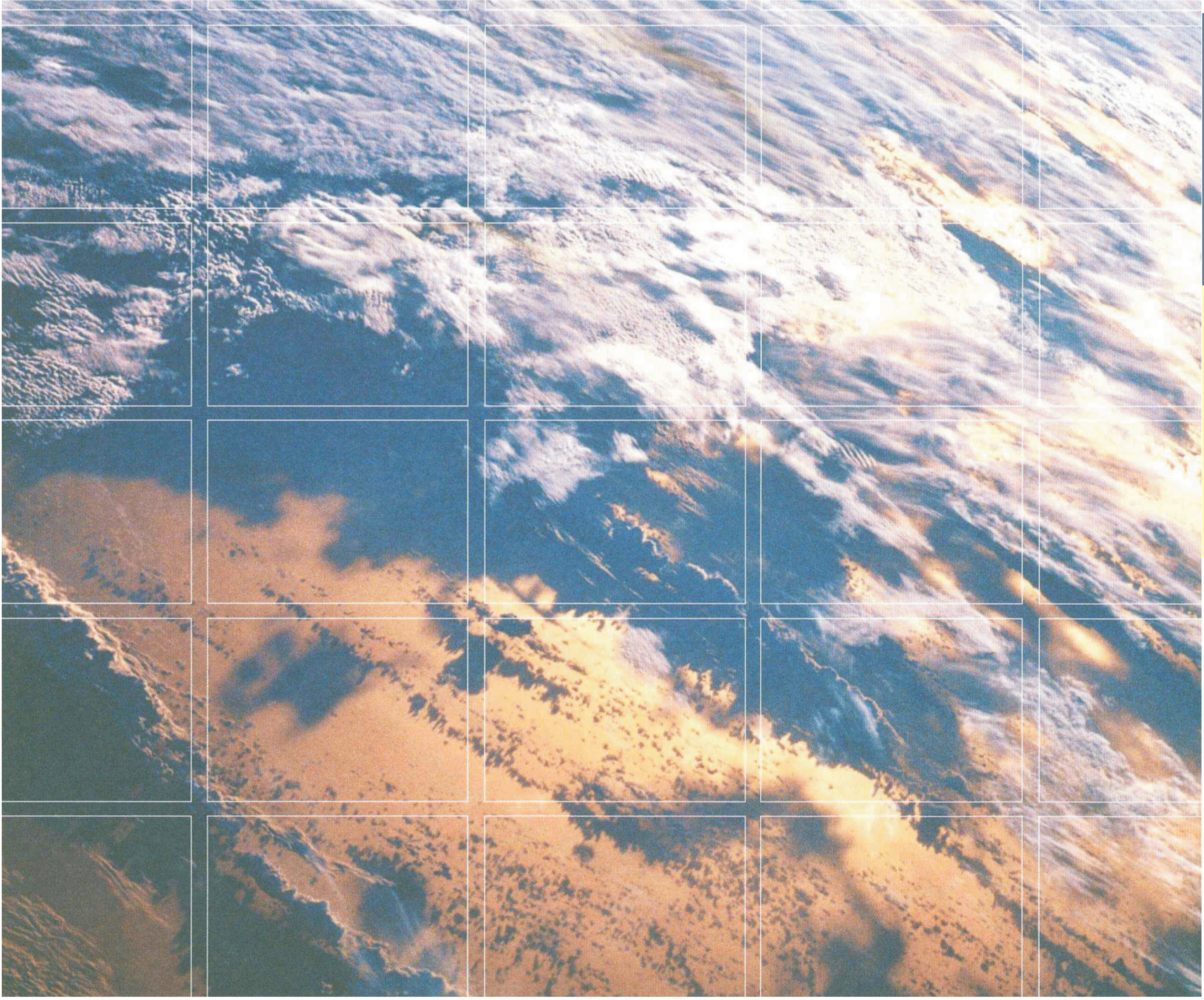

Part 2 - South Soko

Sections 13 - 18

中華電力
CLP Power

ExxonMobil

Capco 青山發電有限公司 Castle Peak Power Co. Ltd.

Liquefied Natural Gas (LNG) Receiving Terminal and Associated Facilities

EIA Study (EIA Study Brief ESB-126/2005)

EIA Report
Part 2 - South Soko
Sections 13 - 18

22nd December 2006

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CONTENTS

ANNEXES

13 *QUANTITATIVE RISK ASSESSMENT*

This section of the EIA presents a summary of the analysis and findings of the Quantitative Risk Assessment (QRA) study undertaken for the proposed LNG Terminal at South Soko and associated facilities including a subsea pipeline from South Soko to Black Point Power Station (BPPS) and a Gas Receiving Station (GRS) at BPPS.

This section is divided into four sub sections: section 1 relates to the general aspects of the QRA study, section 2 relates to the LNG Terminal, section 3 relates to the subsea pipeline while section 4 relates to the GRS.

Further details of the analysis pertaining to each facility are presented in the respective annexes; *Annex 13A* covers the LNG Terminal QRA study details, *Annex 13B* covers the subsea pipeline while *Annex 13C* covers the GRS.

Additional annexes are provided to describe the Safety Management System (*Annex 13D*) and summarise all the assumptions adopted in the QRA study (*Annex 13E*).

SUB-SECTION 1: GENERAL

13.1 LEGISLATION REQUIREMENT AND EVALUATION CRITERIA

The key legislation and guidelines that are considered relevant to the development of the proposed LNG Terminal and associated facilities are as follows:

- *Gas Safety Ordinance*, Chapter 51
- *Hong Kong Planning Standards and Guidelines* (HKPSG), Chapter 12
- *Dangerous Goods Ordinance*, Chapter 295
- *Environmental Impact Assessment Ordinance (EIAO)*, Chapter 499
- *The EIA Study Brief*, Section 3.7.9.1

There is some overlap in the requirements of the various pieces of legislation and guidelines. The requirement for a Quantitative Risk Assessment study is contained in the *EIAO* and HKPSG. Such a study, although not required explicitly in the *Gas Safety Ordinance*, is implied in the regulations and has been an established practice for similar installations in the SAR.

13.1.1 EIAO Technical Memorandum (EIAO-TM)

The requirement for a QRA of projects involving storage, use and transport of dangerous goods where risk to life is a key issue with respect to Hong Kong Government Risk Guidelines (HKRG) is specified in Section 12 of the EIAO-TM.

The relevant authority for an QRA study relating to an LNG Terminal and associated facilities is the Gas Standards Office (GSO) of the Electrical and Mechanical Services Department (EMSD), as specified in Annex 22 of EIAO-TM.

Annex 4 of EIAO-TM specifies the Individual Risk and Societal Risk Guidelines.

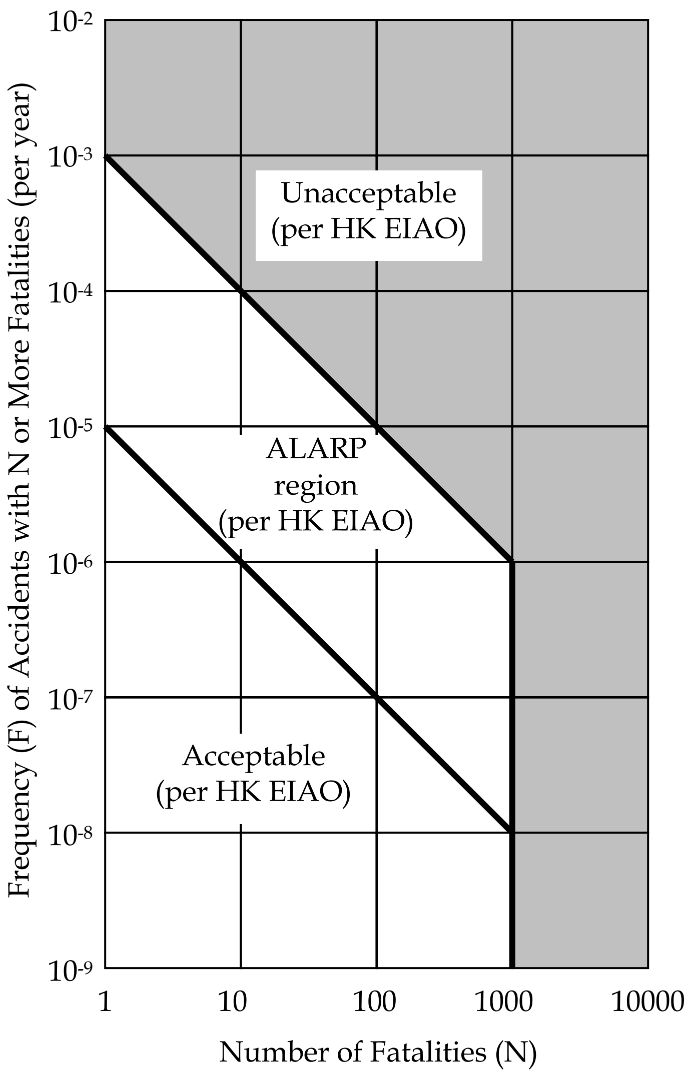
13.1.2 Risk Measures and Hong Kong Government Risk Guidelines (HKRG)

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 whole population. The HKRG is presented graphically in *Figure 13.1*. 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 HKRG to demark "acceptable" or "unacceptable" societal risks. The intermediate region indicates the acceptability of societal risk is borderline and should be reduced to a level which is "as low as reasonably practicable" (ALARP). It seeks to ensure that all practicable and cost-effective measures which can reduce risks will be considered.

Figure 13.1 ***Hong Kong Government Risk Guidelines***



13.2 *STUDY OBJECTIVES AND METHODOLOGY*

The objective of the QRA study is to assess the risk to life of the general public including the workers of nearby plants from the proposed facilities during its operational phase. The results of the QRA are compared with the HKRG.

The detailed requirements of the study are (see *Section 3.4.9.1* of the EIA study brief):

- To identify all credible hazardous scenarios associated with storage, handling and operation of the LNG facility, which has potential to cause fatalities;

- To carry out the QRA expressing population risks in both individual and societal terms;

- To compare the individual and societal risks at the proposed development sites with the HKRG;

- To identify and assess practical and cost effective risk mitigation measures as appropriate;

- To identify all LNG leakage scenarios and propose a safety management system for the operational phase of the project with an aim to contain any accidental leakage in short notice and to prevent and/or minimise any leakage.

The elements of the QRA are shown schematically in *Figure 13.2*.

An overview of the methodology employed is provided here to briefly introduce the study approach, while the details are included in the respective sections/ annexes.

Relevant data on the proposed facilities such as their preliminary layout drawings and design basis as well as population data in the vicinity were collected and reviewed.

A Hazard Identification (HAZID) Study was conducted to identify all hazards, both generic and site specific. A review of literature and accident databases were also undertaken. These formed the basis for identifying all hazardous scenarios for the QRA Study.

The frequencies, or the likelihood, of the various outcomes resulting from an LNG/gas release scenario were derived from historical databases and, where necessary, these were modified to take into account local factors.

For all identified hazards assessed as having a frequency of less than 10^{-9} per year, the frequency assessment will be documented but no quantification of consequences will be performed.

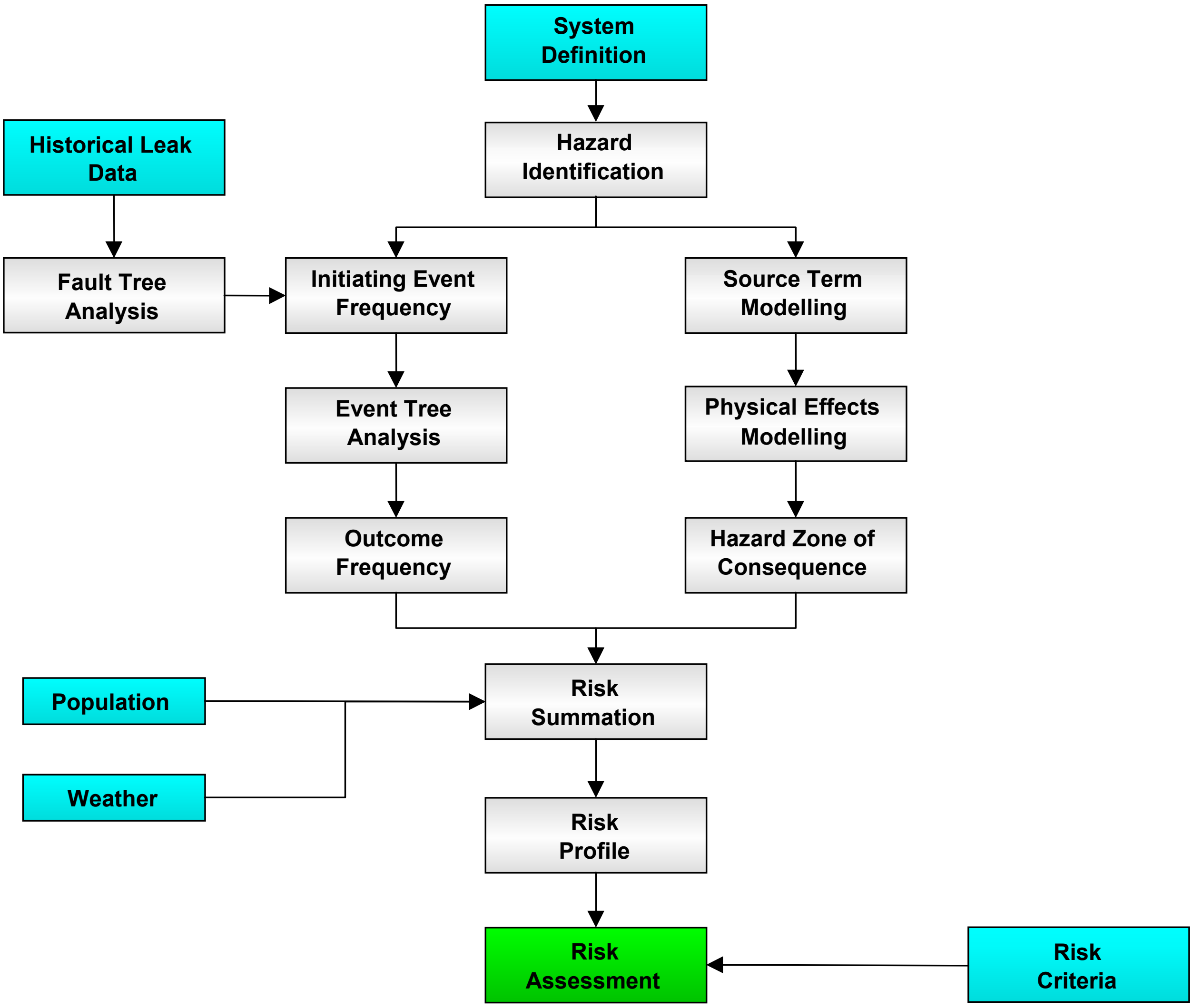
For hazards with frequencies greater than 10^{-9} per year, the consequences of each release were modelled.

Hydrocarbon releases have been modelled using the *PHAST* consequence modelling package developed by Det Norske Veritas, Inc. (DNV)

The consequence and frequency data were subsequently combined using ERM's proprietary software Riskplot™ to produce the required risk calculations.

Finally, the results from the risk assessment were compared with the HKRG and found to be acceptable. No mitigation measures are therefore proposed.

Figure 13.2 Schematic Diagram of QRA Process



SUB-SECTION 2: TERMINAL

The QRA study for the terminal includes all planned facilities at the site, including unloading operations at the jetty, LNG storage tanks, sendout pumps, LNG vaporisers and the boil-off gas system.

This section presents a summary of the QRA study for the facilities at the terminal while *Annex 13A* gives further details.

As per the Study Brief, the QRA study for the terminal is also required to include the marine transit risks for LNG carriers within 500m of the jetty. A Marine Quantitative Risk Assessment (MQRA) study has been separately conducted by DNV. The risk results from the MQRA study for the 500m section at the jetty have been combined with the risk results for the facilities at the terminal to produce an overall risk result for the terminal, which is presented in this section. For further details on marine transit risks, DNV's report may be referred.

13.3 FACILITY DETAILS

13.3.1 Site Facilities

The proposed LNG Terminal and associated facilities will be built to provide a peak natural gas sendout capacity of 1000 million standard cubic feet per day (MSCFD).

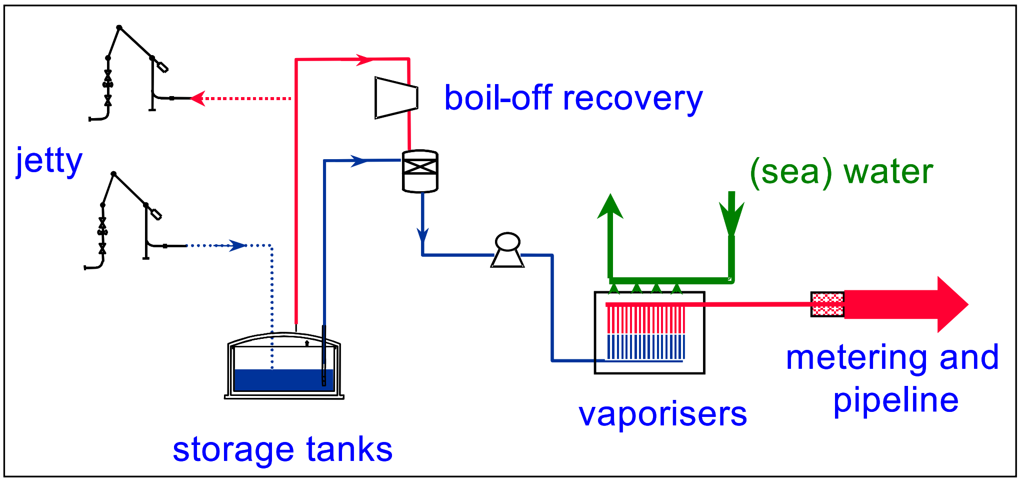
The Terminal will comprise the following primary components:

- one jetty with a berth for LNG carriers;
- initially up to two 180,000m^3 full containment LNG storage tanks (for *Phase I*,) followed by one additional tank (for *Phase II*);
- two in-tank LNG single stage centrifugal pumps for each tank, capable of delivering LNG at about 7 barg;
- four High Pressure LNG Booster pumps including one spare for *Phase I* and three additional pumps for *Phase II*, to deliver at about 101 barg;
- four including one spare (plus one additional for *Phase II*) open-rack seawater vaporisers.

