptable" region.

- Case 0: 2016 as the baseline condition year;
- Case 1a: 2019 as the expected peak impact (in HtLA context) construction year of the 1st CCGT unit;
- Case 1b: 2020 as the expected year of operation of the 1st CCGT unit;
- Case 2a: 2034 as the assumed peak impact (in HtLA context) construction year of the 2nd CCGT unit; and
- Case 2b: 2035 as the assumed year of operation of the 2nd CCGT unit.

The breakdown for FN curves by types of dangerous goods for each of the assessment year is also presented at *Figure 5.21* to *Figure 5.25*.

From the hazard to life assessment, the risk from the baseline case is largely contributed by natural gas release scenarios onto marine population. It is noted that the risk in terms of fatality frequency is increasing along the assessment years mainly due to the operation of two additional CCGT units (additional gas-filled process equipment/ pipework). The maximum number of fatality is just slightly increased over the years because the

surrounding population growth within the hazardous impact zone is not significant.

Therefore, it can be concluded that the cumulative risk level of the Project is within the "Acceptable" region and in compliance with the societal risk criteria in Section 2 of Annex 4 of *EIAO-TM*.

5.12 UNCERTAINTY ANALYSIS

This section assesses the level of uncertainty in the estimation of individual risk and societal risk by carrying out sensitivity analysis studies on the key parameters and modelling assumptions, in association with the hazard to life assessment. The purpose of this is to gauge the level of confidence in the hazard assessment results.

5.12.1 *Consequence Modelling*

Detection and shutdown systems have been provided at BPPS for both natural gas and hydrogen gas facilities; however, the automatic shutdown systems are installed at GRS and hydrogen trailer bay areas only. As a conservative approach, it was assumed the detection and shutdown system is not available. As such, the closing time (release duration) of thirty (30) minutes was used to estimate the inventories released from the isolation failure scenarios for consequence modelling in this QRA study.

Natural gas containing methane, ethane, propane, etc. was conservatively assumed as pure methane as a representative material in this QRA study. The maximum surface emissive power of pure methane is higher than that of natural gas for consequence modelling. Due to that flammable characteristic, the consequence distances for both flash fire and jet fire hazardous scenarios associated with pure methane are therefore more conservative.

The flammable mass for fireball modelling was conservatively estimated by the initial flow rate continuing for ten (10) seconds even though the initial release rate is decreasing rapidly in case of the full bore rupture scenario of pipeline. This approach is consistent with the approved study, Safety Case Report [(1)].

The maximum storage capacity for non-fuel dangerous goods including hydrogen, CO_2 and distillate oil was considered as the reasonably worst case for consequence modelling in this QRA study.

5.12.2 *Failure Frequencies*

The failure frequencies for natural gas facilities were selected from Hawksley [(2)], who presents his own derived data for both above and below ground

(1) DNV, *Safety Case Report for Black Point Gas Supply Project*, Report No.: PP019678, Revision No.2, August 2013.

(2) Hawksley, J.L., *Some Social, Technical and Economic Aspects of the Risks of Large Plants*, CHEMRAWN III, 1984.

pipework in 1984. This historical database was also suggested in the approved EIA studies [1] [2] for natural gas facilities.

The failure database adopted in the Safety Case Report [3] is the generic leak frequencies developed by DNV based on the Hydrocarbon Release Database (HCRD) from UK HSE. The database is based on approximately 4,000 recorded leaks recorded between October 1992 and March 2010 from the UK sector of the North Sea which has been collected by the UK HSE. In general, the database for offshore facilities gives higher leak frequencies than most of the onshore sources of data.

The natural gas facilities at BPPS mainly consist of both above and underground pipework; therefore, it is more applicable to adopt failure frequencies suggested by Hawksley [4] in this QRA study.

Moreover, the failure rates from Hawksley [4] are also compared with that suggested by UK HSE [5], which was established by the Hazardous Installations Directorate (HID) C15 of the UK HSE in 2012. The UK HSE failure rates [5] are intended for use on Land Use Planning cases and have been in use for several years. After review, it is found that the failure rates for pipework from Hawksley [4] and UK HSE [5] are in the same order of magnitude.

For other dangerous good facilities, the majority of the failure frequencies were selected from the data also suggested by the approved EIA studies, including Purple Book [6] and COVO Study [7], as these international databases were developed for risk assessments for the use, handling, transport, and storage of dangerous substances.

These databases are based on failure data collected from a variety of onshore facilities including refineries, LPG storage, etc., and other dangerous substances installations such as chlorine and ammonia storage tanks with professional judgment applied as appropriate.

Based on the discussions above, it can be concluded that the uncertainty related to failure frequencies of equipment/ facilities from BPPS is deemed insignificant.