The key features of the proposed LNG Terminal are depicted in the preliminary terminal layout diagram (See *Figure 3.1* in *Section 3*). LNG is transferred by pumps under cryogenic conditions from the carrier to the tanks and from the tanks to the vaporisers. LNG is stored at near atmospheric pressure under cryogenic conditions. The vaporisers convert the LNG into gas phase for sendout to the pipeline.

Figure 13.3 shows a schematic of the overall process in an LNG terminal. A more detailed Process Flow Diagram for the Terminal, including details on the design features and the operating philosophy are included in *Annex 13A1*. Further details of safety features and the Safety Management System are provided in *Annex 13D*.

Figure 13.3 Process Overview



13.3.2 Land Use in the Vicinity

On South Soko Island, a number of unused Private Lots and derelict buildings are present as well as a recently refurbished Tin Hau Temple, but there is no permanent development or resident population at either South Soko or North Soko. A government owned low level radioactive waste storage facility is located on North Soko Island but this has no permanent staff and waste material will be delivered just twice a year.

13.3.3 Population Data

There is no residential population within 2km of South Soko Island and none proposed. The nearest areas of population are about 6km away on Lantau Island, where a population of about 10,000 is spread along the southern coast. The island of Cheung Chau has a population of 21,000 but is 13km away.

Marine population in the vicinity has been considered based on the marine traffic data provided by BMT [1]; approximately 0.4 person/km^2 is estimated in the vicinity of South Soko indicating very little marine activity. The Adamasta Channel is about 4km from the South Soko site and comprises of mainly ferries to Macau and some ocean going vessels.

Further details on land use adjoining the proposed site, as well as the land and marine population surrounding South Soko, are presented in *Annex 13A2*.

13.3.4 *Weather Data*

Weather data for the South Soko site is based on data from Cheung Chau weather station which is the closest and most relevant. Details are presented in *Annex 13A3*.

13.4 *HAZARD IDENTIFICATION*

Hazards associated with the LNG terminal 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 Hazard Identification (HAZID) process was undertaken to identify any local or site specific factors.

13.4.1 *Hazards from LNG*

LNG is an extremely cold, non-toxic, non-corrosive and flammable substance. If LNG is accidentally released from a temperature-controlled container, it will likely contact warm surfaces and air that transfer heat into the liquid. The heat input begins to vaporise some of the liquid, returning the liquid to the gaseous phase. The relative proportions of liquid and gaseous phases immediately following a release depend on the release conditions. The liquid phase will form an LNG pool on the ground which will begin to "boil", due to heat input from the surrounding environment.

Immediately following vaporisation, the gas is colder and heavier than the surrounding air and forms a vapour cloud. As the gas disperses, it mixes with the surrounding air and warms up. The vapour cloud will only ignite if it encounters an ignition source while concentrated within its flammability range.

Downstream of the vaporisers the natural gas will be in the gas phase. A release from this piping and equipment will result in a gaseous phase release directly.

13.4.2 *Hazard Effects*

In the event of an accidental release of LNG from piping or equipment, the characteristics of the possible hazardous effects are described below.

Pool Fire

A pool fire occurs when a flammable liquid is spilt onto the ground and ignited. A pool formed from the release of liquid LNG will initially spread due to the gravitational and surface tension forces acting on it. As the pool spreads, it will absorb heat from its surroundings causing evaporation from the pool surface. Ignition of this vapour leads to a pool fire.

Jet Fire

Jet fires result from ignited releases of pressurised flammable gas or superheated/pressurised liquid. The momentum of the release carries the materials forwards in a long plume entraining air to give a flammable mixture. Jet fires only occur where the LNG is being handled under pressure or when handled in gas phase and the release is unobstructed.

Flash Fire

Following an LNG release, a large proportion of the liquid will evaporate immediately to form a cloud of methane, initially located around the release point. If this cloud is not ignited immediately, it will move with the wind and be diluted as a result of air entrainment. Similarly, a gas release may not be ignited immediately and will disperse in the air.

The dispersing vapour cloud may subsequently come in contact with an ignition source and burn rapidly with a sudden flash. If the source of material which created the cloud is still present, then the fire will flash back to the source giving a pool fire or, if under pressure, a jet fire. Direct contact with the burning vapours may cause fatalities but the short duration of the flash fire means that thermal radiation effects are not significant outside the cloud and thus no fatalities are expected outside of the flash fire envelope.

Vapour Cloud Explosion

A flash fire is the most likely outcome upon ignition of a dispersing vapour cloud from an LNG release. If ignited in open (unconfined) areas, pure methane is not known to generate damaging overpressures (explode). However, if the gas is ignited in areas where there is significant degree of confinement and congestion an explosion may result.

Fireball

Immediate ignition of releases caused by a rupture in a gas piping may give rise to a fireball upon ignition. Fireballs have very high thermal radiation, similar to jet fires although the duration of the event is short.

To summarise, a liquid phase release may result in a flash fire, vapour cloud explosion, pool fire or jet fire. A gas phase release can result in a flash fire, fireball or jet fire.

13.4.3 *Review of Industry Incidents*

A review of industry incidents at LNG terminal facilities was carried out. Incident records over the last few decades show small LNG vapour releases and minor fires with impact limited to within the plant boundary. These were associated with leaks from valves and process equipment. There have been no instances of leaks to the environment from full containment tanks. There have been no injuries or fatalities recorded outside a plant boundary since 1944. Other incidents have occurred during the construction and repair of LNG facilities but no LNG was directly involved.

In general LNG facilities have shown an exceptionally high safety record due to the high level of safety features incorporated in an LNG terminal design including the use of full containment tanks and emergency shutdown systems.

13.4.4 *HAZID Study*

A Hazard Identification (HAZID) Study was conducted in October 2005 involving representatives from the Project Proponent: CLP and ExxonMobil and their expert consultants: ARUP, Foster Wheeler and ERM. The potential hazards posed by the facility were identified based on the HAZID team's expert opinion, past accidents, lessons learnt and checklists. The details of the HAZID study can be found in *Annex 13A4*.

A systematic approach was adopted, whereby the facility was divided into a number of "subsystems" based on the layout and the process; guidewords from the checklist (see *Annex 13A4*) were then applied to each subsystem as relevant.

The Study considered each area of the LNG Terminal and identified any potential hazards that apply to it. The study output served as a basis for identification of scenarios for the QRA study.

13.4.5 *Scenarios for QRA Study*

Scenarios for the QRA study were identified based on the HAZID Study as well as a review of incident records. Loss of containment events have been identified for each section of the terminal, corresponding to the relevant process conditions, as listed in *Table 13.1*.

A detailed discussion on the hazards, particularly in relation to the LNG storage tanks, is given in *Annex 13A5*.

Table 13.1 Scenarios for QRA Study

Plant Section	Initiating Event	Potential Outcome Scenario
Jetty Area Unloading arm Piping & equipment at the jetty	Leak, rupture	Pool fire/Jet fire, Vapour dispersion/ Flash fire
Transfer Piping on Trestle Piping	Leak, rupture	Pool fire/Jet fire, Vapour dispersion/ Flash fire
Tank Area		
Piping on tank roof	Leak, rupture	Pool fire/Jet fire, Vapour dispersion/ Flash fire
Storage Tank	Rupture	Pool fire, Vapour dispersion/ Flash fire
Process Area (HP Pumps, Recondenser, Vaporisers) Piping/equipment	Leak, rupture	Pool fire/Jet fire, Vapour dispersion/ Flash fire /Vapour cloud explosion
Process Area (Compressors) Piping/equipment	Leak, rupture	Jet fire, Gas dispersion/Flash fire, Fireball
Sendout Piping	Leak, rupture	Jet fire, Gas dispersion/ Flash fire, Fireball

13.5 *FREQUENCY ANALYSIS*

This includes an assessment of the likelihood or the frequency of events resulting in a hydrocarbon release from piping and equipment and the subsequent potential outcomes such as fires. Details of the frequency analysis are provided in *Annex 13A6*.

Release frequencies have been derived from generic data on loss of containment events. Reference has been made to a number of sources. A summary is presented in *Table 13.2*. Release scenarios include a range of hole sizes from small leaks to catastrophic rupture.

The frequency of various outcomes following a loss of containment event is estimated using an event tree model. The various outcomes considered include pool fire, jet fire, flash fire and vapour cloud explosions for liquid releases, jet fire and flash fire for continuous gas releases and fireball and flash fire for instantaneous gas releases.

Table 13.2 LNG Release Event Frequencies

Equipment	Release Scenario	Release Phase	Release Frequency	Unit	Reference
Process Vessels	i) 10 & 25mm hole	Liquid	1.00E-05	per year	Crossthwaite et al [2]
	ii) 50 & 100mm hole	Liquid	5.00E-06	per year	Crossthwaite et al
	iii) Full bore rupture	Liquid	1.00E-06	per year	Crossthwaite et al
Pumps	i) Leak	Liquid	1.00E-04	per year	COVO Study [3]
	ii) Full bore rupture	Liquid	1.00E-05	per year	COVO Study
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
Pipe size 600mm to 750mm	i) 10 & 25mm hole	Liquid/ Gas	1.00E-07	per meter per year	Hawksley [4]
	ii) 50 & 100mm hole	Liquid/ Gas	7.00E-08	per meter per year	Hawksley
	iii) Full bore rupture	Liquid/ Gas	3.00E-08	per meter per year	Hawksley
Pipe size 150mm to 500mm	i) 10 & 25mm hole	Liquid/ Gas	3.00E-07	per meter per year	Hawksley
	ii) 50 & 100mm hole	Liquid/ Gas	1.00E-07	per meter per year	Hawksley
	iii) Full bore rupture	Liquid/ Gas	5.00E-08	per meter per year	Hawksley
LNG Storage Tank	i) Rupture	Liquid	1.00E-08	per tank per year	"Purple Book" [5]

13.6 CONSEQUENCE ANALYSIS

This section gives a brief summary of the approach adopted to model the consequences of an LNG/natural gas release. Details are given in *Annex 13A7*.

A range of hole sizes from small leaks to full bore ruptures is considered in the analysis. Discharge rates, dispersion modelling, pool fire modelling, jet fire modelling, fire ball modelling and vapour cloud explosion modelling are considered and are all performed using the *PHAST* suite of models.

The plant was divided into twenty three isolatable process sections based on the provision of emergency shutdown valves. Physical properties of the fluid (pressure, temperature, density, phase) and equipment dimensions (pipe diameter and length) for each section were applied from the heat and mass balances to estimate the maximum release rate and the inventory in each section.

Fire radiation contours are calculated to 7.3, 14.4, 20.9 and 35.5 kW/m², and the fatality to people within each contour calculated. Overpressure effects from vapour cloud explosions are calculated to 5psi and 2psi contours. Dispersion of vapour clouds is determined to 0.85 of the lower flammability limit. A range of weather conditions is also considered, to represent a full year of conditions that occur within Hong Kong. Details of the consequence modelling and the results obtained are given in *Annex 13A7*.

13.7 RISK RESULTS

13.7.1 *Individual Risk Results*

The individual risk (IR) contours associated with the LNG terminal are shown in *Figure 13.4*. The maximum off-site risk is less than 1 x 10^{-5} per year at the site boundary, and hence meets the HKRG requirements.

Figure 13.4 Individual Risk Contours

1 x 10^{-5} per year

13.7.2 *Societal Risk Results*

The societal risk for the South Soko site has been estimated based on marine and land population in the area. Three cases are considered: year 2011, year 2021 "no Tonggu" and year 2021 "with Tonggu". The potential development of the Tonggu Waterway will increase the marine traffic through the Adamasta Channel and also south of South Soko so this possibility was considered in the analysis.

The societal risk results for the onshore terminal facilities have been combined with the risk results for the LNG carrier during berthing manoeuvres within 500m of the jetty to produce the overall societal risk results (*Figures 13.5-13.7*). The results for the berthing manoeuvres are taken from the Marine Quantitative Risk Assessment (MQRA).

Most of the points on the curve arise from scenarios involving the catastrophic failure of the LNG storage tanks. This is a very low frequency event but shows up in the FN curves because South Soko is remote and releases from other sections of the terminal are unable to reach populated areas.

Slight changes in the marine traffic for the three cases have resulted in small differences in the risk. The 2021 "No Tonggu" case has an increase in marine traffic predicted compared to 2011 and so the risks increase slightly. For 2021 "with Tonggu", the marine population in the vicinity of South Soko is the same as the 2021 "No Tonggu" case, but the increased traffic south of South Soko increases the frequency of carrier collisions. Hence, the risks increase slightly (*Figure 13.7*). Also shown in the figures are results for large (215,000 m^3) and small (145,000 m^3) carriers. If LNG is delivered from smaller carriers, the number of transfers required per year will be higher. The frequency of possible releases therefore increases, but the consequences would be less severe.

The risks for all cases are well within the *Acceptable Region* as per HK EIAO.

The Potential Loss of Life (PLL), or equivalent fatalities per year, are given in *Table 13.3*. The total PLL for the whole terminal is very low at 3.4 x 10^{-7} per year, or equivalently, one fatality every 3 million years.

13.3 *Potential Loss of Life*

Section		**2011**		**2021**	
		PLL	%	PLL	%
T2	LNG tank 2	1.18 x 10^{-7}	34.7	1.18 x 10^{-7}	34.7
T1	LNG tank 1	1.14 x 10^{-7}	33.5	1.14 x 10^{-7}	33.5
T3	LNG tank 3	1.08 x 10^{-7}	31.8	1.08 x 10^{-7}	31.8
L05	Liquid unloading line from shore to tank	1.13 x 10^{-10}	0.07	1.13 x 10^{-10}	0.07
	Total	3.39 x 10^{-7}	100	3.39 x 10^{-7}	100

Figure 13.5 FN Curve for 2011

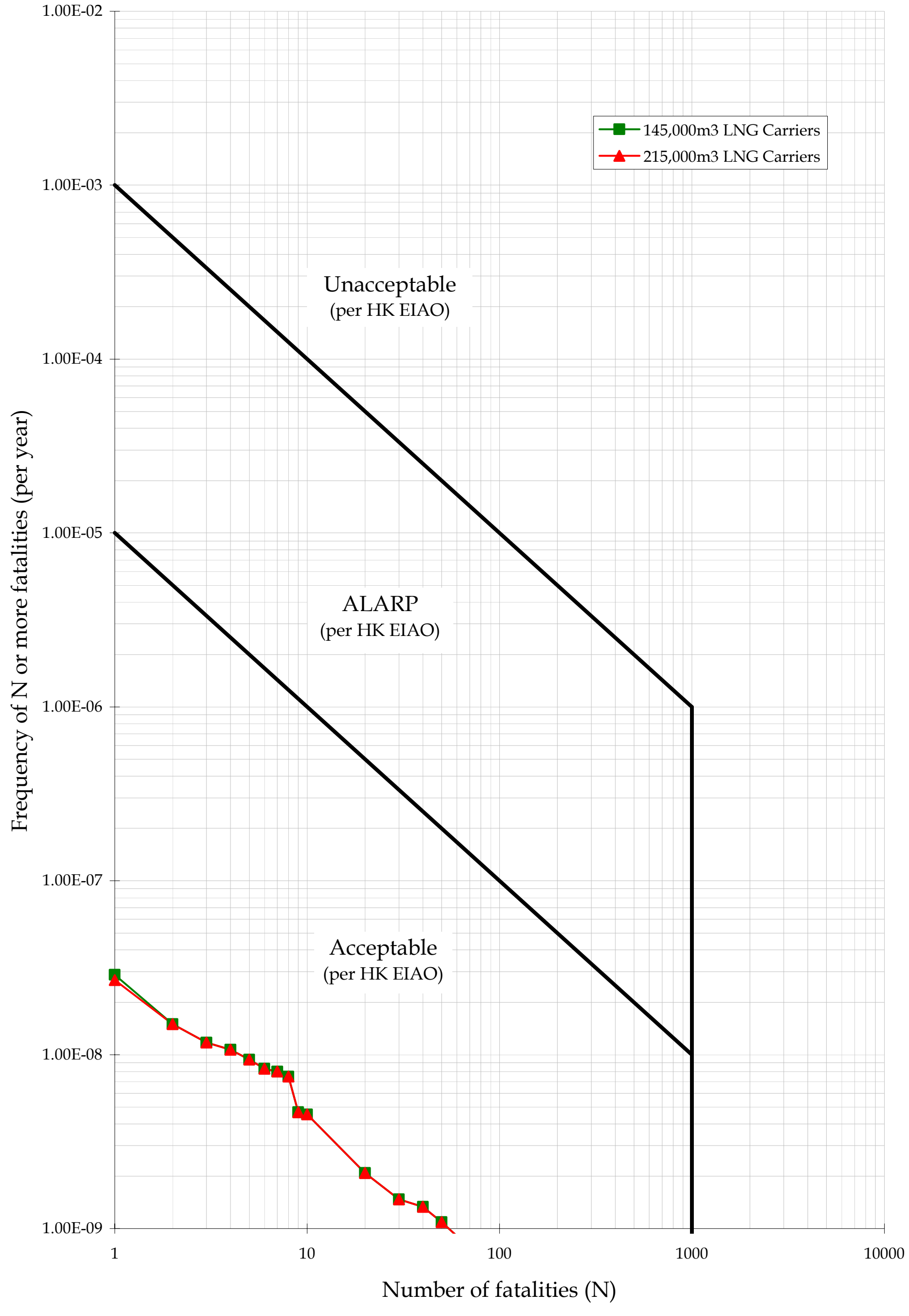


Figure 13.6 FN Curve for 2021 "No Tonggu"

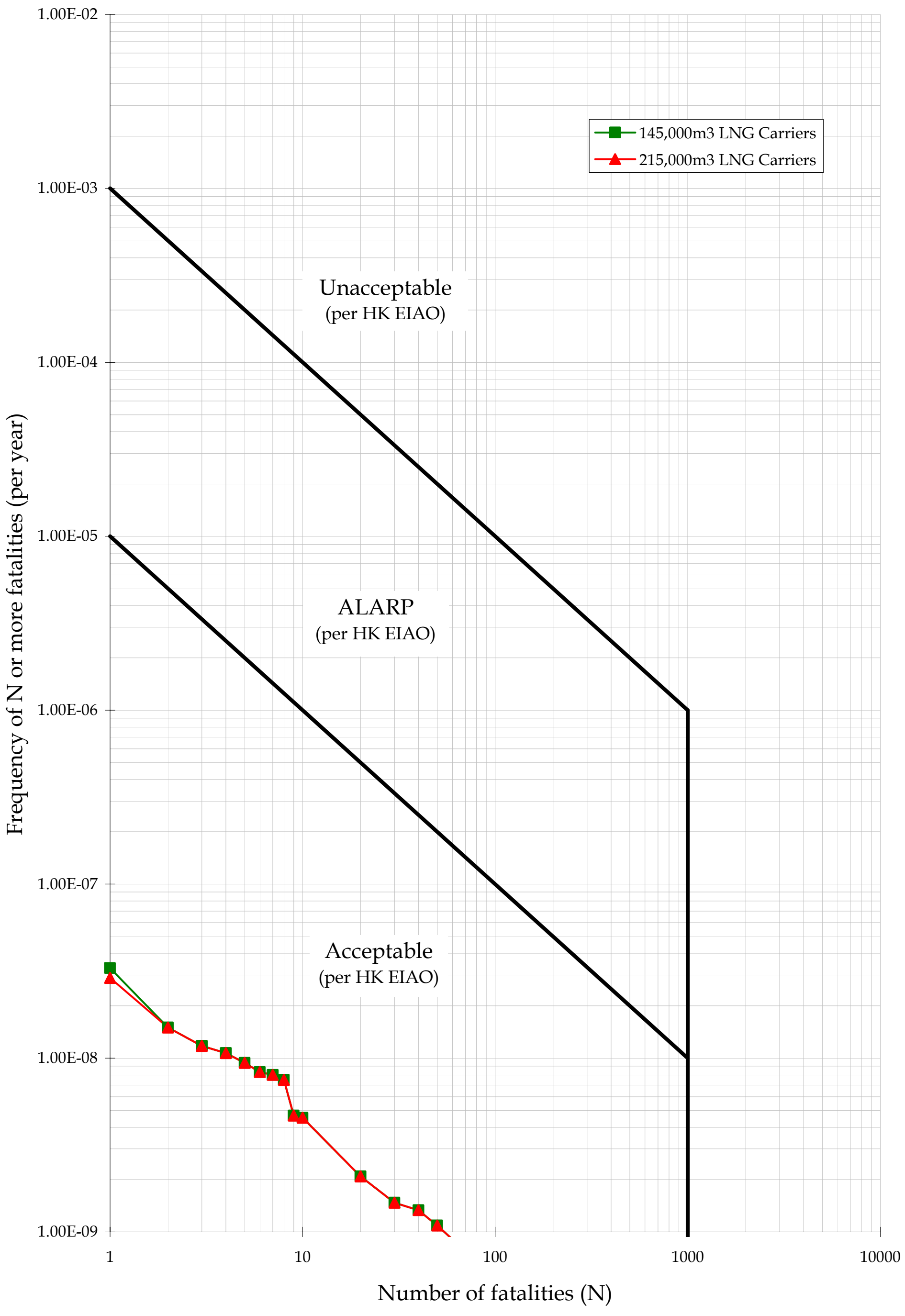
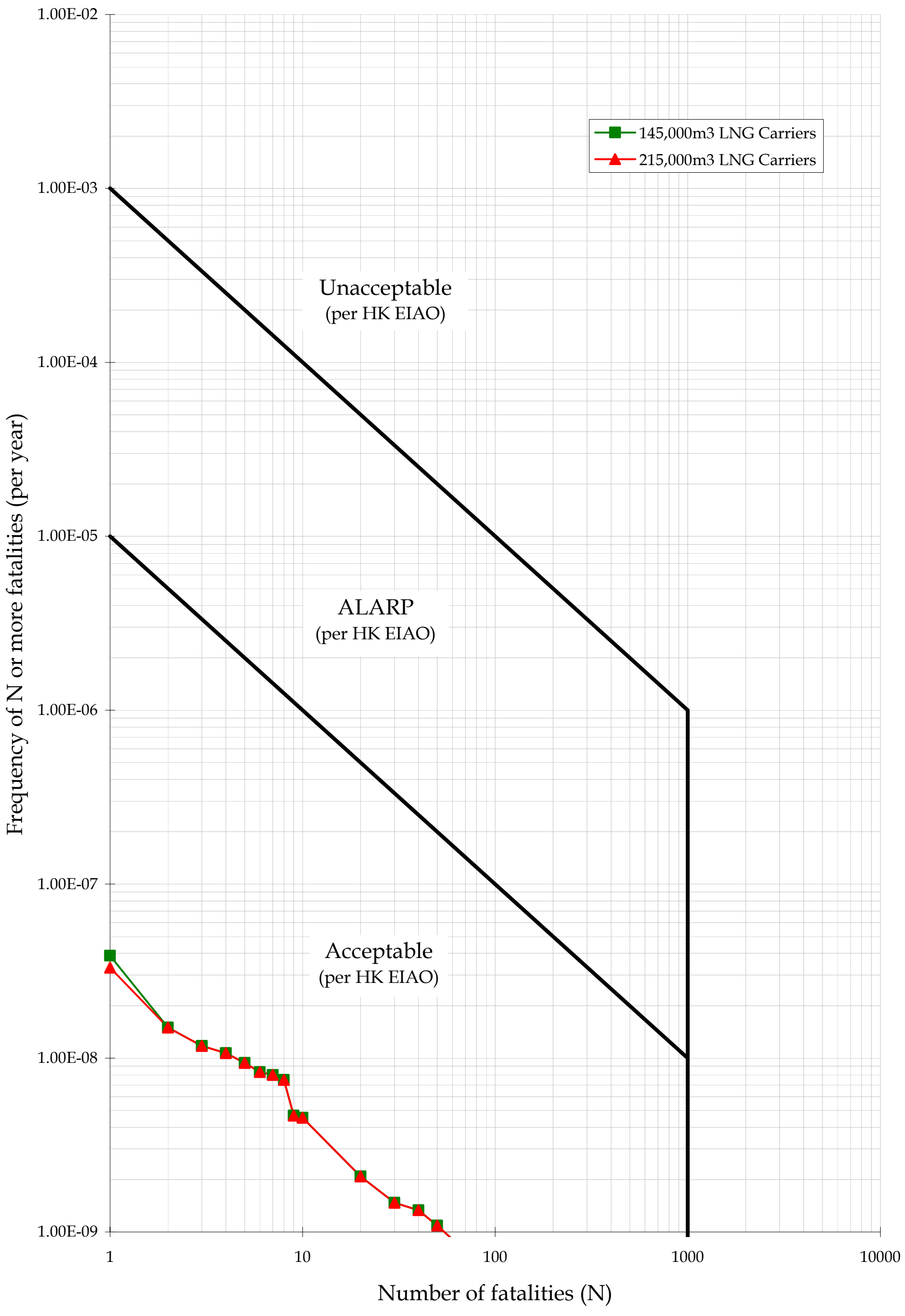


Figure 13.7 FN Curve for 2021 "With Tonggu"



13.8 CONCLUSIONS OF QRA STUDY FOR TERMINAL

The results indicate that the societal risks from the proposed facility are within the *Acceptable Region* of the HK EIAO. The individual risks also meet the requirements of the HKRG.

SUB-SECTION 3: PIPELINE

The proposed subsea pipeline will transport compressed natural gas from the LNG terminal in South Soko Island to CAPCO's Black Point Power Station. This section presents a summary of the QRA study for the subsea pipeline while *Annex 13B* gives further details.

Three marine traffic scenarios are considered in the analysis. The base case uses marine traffic data for 2011. To take into consideration the impact of future developments, predictions for 2021 traffic volume are also used, with and without the development of the Tonggu Waterway.

13.9 PIPELINE AND MARINE DATA

13.9.1 Pipeline Route

The proposed pipeline takes a subsea route from the LNG terminal at South Soko to Black Point Power Station (*Figure 13.8*), crossing the waterways of the Adamasta Channel and Urmston Road (not a designated channel).

The pipeline with a total length of about 38km will be buried to 3m below the seabed with varying levels of rock armour protection (*Figures 13.8* and *13.9*). Type 1B protection provides 1m of rock armour backfill and 2m of natural backfill above the pipeline. This provides protection for anchors up to 2 tonnes, essentially protecting against anchors from all ships below about 10,000 dwt. Trench types 2A/B are used on the shore approaches and are designed for protection from 2 tonne anchors and any future construction vessels. Trench types 2A/B are also designed to protect against scouring effects from wave action so that the pipeline is sufficiently protected when it makes the transition from subsea to land. The waterways of Urmston Road and the Adamasta Channel will have type 3A or 3B trenches consisting of 3m of rock armour backfill. Types 3A and 3B are essentially similar and are designed to protect against 20 tonne anchors. This covers the full range of ships currently operating in Hong Kong and also those expected in future.

13.9.2 Marine Traffic

The marine traffic report [1] divides the pipeline route into sections using 'gate posts' that roughly correspond to key locations along the route. Radar tracks of marine vessel movements are then used to determine the number of vessels crossing between pairs of gate posts each day. Based on the vessel speed and apparent size from the radar returns, vessels are also divided into six categories (*Table 13.4*). The same marine vessel classes as that used in the marine traffic report are used in this QRA study, although some interpretation of the data was required; to distinguish between fast ferries and fast launches in vessel class A2, for example.

Figure 13.8 Pipeline Route

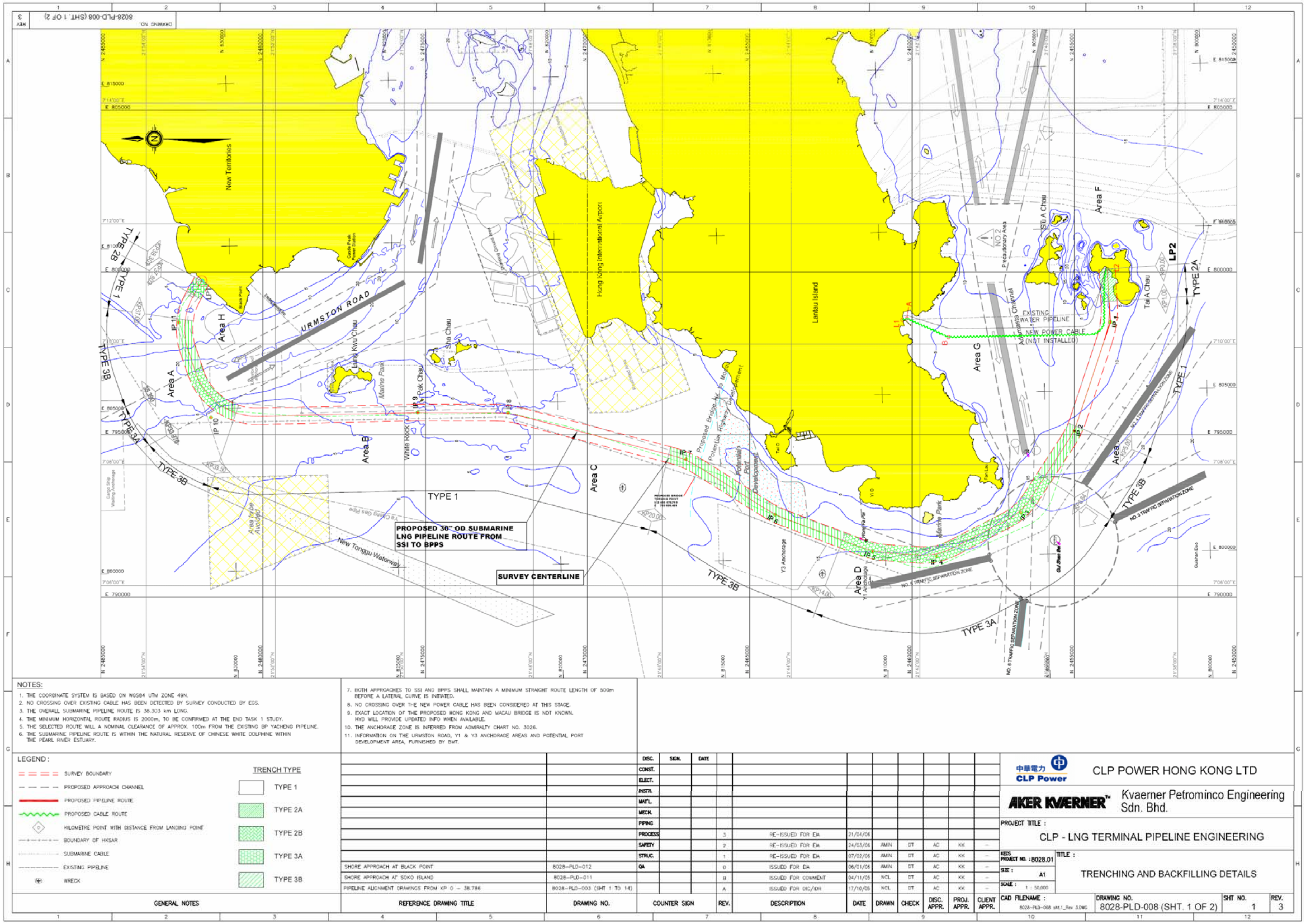


Figure 13.9 Pipeline Trench Types

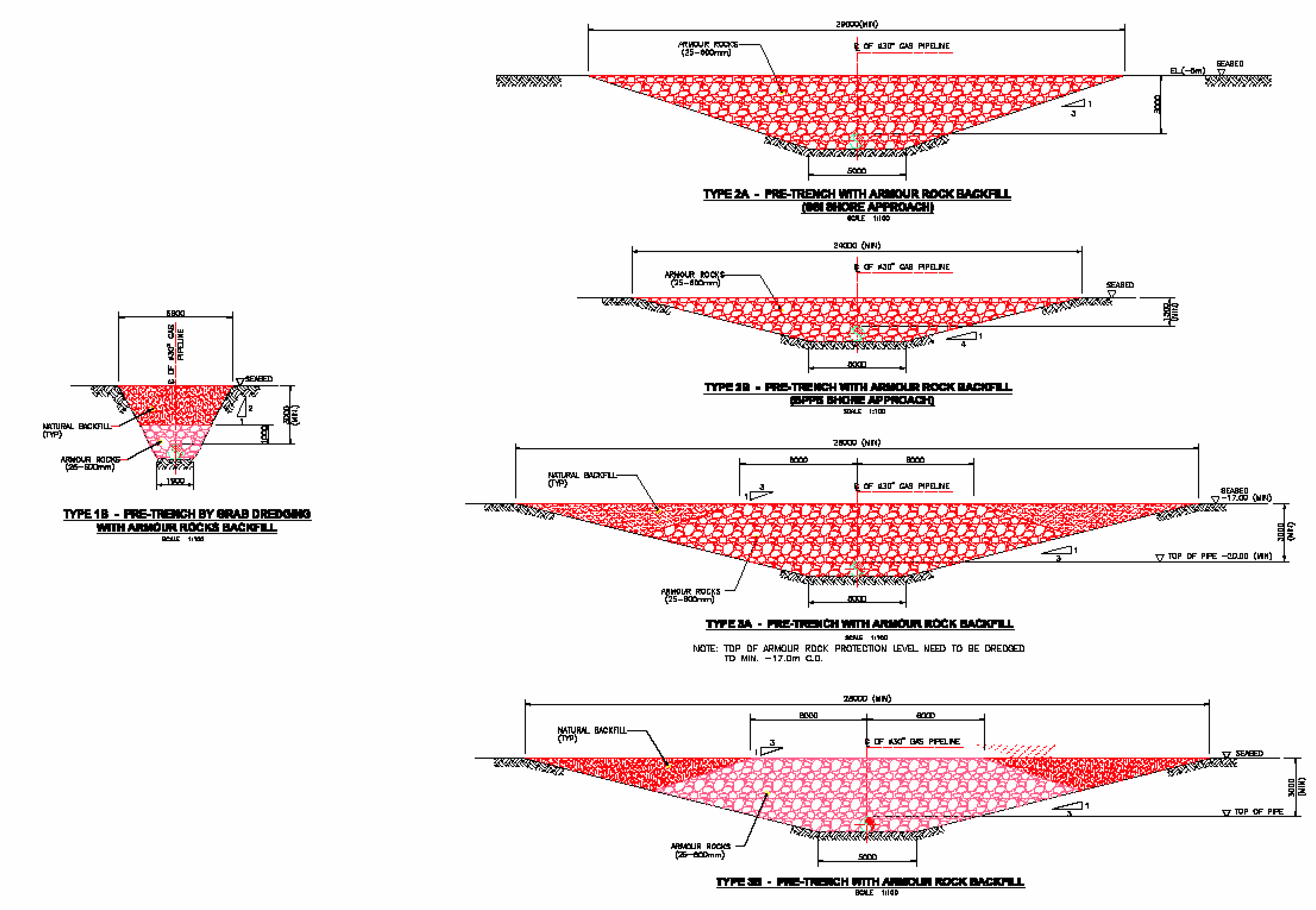


Table 13.4 Vessel Classes Adopted for Assessment

Class	Type	Typical Length (m)	Typical Beam (m)	Typical Draft (m)	Typical Displace-ment (tonnes)	Typical Anchor Size (tonnes)
"A1" - Fishing Vessels & Small craft		5 – 30	2 – 7.5	1 - 3	1 – 400	< 1
"B1" - Rivertrade coastal vessels		35 – 75	8 - 12	2.5 – 4.5	1,500	< 2
"C1" - Ocean-going Vessels		75 – 350	12 - 45	4 - 15	1,500 – 150,000	2 – 15
"A2" - Fast Launches and Fast Ferries		10 – 30	3 - 7.5	1 – 2.5	1 - 150	< 0.1
"B2" - Fast Ferries		30 - 50	7.5 - 12	1.5 - 2.5	100 – 150	< 0.5
"C2" - Fast Ferries & Ocean-going Vessel	*As above*					

It was also necessary to make some assumptions regarding the population of each class of vessel. These are given in *Table 13.5*.

Table 13.5 Vessel Population

Class	**Population**
Fishing vessels	5
Rivertrade coastal vessels	5
Ocean-going vessels	21
Fast launches	5
Fast ferries	450/350/280/175/105/35*
Other	5

* A distribution was assumed for the fast ferry population to reflect the occupancy at different time periods so that on average, the population is similar to the average load factor published by the Marine Department.