(1) ERM, EIA for *Black Point Gas Supply Project* (Register No.: AEIAR-150/2010), February 2010.

(2) ERM, EIA for *Liquefied Natural Gas (LNG) Receiving Terminal and Associated Facilities* (Register No.: AEIAR-106/2007), December 2006.

(3) DNV, *Safety Case Report for Black Point Gas Supply Project*, Report No.: PP019678, Revision No.2, August 2013.

(4) Hawksley, J.L., *Some Social, Technical and Economic Aspects of the Risks of Large Plants*, CHEMRAWN III, 1984.

(5) UK HSE, *Failure Rate and Event Data for use within Risk Assessments*, 28 July 2012.

(6) *Guidelines for Quantitative Risk Assessment*, "Purple Book", 2005.

(7) Rijnmond Public Authority, *A Risk Analysis of Six Potentially Hazardous Industrial Objects in the Rijnmond Area – A Pilot Study*, COVO, D. Reidel Publishing Co., Dordrecht,1982.

5.12.3 *Ignition Probability*

It is noted that the ignition sources for underground environment is limited; however, it has been conservatively assumed the ignition probability from Cox, Lees and Ang (1) to be applied on both above and underground environment, particularly for fireball scenario associated with high fatality number.

Moreover, the total ignition probability for a large leak of hydrogen has been conservatively assumed as 0.99 based on the study from Cadwallader and Herring (2). The large leak was assumed as the release rate is larger than 1 kg s^{-1} only.

The ignition estimation approaches for both natural gas and hydrogen gas adopted in this QRA study are probably on conservative side.

5.12.4 *Aircraft Crash Hazard Analysis*

The number of flights at Chek Lap Kok in 2035 (the operation phase of 2nd CCGT unit) was estimated as 685,000 (assumed as linear growth of a period from 1999 to 2014), which is in the same order of magnitude with the estimated number of flights as 620,000 in 2032 from the approved EIA study for *Expansion of Hong Kong International Airport into a Three-Runway System* (3). As a conservative approach, the estimated number of flights in 2035 was also taken into account for all the proposed assessment years in this QRA study.

The official operation mode for a three-runway system has not been officially confirmed yet, however, the preferred operation mode based on the latest available information from the approved EIA study (3) has been considered in this QRA study to analyse the aircraft crash hazard on the Project Site. The failure frequency associated with aircraft crash hazard was estimated as 1.2×10^{-8} per year, which has already been taken into account in this QRA study.

In conclusion, after taking into account the uncertainty in the hazard to life assessment by adopting historical database with similar hazardous facilities characteristics, conservative assumptions/ parameters, latest available information and worst case scenario, this give confidence that the actual risk levels associated with hazardous facilities at BPPS during both construction phase and operation phase of the project will not exceed the cumulative risks estimated in this QRA study and thus in compliance with the risk criteria in Section 2 of Annex 4 of *EIAO-TM*.

(1) Cox, Lees and Ang, *Classification of Hazardous Locations*, IChemE.

(2) Cadwallader and Herring, *Safety Issues with Hydrogen as a Vehicle Fuel*, Idaho National Engineering and Environmental Laboratory, Lockheed Martin, September 1999.

(3) Mott MacDonald, EIA for *Expansion of Hong Kong International Airport into a Three-Runway System*, (Register No.: AEIAR-185/2014), November 2014.

5.13 RECOMMENDATION FOR CONSTRUCTION PHASE

The following mitigation measures should be considered to further manage and minimise the external hazards from constructions activities risk during construction phases of the Project. With the implementation of the following mitigation measures, the failure frequencies associated with the construction activities should be well covered by the general failure frequencies summarized in *Section 5.9*.

- Ensure speed limit enforcement is specified in the contractor's method statement to limit the speed of construction vehicles on-site;
- Conduct speed checks to ensure enforcement of speed limits and to ensure adequate site access control;
- Provide escort for hydrogen and CO_2 delivery vehicle drivers to ensure the right access route is used during the construction phases of the Project;
- A lifting plan, with detailed risk assessment, should be prepared and endorsed for heavy lifting of large equipment;
- Vehicle crash barrier, designed for the specific speed limit at the BPPS, should be provided between the construction site and the distillate oil storage facilities during 1st CCGT unit construction phase. Also, a vehicle crash barrier is to be provided between the construction site and the 1st CCGT unit during 2nd CCGT unit construction phase;
- Any lifting operation near or over live equipment should be strictly minimised. If such operation cannot be avoided, lifting activities should be assessed, controlled and supervised. Adequate protection covers should also be provided on the existing BPPS facilities in case the operation of lifting equipment has a potential to impact live equipment at BPPS. Process isolation should be achieved in case that live equipment protection becomes impractical;
- The hydrogen road trailer and carbon dioxide road tanker delivery should follow alternative route, which is further from the construction site, during crane operation and movement of construction vehicles in the vicinity;
- Ensure that a hazardous area classification study is conducted and hazardous area maps are updated before the start of the construction activities to ensure ignition sources are controlled during both construction and operation phases;
- Ensure work permit system for hot work activities within the Project Site is specified in the contractor's method statement to minimise/ control ignition sources during construction phase;
- Ensure effective communication system/ protocol is in place between the construction contractors and operation staff;