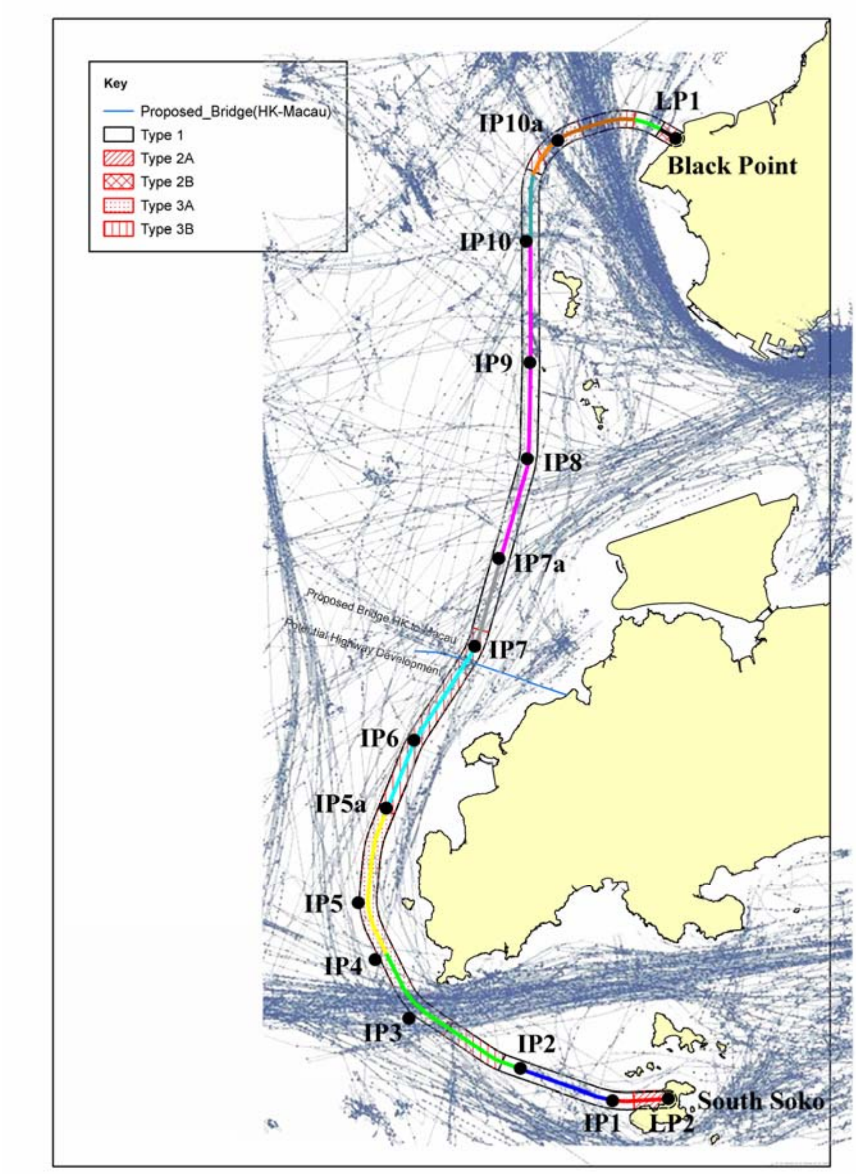
13.9.3 *Segmentation of the Route*

Based on considerations of the marine traffic data and the level of rock armour protection proposed for the pipeline, the pipeline route was divided into 12 sections for analysis (*Table 13.6, Figure 13.10*).

Table 13.6 Pipeline Segmentation

Section		Gate [1] From	Gate [1] To	Kilometre Post From	Kilometre Post To	Length (km)	Typical water depth (m)	Trench type
1	South Soko Approach	LP2	IP1	0	1.6	1.6	5	2A
2	West Soko	IP1	IP2	1.6	4.5	2.9	8	1
3	Adamasta Channel	IP2	IP4	4.5	9.8	5.3	25	3B/3A
4	West Lantau	IP4	IP5a	9.8	14.2	4.4	20	3A
5	Tai O	IP5a	IP7	14.2	19.5	5.3	17	3B
6	North Lantau	IP7	IP7a	19.5	22.2	2.7	7	1
7	Sha Chau	IP7a	IP10	22.2	31.6	9.4	6	1
8	North Lung Kwu Chau	IP10		31.6	33.5	1.9	4	1
9	Urmston Road West		IP10a	33.5	34.7	1.2	20	3B/3A
10	Urmston Road Central	IP10a		34.7	37.0	2.3	20	3A/3B
11	Urmston Road East			37.0	37.8	0.8	5	1
12	Black Point Approach		LP1	37.8	38.3	0.5	4	2B

Figure 13.10 Segmentation of the Route



In some sections, the gate post locations were modified in this study to reflect changes in conditions. For example, the section from gates IP10a to LP1 spans different trench types and a sharp change in traffic intensity. In this case, the pipeline was divided into smaller sections and assumptions made regarding the marine traffic distribution based on the radar tracks (overlaid in *Figure 13.10*). Following this interpretation of the marine date, the traffic used for this study is as summarised in *Table 13.7*. Similar traffic tables were constructed for the future 2021 scenarios (*Tables 13.8* and 13.*9*). With the Tonggu Waterway development, an increase in ocean-going vessels is expected to pass through the Adamasta Channel with a corresponding reduction in ocean-going vessel traffic in Urmston Road.

Table 13.7 Traffic Volume Assumed for Base Case 2011

		Traffic volume (ships per day)						
Section		**Fishing**	**River-trade**	**Ocean-going**	**Fast Launch**	**Fast ferry**	**Other**	**Total**
1	South Soko Approach	0	0	0	1	0	0	1
2	West Soko	21	0	0	2	6	4	33
3	Adamasta Channel	126	16	7	83	260	4	496
4	West Lantau	11	2	3	4	9	4	33
5	Tai O	42	1	4	7	12	4	70
6	North Lantau	37	12	0	5	11	6	71
7	Sha Chau	79	22	0	28	44	27	200
8	North Lung Kwu Chau	21	3	0	24	31	8	87
9	Urmston Road West	21	2	6	23	30	2	84
10	Urmston Road Central	250	265	144	117	150	5	931
11	Urmston Road East	11	13	0	5	7	2	38
12	Black Point Approach	2	3	0	2	0	0	7
	Total	621	339	164	301	560	66	2051

Table 13.8 Traffic Volume Assumed for 2021 "No Tonggu" Case

		Traffic volume (ships per day)						
Section		**Fishing**	**River-trade**	**Ocean-going**	**Fast Launch**	**Fast ferry**	**Other**	**Total**
1	Soko Approach	0	0	0	1	0	0	1
2	West Soko	22	0	0	2	7	5	36
3	Adamasta Channel	132	17	8	91	307	5	560
4	West Lantau	11	2	3	5	10	5	36
5	Tai O	44	1	4	8	14	4	76
6	North Lantau	39	13	0	6	13	7	78
7	Sha Chau	83	24	0	31	52	30	220
8	North Lung Kwu Chau	22	3	0	26	36	9	96
9	Urmston Road West	22	2	7	25	35	2	93
10	Urmston Road Central	262	290	239	128	177	6	1102
11	Urmston Road East	11	14	0	6	8	2	41
12	Black Point Approach	2	3	0	2	0	0	7
	Total	650	369	261	331	659	76	2346

Table 13.9 Traffic Volume Assumed for 2021 "With Tonggu" Case

		Traffic volume (ships per day)						
Section		Fishing	River-trade	Ocean-going	Fast Launch	Fast ferry	Other	Total
1	Soko Approach	0	0	0	1	0	0	1
2	West Soko	22	0	0	2	7	5	36
3	Adamasta Channel	132	17	162	91	307	5	714
4	West Lantau	11	2	3	5	10	5	36
5	Tai O	44	1	4	8	14	5	76
6	North Lantau	39	13	0	6	13	7	78
7	Sha Chau	83	24	0	31	52	30	220
8	North Lung Kwu Chau	22	3	0	26	36	9	96
9	Urmston Road West	22	2	7	25	35	2	93
10	Urmston Road Central	262	290	85	128	177	6	948
11	Urmston Road East	11	14	0	6	8	2	41
12	Black Point Approach	2	3	0	2	0	0	7
	Total	650	369	261	331	659	76	2346

13.9.4 *Pipeline Protection*

Varying levels of rock armour protection are proposed for each section of the pipeline based on a qualitative assessment of the hazards identified by the pipeline engineering consultant (Aker Kvaerner) and marine traffic consultant (BMT). These levels of rock armour protection are assumed in the base case analysis as well as future traffic scenarios presented in this report.

13.10 *METHODOLOGY*

Key elements of the risk assessment methodology are described in the following sections.

13.10.1 *Hazard Identification*

Hazards were identified by reviewing worldwide databases and reports on incidents related to subsea pipelines. A HAZID (Hazard Identification) workshop was also conducted for the proposed pipeline to identify any route/site specific issues. The details of the hazard identification process are presented in *Annex 13B*.

The main hazard associated with a subsea pipeline is loss of containment resulting in gas release which could be ignited by a passing marine vessel in the vicinity. A loss of containment could occur from:

- Failures due to external impact (such as anchor drag)
- Spontaneous failures from corrosion and material/weld defects
- Natural hazards

13.10.2 *Frequency Estimation*

Frequency assessment is the estimation of the likelihood of occurrence of each scenario based on the hazard identification exercise. The approach adopted here for estimating frequency of pipeline failure is to apply worldwide historical data, with appropriate modifications for the specific pipeline environment.

The database that is most comprehensive and relevant is PARLOC 2001 [6]. This covers 300,000 km-years of subsea pipeline experience dating from the 1960s to 2000. This database provides failure frequencies for different causes such as corrosion, material defects, external impact etc. It also provides a breakdown for different diameter pipelines, location and contents of pipeline.

To validate this approach, particularly for anchor/impact damage where the specific marine traffic environment is more relevant, alternative calculations were performed for comparison. These were based on marine incident rates in Hong Kong waters, from which likelihood of emergency anchoring events were estimated. Frequency of anchoring was also estimated from the number of anchor marks found on the seabed based on recent geophysical surveys [7]. These alternate approaches were found to give similar failure frequencies to that derived from the PARLOC data. The frequencies used in the analysis are summarised in *Table 13.10* while details are presented in *Annex 13B*.

The CAPCO pipeline will have rock armour protection along its whole length. To allow for this, protection factors are incorporated into the analysis. Trench types 1 and 2A/B are designed to protect against 2 tonne anchors. They are assumed to be 99% effective. They are also assumed to provide some protection (50%) against larger anchors. Trench type 3A/B is designed to protect against 20 tonne anchors, covering all ships currently operating in Hong Kong and those expected in the future. This trench type was assumed to be 99% effective for large anchors and provide even greater protection (99.9%) against smaller anchors, i.e. below 2 tonnes (see *Table 13.10*). Note that the rock armour design will be finalised during the engineering stage based on these performance considerations. The above assumptions are therefore conservative.

The frequencies used in the analysis are summarised in *Table 13.10* while details are presented in *Annex 13B*. The probability of damage to the pipeline leading to a gas release is estimated as 0.37% for the 38km section during the lifetime of the facility, assumed as 30 years.

Table 13.10 Summary of Failure Frequencies Used

Pipeline section	Trench type	Corrosion /defects (/km/year)	Anchor/Impact			Others /km/year	Total /km/year
			Frequency (/km/year)	Protection factor (%) anchor<2	Protection factor (%) Anchor>2		
South Soko Approach	2A	1.18×10^{-6}	1.37×10^{-5}	99	50	1.34×10^{-6}	2.66×10^{-6}
West Soko	1	1.18×10^{-6}	1.37×10^{-5}	99	50	1.34×10^{-6}	2.66×10^{-6}
Adamasta Channel	3B/3A	1.18×10^{-6}	8.6×10^{-4}	99.9	99	1.34×10^{-6}	3.49×10^{-6}
West Lantau	3A	1.18×10^{-6}	1×10^{-4}	99.9	99	1.34×10^{-6}	2.70×10^{-6}
Tai O	3B	1.18×10^{-6}	8.6×10^{-4}	99.9	99	1.34×10^{-6}	3.82×10^{-6}
North Lantau	1	1.18×10^{-6}	1×10^{-4}	99	50	1.34×10^{-6}	3.52×10^{-6}
Sha Chau	1	1.18×10^{-6}	1×10^{-4}	99	50	1.34×10^{-6}	3.52×10^{-6}
North Lung Kwu Chau	1	1.18×10^{-6}	1×10^{-4}	99	50	1.34×10^{-6}	3.52×10^{-6}
Urmston Road West	3B/3A	1.18×10^{-6}	8.6×10^{-4}	99.9	99	1.34×10^{-6}	3.93×10^{-6}
Urmston Road Central	3A/3B	1.18×10^{-6}	8.6×10^{-4}	99.9	99	1.34×10^{-6}	4.58×10^{-6}
Urmston Road East	1	1.18×10^{-6}	1×10^{-4}	99	50	1.34×10^{-6}	3.52×10^{-6}
Black Point Approach	2B	1.18×10^{-6}	1×10^{-4}	99	50	1.34×10^{-6}	3.52×10^{-6}

13.10.3 *Scenario Development*

The outcome of a hazard is predicted using Event Tree Analysis (ETA) to investigate the way initiating events could develop. This considers the cause of failure, the hole size distribution, the likelihood that a marine vessel will be in the area and the probability that the gas will be ignited. Historical data is used where appropriate; for the hole size distribution and ignition probability. The probability that a ship will pass through the flammable plume is calculated based on the size of the plume (obtained from dispersion modelling) and the marine traffic density.

13.10.4 *Consequence Analysis*

In the event of loss of containment in a subsea pipeline, the gas will release as a jet but is expected to lose momentum and bubble to the sea surface and disperse into the atmosphere as a buoyant gas. The dispersing plume may encounter an ignition source, say from a passing vessel, while within its flammable limits, leading to a flash fire, which will propagate through the gas cloud.

The flash fire could cause injury to personnel on marine vessels. It may also cause secondary fires on the vessel.

If a vessel passes close to the 'release area' (where bubbles of gas break through the sea surface), the consequences will be more severe. 100% fatality is assumed for this scenario. Once a fire has ignited, it is presumed that no further ships will be involved because the fire will be visible and other ships can take action to avoid the area. In other words, it is assumed that at most, only one ship will be affected.

Additional consequences may also arise from the proposed Hong Kong to Zhuhai Macau bridge (HKZM). Although the alignment of the bridge is not yet finalised, it is expected to straddle the CAPCO pipeline within the Tai O section (*Figure 13.8*). Impact on vehicle population due to flash fire events was considered in the analysis, as detailed in *Annex 13B*.

The pipeline alignment brings the North Lantau section of the pipeline within 3.7km of the thresholds for runways 07L and 07R of Chep Lap Kok Airport. Due to the shallow approach angle of aircraft, the possibility of a vapour cloud due to a large leak/rupture from the gas pipeline affecting a passing aircraft on the final approach to the airport was included in the analysis. See *Annex 13B* for details.

Helicopters plying to and from Macau fly at about 500 feet altitude. They cross the pipeline at the Adamasta Channel section on the Macau bound journey. The possibility of large leaks/ruptures affected a passing helicopter was included in the analysis.

13.11 RISK RESULTS

13.11.1 Base Case 2011

The individual risk (IR) and potential loss of life (PLL) are given in *Table 13.11*. These risks are expressed in terms of per km to give a uniform basis for comparison between the various sections. The individual risk is less than 1 x 10^{-5} per year for all sections of the pipeline. The total PLL, or equivalent annual fatality, for the whole length of pipeline is 1.4 x 10^{-4} per year.

Table 13.11 Risk Results Based on Estimated 2011 Marine Traffic

Section		IR (per km-year)	PLL (per km-year)
1	South Soko Approach	8.6 x 10^{-9}	4.3 x 10^{-8}
2	West Soko	1.1 x 10^{-8}	3.8 x 10^{-7}
3	Adamasta Channel	1.1 x 10^{-7}	7.6 x 10^{-6}
4	West Lantau	1.3 x 10^{-8}	5.1 x 10^{-7}
5	Tai O	2.3 x 10^{-7}	3.6 x 10^{-6}
6	North Lantau	7.9 x 10^{-8}	3.5 x 10^{-6}
7	Sha Chau	7.0 x 10^{-8}	3.1 x 10^{-6}
8	North Lung Kwu Chau	8.0 x 10^{-8}	5.2 x 10^{-6}
9	Urmston Road West	1.2 x 10^{-7}	5.6 x 10^{-6}
10	Urmston Road Central	3.9 x 10^{-7}	6.6 x 10^{-6}
11	Urmston Road East	8.0 x 10^{-8}	2.9 x 10^{-6}
12	Black Point Approach	6.7 x 10^{-8}	3.3 x 10^{-7}

On a per km basis, the highest risks come from the Urmston Road and Adamasta Channel sections of the pipeline. This is because of the high traffic volume along these sections.

The FN curves for each section are presented in *Figure 13.11*. These are also expressed on a per km basis for comparison with the HKRG. The FN curves for all sections of the pipeline lie within the *Acceptable Region*.

The FN curves also show that the highest risks are associated with Urmston Road and the Adamasta Channel. Despite the high level of pipeline protection, the marine traffic volume is very high along these sections. The curves for these two sections actually cross over. The Adamasta Channel has a higher frequency of larger number of fatalities due to the relatively high number of fast ferries along this section. The Urmston Road has a higher frequency of lower number of fatalities due to the higher number of ocean-going vessels.

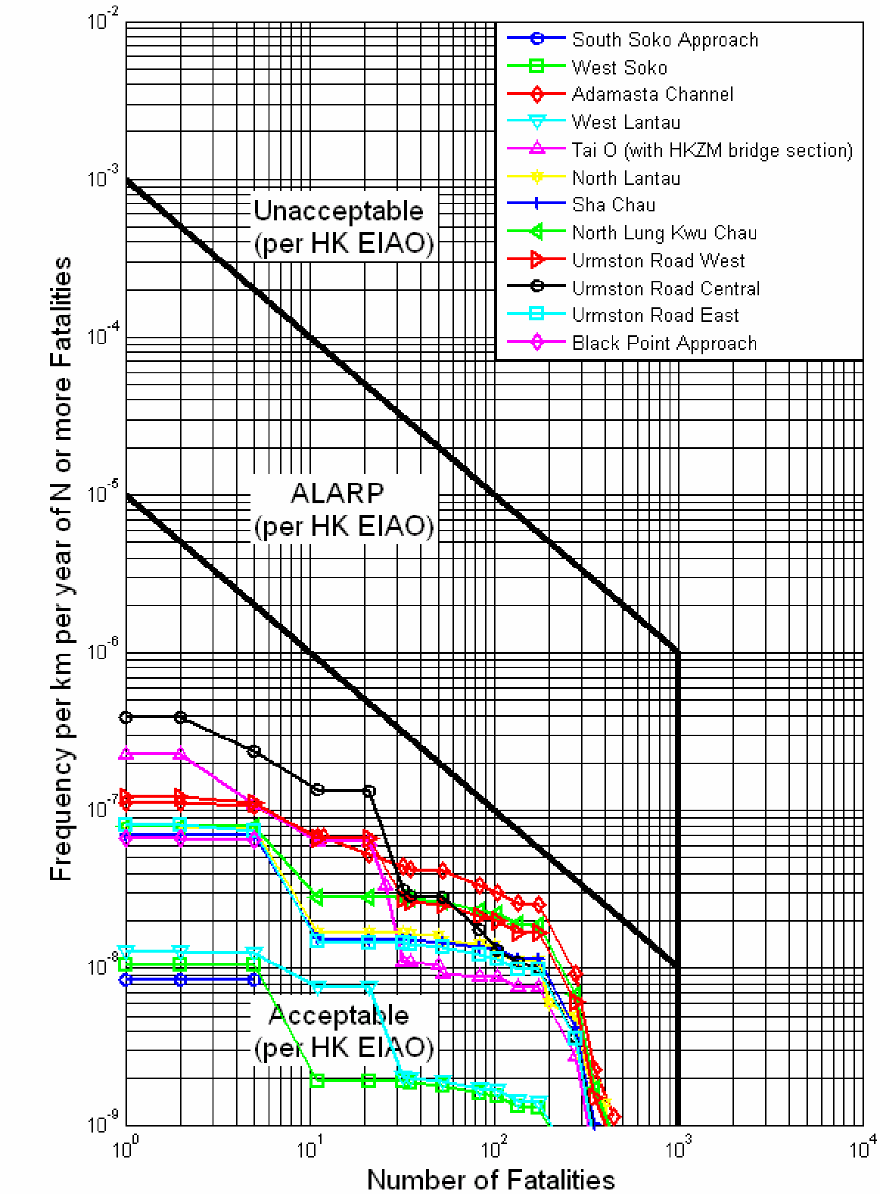
The Adamasta Channel was assigned a high failure frequency based on the high traffic volume but the data suggests that the marine vessel incident rate in this area, and hence the likelihood of emergency anchoring, is actually low. The approach has therefore been conservative.

The Sha Chau and North Lantau sections display the next highest risks. These sections were assigned an intermediate failure frequency based on the marine traffic, however, the shallow water along these sections means that only small draft vessels are present. The results are hence conservative.

For the Tai O section, results are presented inclusive of the HKZM bridge. The presence of the bridge does increase the risks slightly but the risks are still comfortably within the *Acceptable Region*. Similarly, aircraft on the approach to the airport and helicopters travelling to Macau make small contributions to the North Lantau and Adamasta Channel sections respectively, but the risks are in the *Acceptable Region* per HK EIAO.

The lowest risk occurs in the South Soko Approach and West Soko sections. This arises from the low traffic volume in this area.

Figure 13.11 FN Curve for each Section for Base Case 2011



13.11.2 *2021 "No Tonggu" Scenario*

The estimated future marine traffic scenario for year 2021 without the Tonggu Waterway development was also assessed, based on the future marine traffic predictions provided by BMT [1]. The frequency of damage due to anchor drop/drag was assumed to increase 15% in line with the average increase in density of marine vessels from 2011 to 2021. The frequency of corrosion failures and other types of failures was left unchanged.

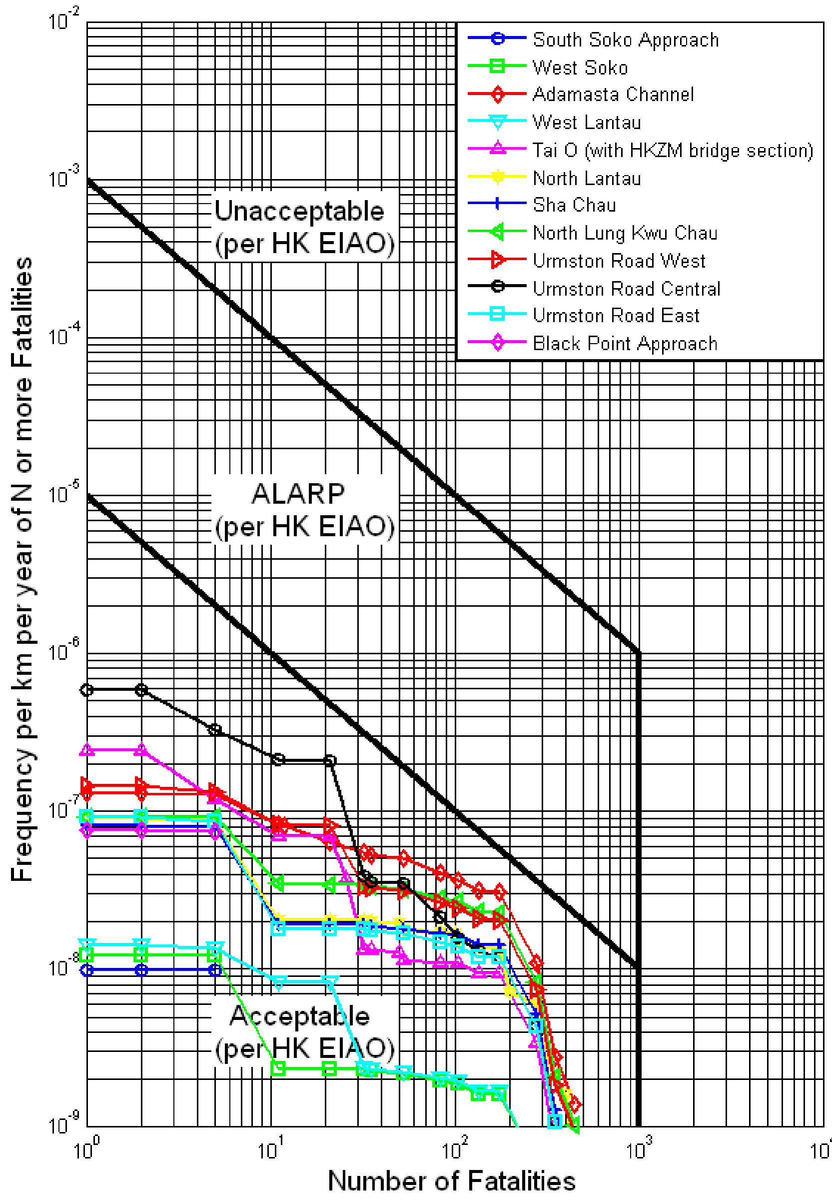
The IR and PLL values are shown in *Table 13.12*. The greatest increase in risk occurs in Urmston Road and the Adamasta Channel. These are the main routes for fast ferries which are predicted to have the greatest increase in traffic. The IR for all sections remain below 1 x 10^{-5} per year. The total PLL for the 38km of pipeline increases to 1.7 x 10^{-4} per year.

Table 13.12 Risk Results Based on 2021 "No Tonggu" Case

Section		IR (per km-year)	PLL (per km-year)
1	South Soko Approach	9.8×10^{-9}	4.9×10^{-8}
2	West Soko	1.2×10^{-8}	4.7×10^{-7}
3	Adamasta Channel	1.3×10^{-7}	9.2×10^{-6}
4	West Lantau	1.4×10^{-8}	5.8×10^{-7}
5	Tai O	2.4×10^{-7}	4.2×10^{-6}
6	North Lantau	9.1×10^{-8}	4.2×10^{-6}
7	Sha Chau	8.1×10^{-8}	3.8×10^{-6}
8	North Lung Kwu Chau	9.3×10^{-8}	6.3×10^{-6}
9	Urmston Road West	1.5×10^{-7}	6.8×10^{-6}
10	Urmston Road Central	5.9×10^{-7}	9.1×10^{-6}
11	Urmston Road East	9.3×10^{-8}	3.5×10^{-6}
12	Black Point Approach	7.7×10^{-8}	3.8×10^{-7}

The FN curves (*Figure 13.12*) also show a slight increase but still lie in the *Acceptable Region*.

Figure 13.12 FN Curve for each Section for 2021 "No Tonggu" Case



13.11.3 2021 "With Tonggu" Scenario

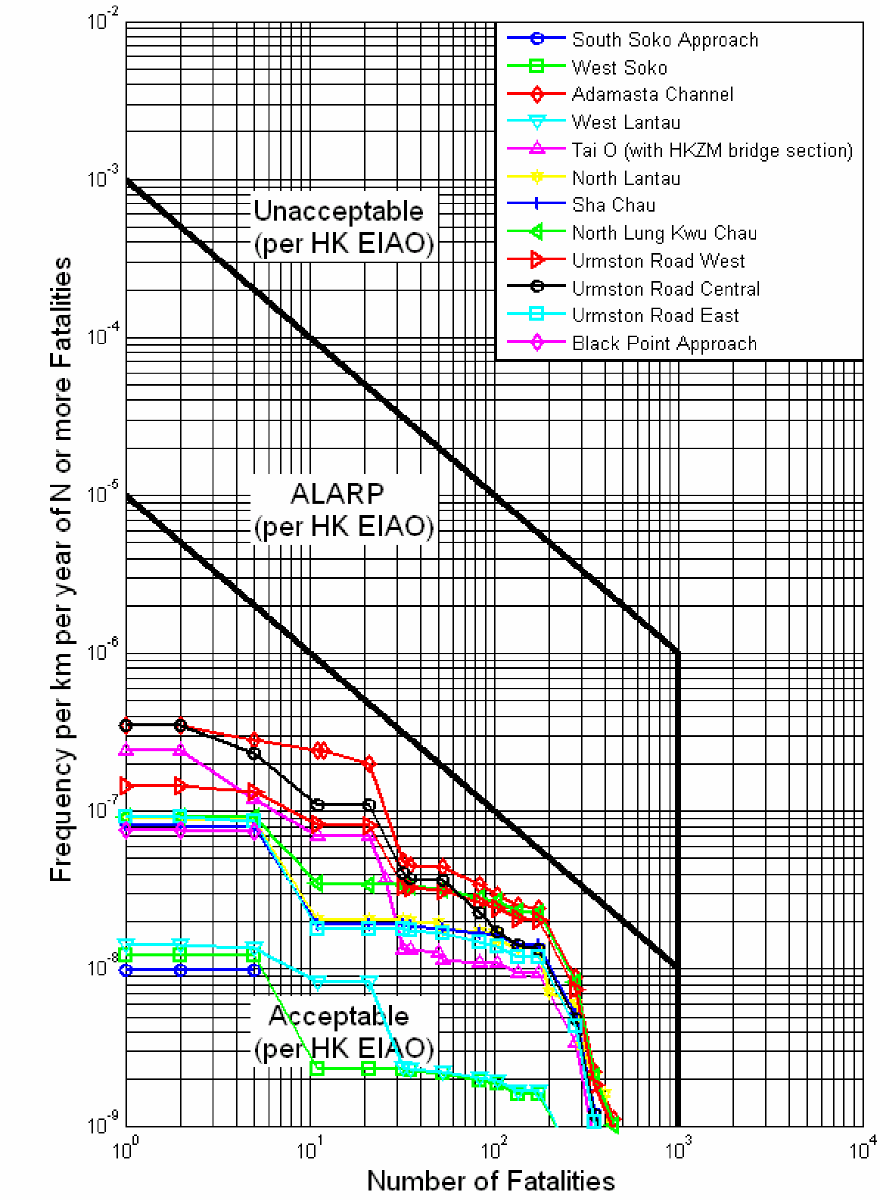
Results from the 2021 future scenario with Tonggu Waterway development are shown in *Table 13.13* and *Figure 13.13*. In this simulation, the frequency of anchor damage was again increased by 15% compared to 2011 in line with the average increase in traffic volume, while the frequency of failure due to corrosion and other causes was left unchanged.

The development of the Tonggu Waterway diverts many of the ocean-going vessels away from Urmston Road and into the Adamasta Channel. The IR, PLL and FN curves therefore show an increase in risk in the Adamasta Channel and a corresponding decrease for Urmston Road. The total PLL for the 38km pipeline remains the same at 1.7×10^{-4} per year. All IR values are below 1×10^{-5} per km-year and all FN curves remain in the *Acceptable Region*.

Table 13.13 Risk Results Based on 2021 "With Tonggu" Case

Section		IR (per km-year)	PLL (per km-year)
1	South Soko Approach	9.8×10^{-9}	4.9×10^{-8}
2	West Soko	1.2×10^{-8}	4.7×10^{-7}
3	Adamasta Channel	3.5×10^{-7}	1.1×10^{-5}
4	West Lantau	1.4×10^{-8}	5.8×10^{-7}
5	Tai O	2.4×10^{-7}	4.2×10^{-6}
6	North Lantau	9.1×10^{-8}	4.2×10^{-6}
7	Sha Chau	8.1×10^{-8}	3.8×10^{-6}
8	North Lung Kwu Chau	9.3×10^{-8}	6.3×10^{-6}
9	Urmston Road West	1.5×10^{-7}	6.8×10^{-6}
10	Urmston Road Central	3.5×10^{-7}	7.0×10^{-6}
11	Urmston Road East	9.3×10^{-8}	3.5×10^{-6}
12	Black Point Approach	7.7×10^{-8}	3.8×10^{-7}

Figure 13.13 FN Curve for each Section for 2021 "With Tonggu" Case



13.12 CONCLUSIONS OF PIPELINE QRA STUDY

A QRA study for the proposed CAPCO pipeline was conducted. The study considered the loss of containment that may occur due to corrosion, material defects and third party damage from ship anchor drops/drags. Based on a review of the hazards, the marine traffic density and pipeline rock armour protection, the 38km proposed route was divided into twelve sections for assessment. Risks have been presented for each section on a per-km basis to provide a uniform basis for comparison.

The base case calculation used marine traffic data for 2011 and levels of rock armour protection for each section as proposed in the pipeline design.

The calculated levels of risk were compared with the HK EIAO and the following conclusions were drawn:

- The FN curves for all sections of the pipeline lie within the *Acceptable Region*.
- The highest risks are generally associated with the Adamasta Channel and Urmston Road where the marine traffic has the highest density.
- IR for all sections are predicted to be less than the 1×10^{-5} per year as per HK EIAO criterion.

Future Marine Traffic Scenarios

For the future 2021 "No Tonggu" case, a 15% increase in marine traffic is expected compared to 2011. This increased the risks marginally. The FN curves still lie within the *Acceptable Region*. The IR is also below the 1×10^{-5} per year as per HK EIAO criterion.

The future 2021 "with Tonggu" scenario redirects a significant number of ocean-going vessels from Urmston Road to the Adamasta Channel. This increases the risk in Adamasta Channel but values are still in the *Acceptable Region*. The IR remains below the 1×10^{-5} per year as per HK EIAO criterion.

It is concluded that for all sections, the risks are acceptable per HK EIAO and no further mitigation measures are warranted.

SUB-SECTION 4: GAS RECEIVING STATION (GRS)

The proposed pipeline from South Soko to Black Point Power Station (BPPS) will terminate at the gas receiving station (GRS) which will be located at the BPPS site. The gas is filtered, heated and letdown to 39 bar for delivery to the generation units.

This section presents the QRA results for the GRS.

13.13 METHODOLOGY

As explained in *Section 3.3.4* of the EIA report, the GRS will contain a pig receiver, inlet filter-separators, metering, pre-heaters and a pressure letdown station. An emergency shutdown valve will be provided at the inlet to the station and also for individual section isolation in the event of any emergency. Preliminary site layout for the GRS along with Process Flow Diagrams and stream details are included in *Annex 13C*.

The methodology for the QRA of the GRS is similar to that adopted for the LNG terminal. The LNG terminal also contains sections of high pressure gas piping (downstream of the vaporizers) which are similar in design to the gas piping in the GRS. The LNG terminal contains submerged combustion vaporizers which are broadly similar to the pre-heaters proposed in the GRS.

The hazards associated with the GRS are mainly accidental releases from the high pressure gas piping. Upon ignition of this flammable gas, this may lead to a jet fire and/or flash fire.

The main population in the vicinity of GRS is the marine traffic along Urmston Road. Details are included in *Annex 13C.*

Meteorological data for the GRS is obtained from the Sha Chau Weather Station. The details on meteorological data, frequency and consequence parameters are included in *Annex 13C*.

13.14 RISK RESULTS AND CONCLUSION

13.14.1 Individual Risk Results

The individual risk is less than 1×10^{-5} per year everywhere on site and at the site boundary, and hence meets the HKRG requirements.

13.14.2 Societal Risk Results

The potential loss of life for the gas receiving station is given in *Table 13.14*. There is essentially no change between 2011 and 2021 and values are very low given the low population in the vicinity. The total PLL is 2.8×10^{-8} per year, or equivalently, one fatality every 35 million years.

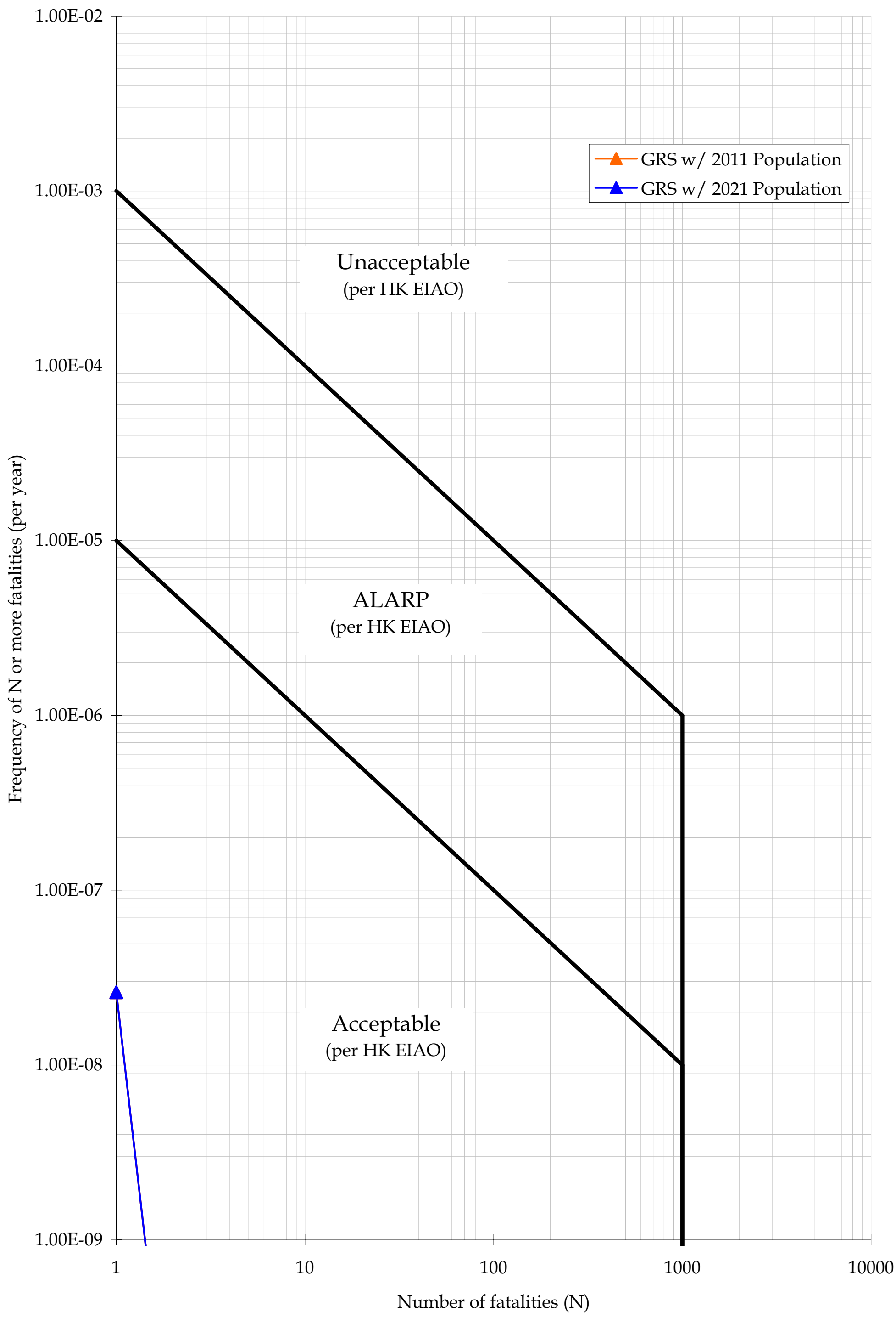
Table 13.14 ***GRS Potential Loss of Life***

Section		**2011 (per year)**		**2021 (per year)**	
G2	Gas heater piping	1.5×10^{-8}	54%	1.5×10^{-8}	54%
G1	Gas piping from shutdown valve through gas filter to control valve	7.5×10^{-9}	27%	7.5×10^{-9}	27%
G3	Pressure control assembly	5.0×10^{-9}	18%	5.0×10^{-9}	18%
	Total	2.8×10^{-8}		2.8×10^{-8}	

Figure 13.14 shows the FN Curve for the GRS at the BPPS. The curves are similar for Year 2011 and Year 2021.