- Ensure the Project Construction Emergency Response Plan is integrated with the Emergency Response Plan for the BPPS during construction phases. The plan should address stop work instructions to be promptly communicated to all construction workers performing hot works in case a confirmed flammable gas (natural gas and hydrogen) detection at the BPPS;

- Ensure that construction activities do not impede the functions of fire and gas detection system, fire protection system, muster areas, fire-fighting vehicle access and escape routes; and

- Ensure a Job Safety Analysis is conducted for construction activities of the Project during the construction phases, to identify and analyse hazards associated with the construction activities (e.g. lifting operations by cranes) onto the existing plant facilities and operations. Potential risks of the construction activities shall be assessed, and risk precautionary measures shall be implemented in Contractor's works procedures.

5.14 *CONCLUSIONS AND RECOMMENDATIONS*

A hazard to life assessment has been conducted to evaluate the risk level associated with the transport and use of natural gas, as well as the transport, storage and use of other dangerous goods (hydrogen, CO_2 and distillate oil) defined in *Dangerous Goods Ordinance* (*Cap. 295*) but not covered by the *Gas Safety Ordinance* (*Cap. 51*) during the construction phase and operation phase of the project. The cumulative risk assessment of the Project has also been assessed in combination with risks associated with natural gas and other dangerous goods facilities at BPPS.

The assessment methodology and assumptions were based on the approved EIA and safety case studies having similar issues, for example: *Black Point Gas Supply Project* (1), *Safety Case Report for Black Point Gas Supply Project* (2), *Liquefied Natural Gas (LNG) Receiving Terminal and Associated Facilities* (3), *Desalination Plant at Tseung Kwan O – Feasibility Study* (4), *In-situ Reprovisioning of Sha Tin Water Treatment Works – South Works – Designs and Construction* (5), *South Island Line (East) – Hazard to Life Assessment* (6). The list of major assumptions refers to *Annex 5A*.

Five (5) cases were considered in this study, which are:

(1) ERM, EIA for *Black Point Gas Supply Project* (Register No.: AEIAR-150/2010), February 2010.

(2) DNV, *Safety Case Report for Black Point Gas Supply Project*, Report No.: PP019678, Revision No.2, August 2013.

(3) ERM, EIA for *Liquefied Natural Gas (LNG) Receiving Terminal and Associated Facilities* (Register No.: AEIAR-106/2007), December 2006.

(4) ERM/ BV, EIA for *Desalination Plant at Tseung Kwan O – Feasibility Study* (Register No.: AEIAR-192/2015), November 2015.

(5) ERM, EIA for *In-situ Reprovisioning of Sha Tin Water Treatment Works – South Works – Hazard to Life Assessment* (Register No.: AEIAR-187/2015), January 2015.

(6) ERM, EIA for *South Island Line (East) – Hazard to Life Assessment* (Register No.: AEIAR-155/2010), Report No.: 248137/51/F, August 2010.

- 2016 as the baseline condition year;
- 2019 as the expected peak impact (in HtLA context) construction year of the 1st CCGT unit;
- 2020 as the expected year of operation of the 1st CCGT unit;
- 2034 as the assumed peak impact (in HtLA context) construction year of the 2nd CCGT unit; and
- 2035 as the assumed year of operation of the 2nd CCGT unit (for worst-case assessment purpose).

In all cases, the individual risk is in compliance with the risk criteria in Section 2 of Annex 4 of *EIAO-TM* and the societal risk lies in the acceptable region.

Therefore, the construction and operation phases of the Project are acceptable in terms of both individual risk and societal risk as stipulated in Section 2 of Annex 4 of *EIAO-TM.*

Safety management measures shall be implemented during the construction phase of the Project to ensure that the risks associated with the transport and use of natural gas, as well as the transport, storage and use of other dangerous goods at BPPS are in compliance with the risk criteria in Section 2 of Annex 4 of *EIAO-TM* and stays in the "Acceptable" region.

Since both the individual and societal risks posed by the Project and the existing BPPS facilities to off-site population meet the risk criteria in Section 2 of Annex 4 of *EIAO-TM*, no further mitigation measures are required.