It can be seen that the societal risk for the GRS is within the *Acceptable Region* as per HK EIA Ordinance.

Figure 13.14 FN Curve for GRS, Year 2011 and 2021



REFERENCES

[1] BMT Asia Pacific Ltd, Marine Impact Assessment for Black Point & Sokos islands LNG Receiving Terminal & Associated Facilities, Pipeline Issues, Working Paper #3, Issue 6, May 2006.

[2] Crossthwaite, P.J., Fitzpatrick, R.D. & Hurst, N.W., Risk Assessment for the Siting of Developments Near Liquefied Petroleum Gas Installations, IChemE Symposium Series No 110, 1988.

[3] 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.

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

[5] Guidelines for Quantitative Risk Assessment – Purple Book, 1st Edition, Committee for the Prevention of Disasters, 1999.

[6] PARLOC 2001: The Update of Loss of Containment Data for Offshore Pipelines, 5th Edition, Health & Safety Executive, 2003

[7] Hydrographic and geophysical Survey for Proposed LNG Terminal, Final Survey Report, EGS Earth Sciences & Surveying, 2005.

SUB-SECTION 5: BLACK POINT AND SOUTH SOKO LNG TERMINAL MARINE QUANTITATIVE RISK ASSESSMENT

DNV CONSULTING

Black Point and South Soko LNG Import Marine Quantitative Risk Assessment :

Report for Castle Peak Power Company
Report no.: 70015462
Rev 13, December 08 2006

MANAGING RISK

Black Point and South Soko LNG Import Marine Quantitative Risk Assessment

for

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Report No.: 70015462

Subject Group: HSE, QRA

Summary: Castle Peak Power Company, which is a joint venture between CLP Power Hong Kong Limited and ExxonMobil Energy Limited, is planning to develop an LNG Terminal in Hong Kong. Two sites are being considered: Black Point and South Soko.

DNV has been commissioned to carry out a Marine Quantitative Risk Assessment (MQRA) for the transit of the LNG carrier for both options, as part of the requirements of the Environmental Impact Assessment (EIA) stipulated by the Government of Hong Kong.

This document presents the results of the MQRA which indicate that the risk levels associated with the transit of LNG to both sites fall within the acceptable limits specified in the Hong Kong EIA ordinance when mitigation measures are applied.

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Date of issue: December 08 2006

Project No: 70015462

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Contents:

1.0 Introduction

Castle Peak Power Company Limited (CAPCO), a joint venture between CLP Power Hong Kong Limited (CLP) and ExxonMobil Energy Limited (EMEL), is planning to develop a Liquefied Natural Gas (LNG) Receiving Terminal in Hong Kong. Two sites are under consideration: a site at Black Point and one at South Soko.

Det Norske Veritas (DNV) has been commissioned to carry out a Marine Quantitative Risk Assessment (MQRA) for the LNG carrier transit associated with both options, as part of the requirements of the Environmental Impact Assessment (EIA) stipulated by the Government of Hong Kong.

2.0 Study Approach

A Marine Quantitative Risk Assessment (MQRA) has been conducted for Hong Kong to determine the risks to land-based and marine populations along the carrier routes. This analysis is based upon site specific assumptions and the methodology has been developed to comply with the requirements of the Hong Kong government. These risks are then compared to the Hong Kong EIA Ordinance (EIAO) risk criteria. The Hong Kong EIAO risk criteria exist for both Societal Risk and Individual Risk as presented in Annex 4 of the Technical Memorandum on Environmental Impact Assessment Process (ref. 01). The Hong Kong EIAO Societal Risk criteria are illustrated in Figure 2-1, displaying the Acceptable, ALARP (As Low As Reasonably Practicable), and Unacceptable criteria regions. The Hong Kong EIAO Individual Risk criterion is $1x10^{-5}$ per year, for the maximum offsite individual risk. This MQRA is conducted in compliance with the Study Brief entitled "ESB-126/2005 Liquefied Natural Gas (LNG) Receiving Terminal and Associated Facilities" dated June 2005 (ref. 02).

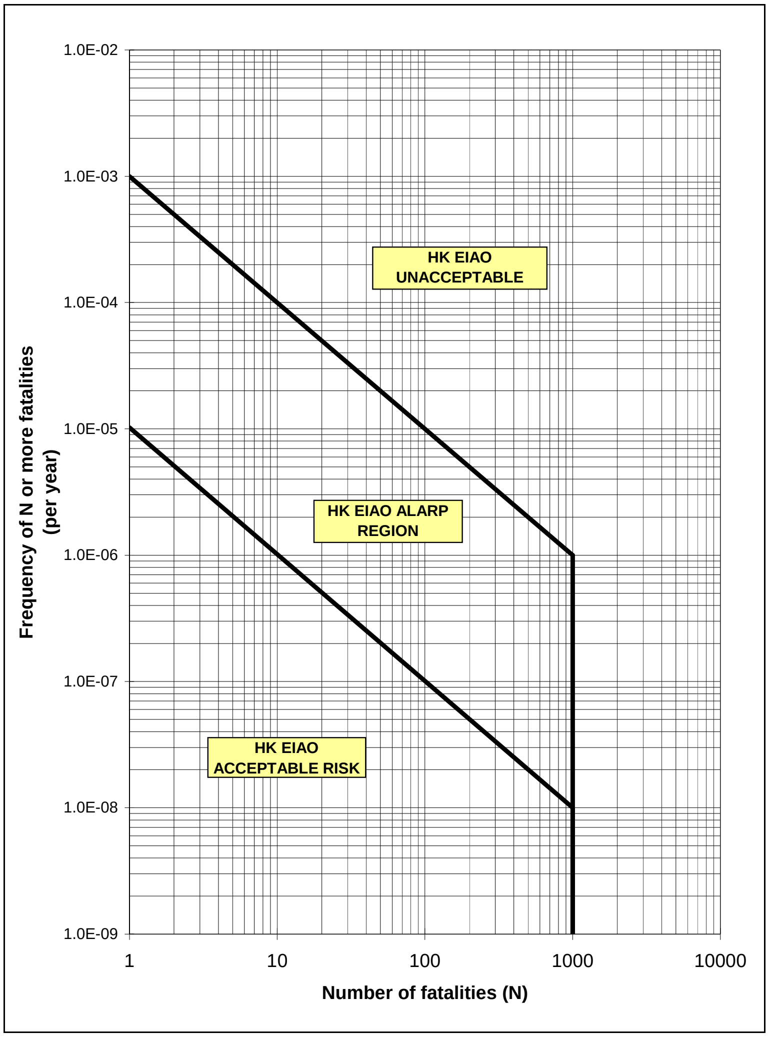


Figure 2-1 Hong Kong EIA Ordinance Societal Risk Criteria

The MQRA methodology involved four main components – scenario identification, release frequency analysis, consequence analysis and risk assessment.

2.1 Scenario Identification

The purpose of this phase was to determine the scenarios that should be included in the MQRA analysis. A Hazard Identification (HAZID) workshop was facilitated and recorded by DNV on 14 November 2005 to develop the list of potential scenarios. Representatives from CAPCO, BMT Asia Pacific Limited and Hong Kong pilots participated in the HAZID process. The team strove to identify all potential hazardous scenarios based on the transit route and the Hong Kong environment.

These potential accident scenarios were grouped into hazard categories and further evaluated to identify which scenarios could credibly lead to a release of the LNG cargo. It is the potential loss of cargo containment and subsequent consequences that pose a potential hazard to life. These “credible scenarios” were then carried forward into the MQRA.

"Credible scenarios", as hereinafter referred to, shall include all scenarios that were determined to potentially result in an off-site fatality and have a probability greater than or equal to $1x10^{-9}$ per year. When a scenario is referred to as "non-credible" or "not credible", this shall hereinafter mean that the scenario would either result in no fatalities, or the probability was determined to be less than $1x10^{-9}$ per year, and therefore falls below the lower bound of the EIAO and Annex 4 of the TM criteria. The credible accidental scenarios that could lead to potential LNG cargo loss are grounding and collision of the LNG carrier.

The risks from potential intentional acts were analyzed through a Security Assessment that was conducted in April 2006 (ref. 03). The approach of conducting this Security Assessment separate from the MQRA was supported by the Hong Kong Security Bureau. It followed a recognized risk assessment methodology, included a multi-disciplinary team, and addressed the risk in a qualitative manner. A quantitative assessment approach was not considered viable given that the frequency of intentional act scenarios could not be defensibly quantified. The Security Assessment results indicated no intentional acts led to risk levels that would compromise the project. Potential risk mitigation measures were identified and will be progressed as the Project details are developed.

Review of the LNG carrier hazard zone impact on the Black Point Power Plant, Castle Peak Power Station in Tap Shek Kok, Permanent Aviation Fuel facility, Eco Park and future CRC LPG terminal show that with the carrier transiting its normal route, the hazard zones do not impact these areas.

2.2 Release Frequency Analysis

Hong Kong harbor marine traffic simulations were conducted by BMT to predict the collision and grounding frequencies for the LNG carrier along the routes and at the berths at Black Point and South Soko.

The traffic and navigation environment of the LNG carriers during approaches impacts the key hazards of collision and grounding risk. As such they are very site specific, and related to the particular characteristics of the waterways within Hong Kong. For this reason, it was inappropriate to develop the risks on the basis of world-wide data and these risks have not been explicitly examined, except as they were specifically relevant to this particular study. Three separate approaches were taken:

- Collision Risk – marine traffic simulation
- Grounding Risk – review of local historic incidence for large vessel transits.
- Collision at Berth - review of local historic incidence for grounding of large vessel transits and its extension to address berth vulnerability.

Collision risk was developed through the application of BMT's "DYMITRI" (Dynamic Marine Traffic Simulation) risk model. The model has been extensively applied in Hong Kong, Singapore and Korea, and represents each vessel as an autonomous agent within the model, constantly scanning the water space ahead of its intended course. Should another vessel be navigating on a course with the potential to cause a collision, avoidance maneuver is taken. The number and nature of avoiding actions have been identified as directly proportional to the frequency of collision incidents.

This model was developed from a foundation of vessel route structures and speed profiles developed during an extensive investigation for Marine Department conducted in 2003 (http://www.mardep.gov.hk/en/publication/pdf/marars.pdf). Traffic levels were benchmarked for 2003 levels and forecast to 2011 and 2021 on the basis of anticipated port developments and cargo flows, and new vessel routes. Marine traffic activity associated with vessels of length (LOA) greater than 75m were represented in the model, having identified that smaller vessels than that would not be able to generate sufficient collision energy to hazard a cargo release.

Prior to use, the model was validated against data covering the last 5 years so that confidence could be held in its use for predictive purposes. The LNG carriers were then introduced into the marine traffic simulation for all arrivals associated with daylight transits; in total almost 25 years of operation were simulated in order to develop a robust data base from which collision frequency predictions could be made.

Each interaction of a vessel within the traffic model and the LNG carrier was recorded, covering the nature of the vessel, its speed, size (displacement), and heading. The energy that could be transferred to an LNG carrier, should a collision occur, was then calculated. The frequency of events that may lead to high energy collisions was captured and used to develop the key frequency input for releases modeled by DNV.

The anticipated grounding rates for LNG carriers during transit to the berth has been developed from a review of historic incidents in Hong Kong waters associated with vessels over 200m LOA. This has allowed the identification of the historic grounding risk on a per vessel, per km basis. This result has been used to develop the baseline risk for LNG transits that has been developed for the 2011 and 2021 timeframes, while including allowance for the multiple tug escorts that will be associated with the carrier arrivals.

The collision at berth analysis has been based on the frequency of vessels that run aground in the vicinity of the proposed LNG terminal, and the identification of the risk associated with a wayward vessel diverting from its course to such an extent that it creates hazards to the LNG carrier at the jetty. Base frequencies have been developed from historic data, and developed for the 2011 and 2021 time frames.

2.3 Consequence Analysis

The consequence of the potential groundings and collisions was calculated by DNV using PHAST V6.51 (Process Hazard Analysis Software Tool). PHAST is the consequence module of the SAFETI (Suite for Assessment of Flammable, Explosive, and Toxic Impact) software package, and is the most widely used consequence modeling software in the oil and gas industry. The parameters and assumptions that might affect the MQRA conclusions are presented in table form in Appendix I.

SAFETI was then used to combine the consequences with data about population, weather conditions and ignition sources to determine the potential impact of the credible scenarios.

2.4 Risk Assessment

SAFETI was used to calculate the individual risk contours and societal FN curves based on the consequence and release frequency analyses. These risk calculations took into account the population, weather and ignition data to determine the overall risk which was compared to the Hong Kong EIA Ordinance (EIAO) risk criteria.

Results were analyzed in order to determine the main contributors to risk, including the most potentially affected populations and key route segments.

3.0 Scenario Identification

3.1 LNG Transport Route

Table 3-1 and Figure 3-1 present the LNG carrier transit routes to the Black Point and South Soko sites. An alternative approach to Black Point via the western side of Lantau Island was not considered due to insufficient water depth to accommodate the LNG carrier draft requirement. Although a project to dredge the Tonggu Channel to a sufficient depth to accommodate the LNG carrier has been speculated, there remains sufficient uncertainty associated with the Tonggu Project venture that it cannot be included as a viable alternative in a project basis at this time. However, given the potential for the Tonggu Waterway, it has been included in the MQRA as a variation in the marine traffic data set as identified in Section 4.1.

Table 3-1 LNG Transit Carrier Route Segments

BLACK POINT ROUTE	
Name	**Description**
BP7	From the point where the LNG carrier enters Hong Kong waters to the end of BP6, 10.17 km along the carrier transit route
BP6	7.51 km from end of BP5 along the carrier transit route
BP5	7.32 km from the end of BP4 along the carrier transit route
BP4	7.31 km from the end of BP3 along the carrier transit route
BP3	7.39 km from the end of BP2 along the carrier transit route
BP2	7.51 km from the end of BP1 along the carrier transit route
BP1	To Black Point terminal, 7.42 km along the carrier transit route
SOUTH SOKO ROUTE	
Name	**Description**
SK4	From the point where the LNG carrier enters Hong Kong waters to the end of SK3, 12.59 km along the carrier transit route
SK3	7.42 km from the end of SK2 along the carrier transit route
SK2	9.43 km from the end of SK1 along the carrier transit route
SK1	To South Soko terminal, 8.90 km along the carrier transit route

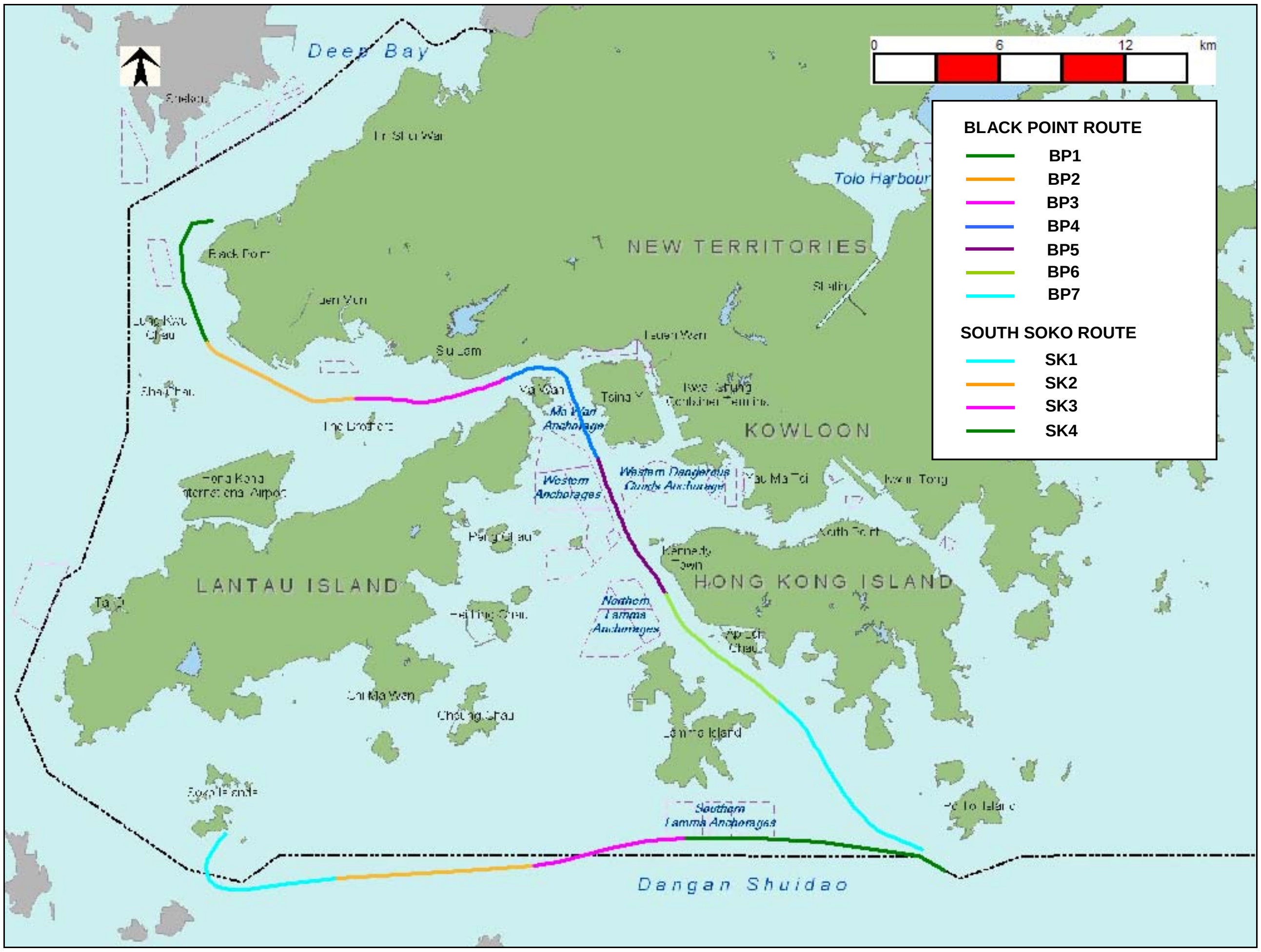


Figure 3-1 LNG Shipping Routes to Black Point and South Soko Terminals

The MQRA modeled arrivals at Black Point and South Soko for two sizes of LNG carrier. Per the project design basis, the MQRA assumes the day-time only passage of the LNG carrier in Hong Kong waters. Two tugs will be in attendance at the LNG carrier's arrival into Hong Kong waters and boarding of local Pilot, with an additional two tugs joining the carrier as it enters the harbor and transits onwards around Ma Wan (for Black Point), and prior to the final approach (for South Soko).

3.2 LNG Carrier Design

The study was based on two sizes of LNG carrier of the membrane design with five cargo tanks. Fifty-one arrivals per year were considered for a class of 215,000 m^3 carrier (maximum cargo tank size of 43,000 m^3). Seventy-five arrivals per year were modeled for a smaller 145,000 m^3 LNG carrier (maximum cargo tank size 29,000 m^3). Modeling five cargo tanks maximizes the typical potential inventory of one tank, thereby using a conservative approach. Where referenced in the document, 215,000 m^3 represents "Large Carrier", and 145,000 m^3 represents "Small Carrier".

The typical safeguards that are present in LNG carrier design and operation are as follows:

- Design in accordance with International Gas Carrier regulations and classification requirements
- Double hull and double bottom
- Forward collision bulkhead
- Independent separated cargo area (five tanks)
- Cargo tanks located away from the engine room
- Slow speed diesel engines – engine contingency
- Double wall piping for fuel supply lines in engine room
- Double wall bunker oil tank
- Water spray on deck and sides of carrier
- Fire protection
- Maximum transit speed of 4 – 12 knots within HK waters
- Two pilots on board
- Tug assist (as described previously)

In the history of LNG shipping, LNG carriers have rarely been involved in collisions and groundings and none of these collisions and groundings led to a breach of an LNG tank. Because of the design of LNG carriers (e.g. double hulls), breach of containment from a collision is a risk only if an LNG carrier collided with another vessel of a large enough size, going at or above a certain speed and striking the LNG carrier at a specific angle. In summary, collisions and groundings involving an LNG carrier are expected to be very rare events and collisions and groundings that lead to the piercing of two hulls and the tank walls of an LNG carrier are expected to be even rarer.

3.3 Modeled Release Hole Sizes

The HAZID workshop and subsequent evaluation identified that a collision or grounding of the LNG carrier could potentially lead to a potential breach of cargo containment and should be considered credible scenarios. The release sizes selected for modeling are 250mm small releases, 750mm medium releases and 1500mm large releases. This approach is in line with recent LNG studies carried out by Sandia National Laboratories and DNV (ref. 04, 05). It is also in line with other DNV LNG studies that have been carried out the world over.

The maximum hole size from DNV (ref. 05) is 1500mm which is an equivalent hole area of 1.8m^2 which is defined as the maximum credible event predicted by the International Maritime Organization (IMO) and operational experience. The Sandia report (ref. 04) defines the credible scenario for high speed collisions to be up to 1.5m^2. By applying the DNV maximum credible hole size, a conservative approach is taken.

The following energy thresholds were used in the MQRA to determine consequence hole sizes:

- E0 = Range of penetration energies to cause a hole in carrier's outer hull = 1.4 to 99 MJ
- E1 = Range of penetration energies to cause 250mm hole = 100 to 110 MJ
- E2 = Range of penetration energies to cause 750mm hole = 111 to 150 MJ
- E3 = Range of penetration energies to cause 1500mm hole = more than 150 MJ

4.0 Release Frequency Analysis

Section 4.0 was provided by BMT.

4.1 Collision Analysis

In the 40 year history of LNG carrier operations, there have been no recorded incidents of a cargo release due to a collision, or prior experience with such vessels transiting Hong Kong waters. Therefore, in order to develop a valid basis for future prediction of local LNG carrier collision risk and release frequency, it was first necessary to develop a model that could accurately represent the "genus" of LNG carriers; i.e. large ocean-going vessels transiting within Hong Kong waters. The specific circumstances required to develop a loss of containment from an LNG carrier could then be applied following identification of the base frequencies.

BMT's *DYMTRI* (Dynamic Marine Traffic simulation) model was adopted as the platform for the traffic simulation having been widely applied in Hong Kong, in particular the 2003 territory-wide "MARA Study" (www.mardep.gov.hk/en/publication/pdf/marars.pdf). The model is a numerical simulation whereby vessels transit along prescribed routes and identify key data associated with any vessel encounter situations where an avoidance maneuver is required. Extensive application and validation has identified that a clear link can be established between the frequency of encounters (opportunities for a mistake to be made) and collisions (events where a mistake has been made).

The key steps associated with assessment are outlined below:

- **Identification of Baseline Traffic** – All vessel activity associated with ships with Length (LOA) greater than 75m, and transits within 2.5km of the LNG carrier route were extracted from the MARA database of radar records, and full-year statistics for 2003 verified to ensure a comprehensive representation of traffic activity at that timeframe. Traffic data were organized into a series of representative routes with a variety of ship classes.
- **Hazard Identification** – The distribution of collision incidents within fairways for all "ocean-going" vessels with LOA > 75m was mapped for Hong Kong Special Administrative Region (HKSAR) waters for a 5 year period.
- **Model Validation** – The model was run for the 2003 traffic activity, and the linkage between model output of "encounters" and historic collisions within fairways (as applicable to LNG carrier transits) confirmed.
- **Traffic Forecasts** – An extensive forecasting exercise was conducted, with particular focus on large ocean-going vessels. "Stochastic" forecast techniques were adopted so that a representative upper-bound scenario could be developed for the 2011 and 2021 timeframes. Key elements considered included:
  - Historic Cargo Trends and Traffic Growth
  - HK Port Master Plan 2020 Study Cargo Forecasts
  - LOA Distribution of Ocean-going Vessels (World-wide, Hong Kong and Shenzhen)
  - Ocean-going and Rivertrade Passenger Vessel activity
  - Non-Container Ocean-going Traffic Forecasts
  - Future Marine Facilities including :
    - Tonggu Waterway
    - Container Terminal 10 (CT10)
    - Local terminals (i.e. Permanent Aviation Fuel Facility, CRC LPG berth at Tsing Yi)

- **Scenario Development** – A series of scenarios "A" to "J" were developed to examine traffic activity at 2011 and 2021 taking into account the presence and location of the Tonggu waterway (which has the potential to divert future traffic growth at Ma Wan away from Hong Kong waters, and CT10 at either Tsing Yi or NW Lantau). The scenarios adopted for consequence examination were those that considered the initial operation of the terminal in 2011, and a span of traffic possibilities for 2021:
  - 2011C – Year 2011, no CT10, or Tonggu Waterway
  - 2021E – Year 2021, no CT10, or Tonggu Waterway
  - 2021F – Year 2021, no CT10, includes Tonggu Waterway
- **Collision Frequency Assessment** – The *DYMITRI* model was run for all scenarios with the LNG carrier introduced into the simulation almost 2,000 times in order to ensure that transits were conducted across the full spectrum of daylight arrivals, and providing the LNG carrier the opportunity to interact with all ships within the traffic "mix". The following key data were output:
  - Anticipated collision location
  - Vessel details, including:
    - Route and vessel class identifier
    - Vessel speed at point that avoidance maneuver is initiated
    - Vessel headings & encounter type (i.e. Overtaking, Crossing, or Headings)
    - Encounter Time.
- The collision data was then processed to ensure that local marine traffic regulations (such as one-way traffic for large Ocean-going vessels within the Ma Wan Channel) were being correctly implemented. The encounter data were rationalized and the total collision frequency identified on a per transit basis, for each individual route segment.
- **Collision Energy Distribution** – Having identified the collision frequency associated with the LNG carrier transit (which at this stage was representative of the transit of any large vessel), it was then necessary to characterize the collision energy associated with each encounter. The detailed data extracted for scenarios C, E & F took account of:
  - The colliding vessel's displacement (assuming an upper-bound envelope of vessel size)
  - The potential for the vessels to collide at a series of angles deviated from the initial encounter angle
  - Impact energy absorbed by the colliding vessel during collision with the double hulled LNG carrier
  - Nominal reduction in speed by the colliding vessel prior to impact
  - Perpendicular penetration energy component into the LNG carrier hull.
- **Vessel Size Modification** – The Model Validation had been conducted on the basis of average traffic activity and collision incidents. Review of the historic record identified that larger vessels (such as the LNG carriers) were relatively safer - undoubtedly encompassing a number of factors such as Pilotage and Vessel Traffic Control. A safety factor of at least 2 was assumed for large vessel transits based on worldwide data. Further analysis would be required to demonstrate the appropriate safety factor adjustment for Vessel Size that would be applicable to specific characteristics of Hong Kong harbor.
- **Impact Frequency on LNG Containment** –The geometry of an LNG carrier is such that cargo tanks are not located along the entire length of the carrier. There is space in the bow and the stern as well as between the tanks. If a collision were to occur in a location not occupied by a cargo tank, then no loss of containment will result. Having identified the impact frequency on a large vessel transiting the LNG carrier's route the frequency of impact on an LNG containment tank was developed with reference to this tank geometry and location.

- **Safety Zone Implementation** – The impact of safety zones around the carrier was investigated by examination of the removal of close-quarters risk, and the increase in average stand-off distances to a collision. A safety factor in the order of at least 10 was identified.

Each encounter event was reported with a frequency-energy couple allowing the cumulative frequency of different energy thresholds to be assessed, on a per transit basis, for each route segment. These data were then carried forward by DNV in their analysis.

4.2 Grounding Analysis

The anticipated grounding rates for LNG carriers during transit to the berth have been developed from a review of historic incidents in Hong Kong waters associated with vessels over 200m LOA. This has allowed the identification of the historic grounding risk on a per vessel, per km basis.

This result has been used to develop the baseline risk for LNG transits that has been directly applied to the 2011 and 2021 timeframes, with a nominal and conservative improvement factor of 2.0 to account for the escort of up to four tugs that will be associated with the carrier arrivals.

4.3 Berth Collision Analysis

The collision at berth has been based on the frequency of vessels that run aground in the vicinity of the LNG terminal, and the identification of the risk associated with a wayward vessel diverting from its course to such an extent that it hazards the LNG carrier at the jetty. Base frequencies have been developed from historic grounding data and directly applied to the 2011 and 2021 traffic environment and time frames.

5.0 Consequence Analysis

5.1 Modeling Hole Sizes

The hole sizes modeled in the MQRA are summarized in Table 5-1.

Table 5-1 Hole Sizes Used in the MQRA

Scenario	Release Hole Diameter	Equivalent Release Size in Area	Location
Small	250 mm	0.05 m^2	Above and Below waterline
Medium	750 mm	0.4 m^2	Above waterline
Large	1,500 mm	1.8 m^2	Above waterline

5.2 Potential Consequences and Impact

The more likely outcome of an LNG release, especially given that the main cause of such a leak would be a ship collision involving friction and heat, is that the release ignites immediately. No gas cloud would be anticipated, but the pool fire grows on the sea surface to its sustainable size. The sustainable size is governed by the balance between the rate at which the LNG is vaporized and the rate at which the fire consumes the vapor.

In the unlikely event of an unignited LNG release onto the sea's surface, temperature differential will cause the LNG to vaporize and form a natural gas cloud. The cloud of natural gas that is initially formed is cold and heavier than air. The gas warms up and the vapor cloud disperses downwind. Regions in the cloud that are within the flammability limits of natural gas may then come into contact with an ignition source, ignite, and form a flash fire. This fire would then burn back to the LNG pool, ignite the pool and form a pool fire. This will be a thin pool, due to gravitational spreading, which cannot sustain the initial burning rate for long, and the pool diameter will shrink to a sustainable size (ref. 06).

Although such a fire is a highly unlikely scenario, the potential human impact of concern is thermal radiation impact. For pool fires, personal injury due to heat radiation is determined by the radiation exposure level and duration. A probit equation was used to calculate the probability of fatality from the thermal exposure. For flash fires, a vulnerable person located within the flash fire envelope (as defined by 0.85 times the Lower Flammability Limit (LFL) extent of the gas cloud) is assumed to be fatally injured.

Vulnerability parameters were used to calculate the fraction of potential fatalities among the people exposed to various types of hazardous events at a certain location. Indoor and outdoor populations have different vulnerability fractions depending on the degree of protection provided by buildings and other shielding. In addition, the vulnerability fraction varies for whether the hazard is a flash fire or pool fire.

The complete list of parameters and fundamental assumptions that might affect the MQRA conclusions is presented in table form in Appendix I.

5.3 Consequence Results

The consequence hazard results produced by the modeled cases along the transit routes for two carrier sizes are presented in Table 5-2. The results consist of distances to the 0.85 LFL and LFL concentrations of the vapor cloud along with the pool fire diameter and distance to thermal radiation hazard levels. The largest dispersion consequence distance for the scenarios generally occurs with F2m/s or D7m/s weather conditions. The largest thermal radiation consequence distance occurs with the D7m/s weather condition.

Table 5-2 Consequence Hazard Results

Carrier	Accident	Release Size	Weather Condition	Distance (m)		Pool Diameter (m)	Radiation (m)		
				0.85 LFL	1.0 LFL		5 kW/m^2	12.5 kW/m^2	35 kW/m^2
Small Carrier	Collision	Small	B2.5	197	168	28	179	120	61
			F2.0	431	255	28	176	115	58
			D3.0	283	229	28	181	124	64
			D7.0	318	273	28	192	138	81
		Medium	B2.5	402	326	83	419	277	144
			F2.0	581	258	83	412	266	136
			D3.0	623	469	83	424	285	151
			D7.0	748	624	83	448	317	192
		Large	B2.5	641	502	167	708	464	244
			F2.0	2187	1217	167	696	449	232
			D3.0	1119	811	167	717	478	256
			D7.0	1269	1009	167	755	534	324
	Grounding	Small	B2.5	139	119	23	150	99	48
			F2.0	157	70	23	147	95	45
			D3.0	216	170	23	151	103	51
			D7.0	212	183	23	161	115	65
Large Carrier	Collision	Small	B2.5	203	172	28	183	122	62
			F2.0	446	265	28	180	117	59
			D3.0	281	223	28	185	126	65
			D7.0	324	275	28	195	140	83
		Medium	B2.5	401	323	85	426	281	146
			F2.0	590	261	85	419	270	138
			D3.0	680	522	85	432	290	154
			D7.0	751	621	85	456	323	195
		Large	B2.5	652	510	170	720	472	249
			F2.0	1716	817	170	708	456	236
			D3.0	1144	829	170	729	485	260
			D7.0	1287	1023	170	769	545	331
	Grounding	Small	B2.5	145	121	24	156	103	50
			F2.0	170	75	24	153	99	47
			D3.0	225	177	24	157	107	53
			D7.0	220	190	24	167	119	68

5.4 Potential Tsing Ma Bridge Impacts

The Tsing Ma Bridge links Tsing Yi Island on the east to Ma Wan Island on the west over Ma Wan Channel. The risk to the population crossing the bridge has been considered in the risk calculations. The consequence impacts to the bridge structure itself are the topic of this section.

It is a suspension bridge with two deck levels and carries both road and railway traffic. There are two towers with one located on Wok Tai Wan on the Tsing Yi side and the other on a man-made island 120 meters from the coast of Ma Wan Island. Since both towers are located on land, it is not possible for the LNG carrier to collide with the bridge towers. Both towers are comprised of two legs constructed with high strength concrete. The decks are constructed of steel.

The scenario that may impact the bridge is an LNG pool fire due to grounding of an LNG carrier or LNG carrier collisions. The grounding and collision scenarios are analyzed through fire consequence modeling. For the potential pool fire caused by grounding scenario, the flame height is not of sufficient height to reach the bridge lower deck as defined by the shipping clearance of the bridge. Thus, the bridge is not expected to be exposed to direct flame impingement. The potential damage on the bridge is assessed based on thermal radiation calculation and structure damage analysis. Some assumptions are made in the assessment due to the lack of the information on bridge structure. The analysis results show that the thermal radiation caused by the pool fire is not high enough to cause the lower deck of the bridge to reach its failure temperature. Therefore, the bridge could not be structurally damaged by the potential pool fire caused by grounding of an LNG carrier.

The potential damage of the pool fire caused by LNG carrier collisions is assessed in the same way. For the pool fire caused by small collision scenario, the bridge is not expected to be exposed to direct flame impingement, but the thermal radiation of the pool fire could cause the lower level of the bridge reach its failure temperature after 1.6 hours exposure to the pool fire. For the potential pool fire caused by medium or large collision scenario, the flame height is assessed to be higher than the clearance height of the bridge, and the direct flame impingement would cause the lower level of the bridge to reach its failure temperature in a short time.

The nature of large LNG pool fire flame has not been explored completely, and some conservative assumptions are made in the flame height and thermal radiation calculations; thus, the assessment on bridge damage must be viewed as conservative and further analysis would be required to fully evaluate the potential risks to the Tsing Ma bridge. Further details regarding the potential impact to the Tsing Ma Bridge are presented in Appendix III.

6.0 Risk Assessment Results

The MQRA determined the risks to land-based and marine populations along the LNG carrier routes based on the consequence and release frequency analyses. The risk assessment results are presented in terms of Individual Risk and Societal Risk.

Every quantitative answer contains some level of uncertainty associated with its result. For the risk assessment results presented in the following section, the uncertainty is contributed to by the frequency analysis, consequence hazard modeling and risk analysis. Considering many factors contribute to the uncertainty, accurate quantification of the uncertainty would be impractical. However the conservative modeling and approaches within the analysis counteract any possible under prediction of the risks.

6.1 Individual Risk

Individual Risk (IR) is expressed as a line of equal risk or iso-risk contours, shown on a map. The contour is a combination of risks from all credible scenarios identified for the project.

IR contours indicate the probability of potential fatality for an individual situated along the risk contour continuously (24 hours a day, 7 days a week) for a year. The contours are marked in decades starting from a risk level of $1x10^{-7}$ per year (one fatality per 10 million years). For example, a person situated on the $1x10^{-7}$ IR contour will be potentially exposed to fatal accidents once per 10 million years. If no risk contour appears for part of the transit route, it implies that the maximum individual risk from this part of the transit route is less than $1x10^{-7}$ per year. While individual risk contours are traditionally used in risk analysis, it should be kept in mind that they are most useful as a comparison tool only as it is very unlikely that any individual would remain in a single location for a whole year.

This “large carrier case” and “small carrier case” used extensively hereafter are defined in Section 3.2. In all cases, for both terminal locations and for the traffic scenario at 2011 and two cases at 2021, the individual risk levels are under the individual risk criteria set out in Annex 4 of the Hong Kong EPD Technical Memorandum on the Environmental Impact Assessment Process (ref. 01), which is a level of 10^{-5} per year (one in 100,000 years).

6.1.1 Black Point Transit Route

The large LNG carrier case individual risk results for the Black Point terminal location are presented in Figure 6-1, Figure 6-2, and Figure 6-3 for 2011C, 2021E, and 2021F, respectively. The small LNG carrier case individual risk results for the Black Point terminal location are presented in Figure 6-4, Figure 6-5, and Figure 6-6 for 2011C, 2021E, and 2021F, respectively. The results show that the $1x10^{-6}$ per year and $1x10^{-7}$ per year IR contour are displayed and thus $1x10^{-6}$ per year is the highest IR risk level for the Black Point route. This is one order of magnitude below the Hong Kong EIAO individual risk criteria.

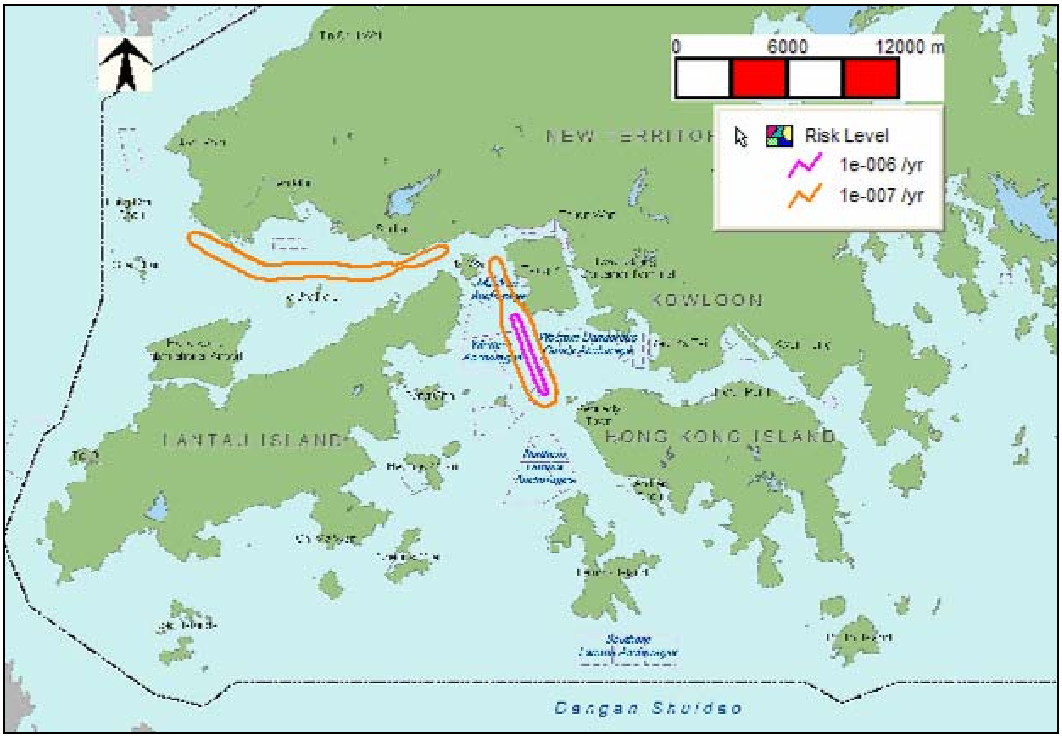


Figure 6-1 IR Contour of Black Point Route, 2011C (Large Carrier)

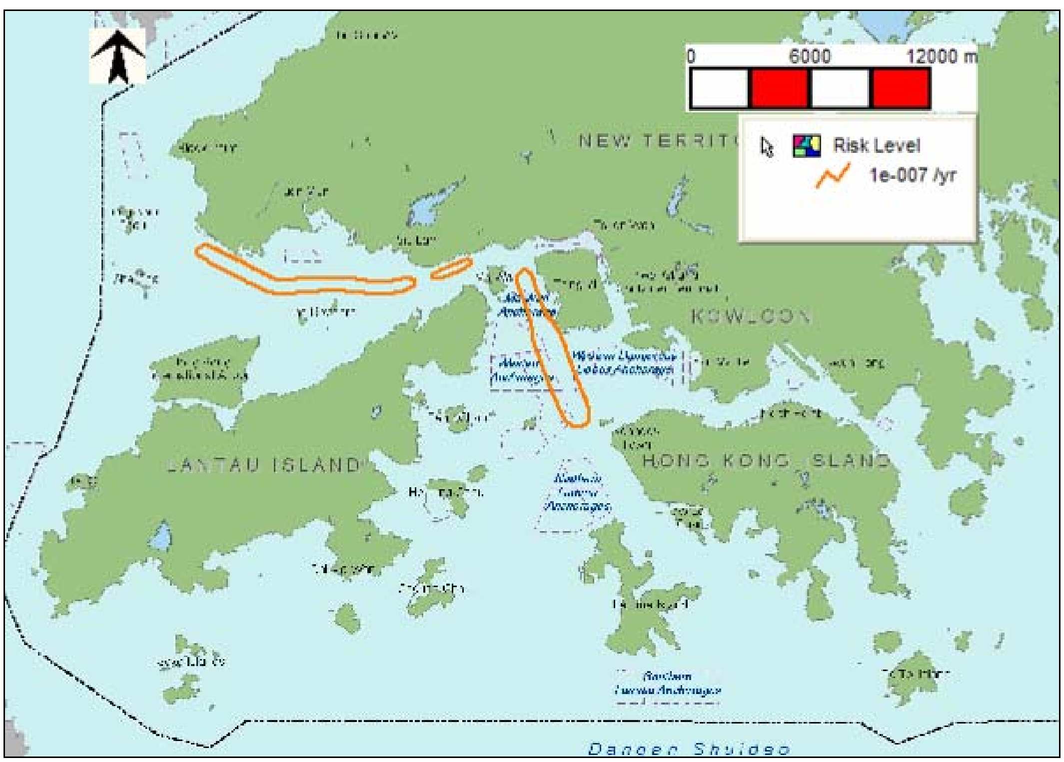


Figure 6-2 IR Contour of Black Point Route, 2021E (Large Carrier)

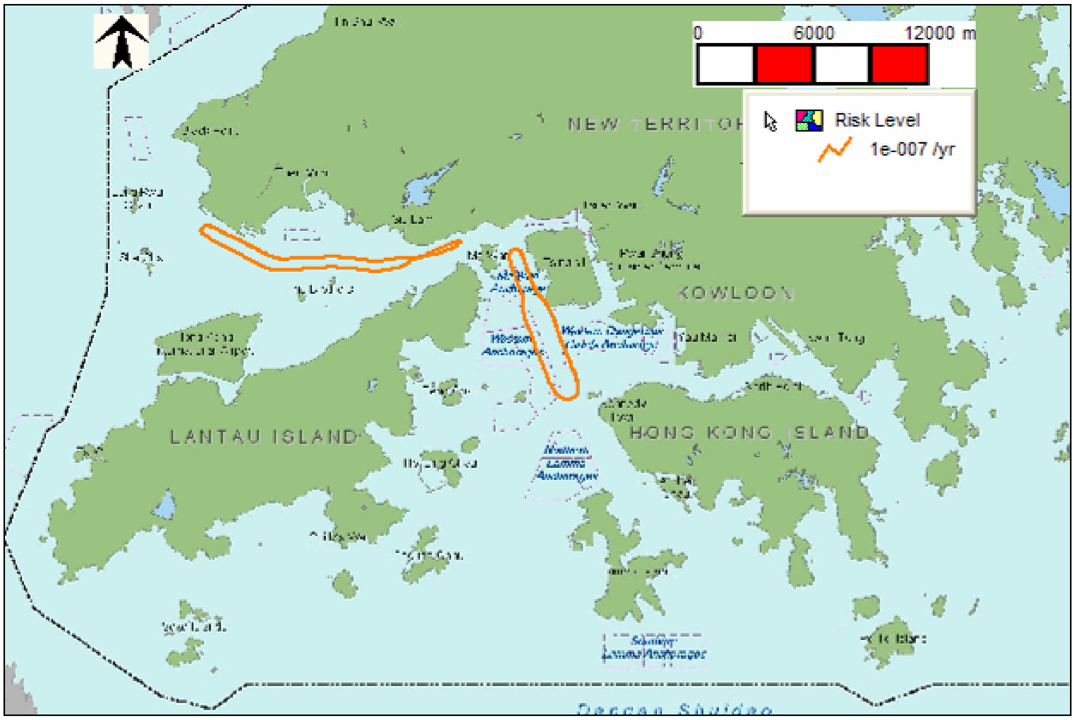


Figure 6-3 IR Contour of Black Point Route, 2021F (Large Carrier)

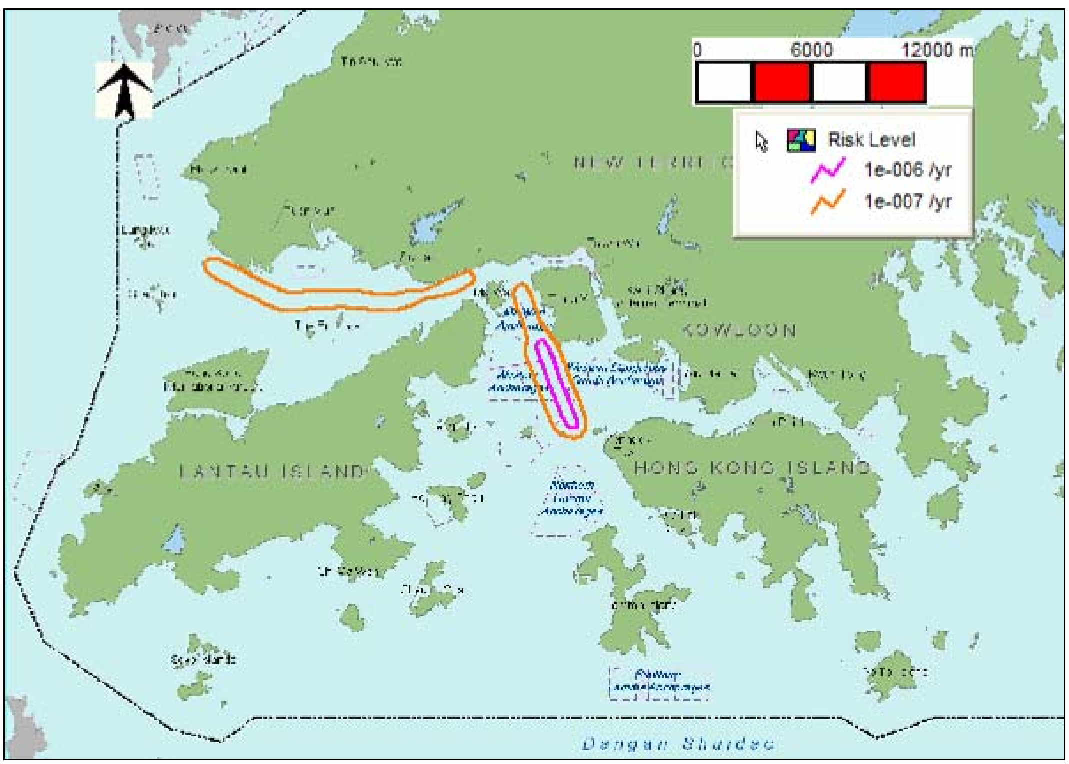


Figure 6-4 IR Contour of Black Point Route, 2011C (Small Carrier)

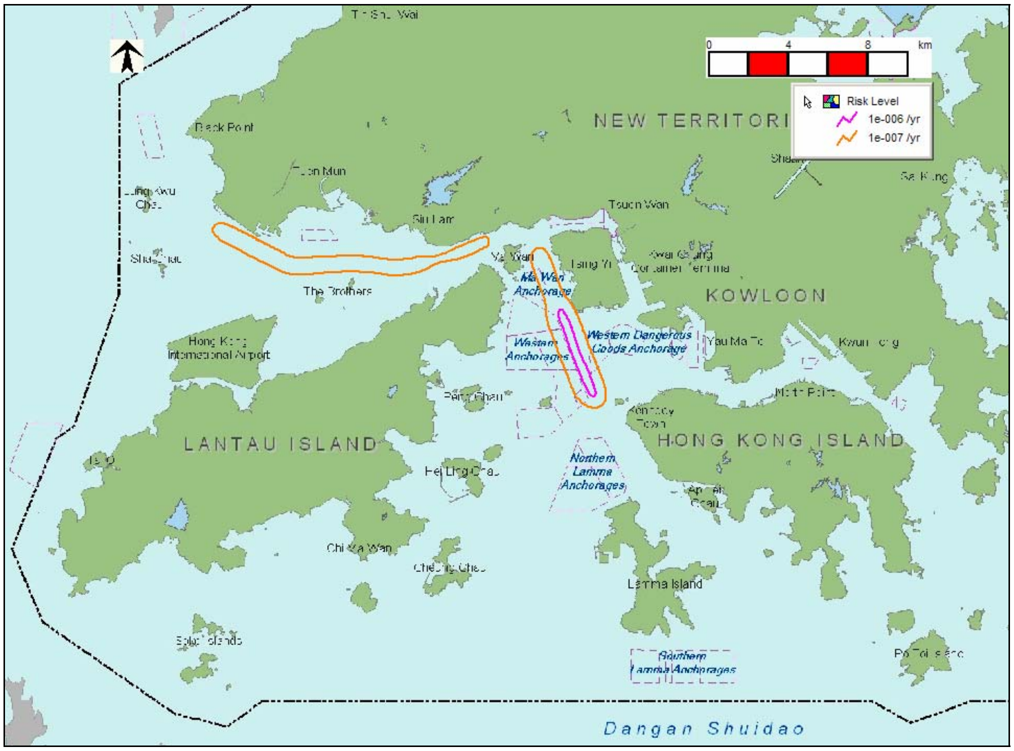


Figure 6-5 IR Contour of Black Point Route, 2021E (Small Carrier)

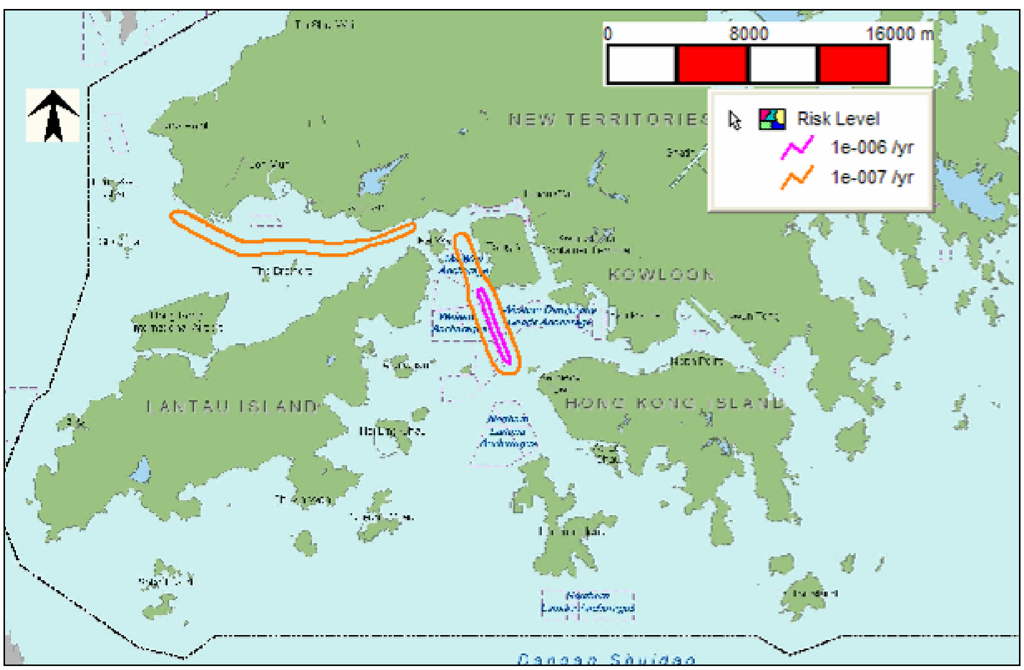


Figure 6-6 IR Contour of Black Point Route, 2021F (Small Carrier)

6.1.2 South Soko Transit Route

The large LNG carrier case individual risk results for the South Soko terminal location are presented in Figure 6-7, Figure 6-8, and Figure 6-9 for 2011C, 2021E, and 2021F, respectively. The small LNG carrier case individual risk results for the South Soko terminal location are presented in Figure 6-10, Figure 6-11, and Figure 6-12 for 2011C, 2021E, and 2021F, respectively. The results mostly show that the $1x10^{-6}$ per year and $1x10^{-7}$ per year contour are displayed and thus $1x10^{-6}$ per year is the maximum for the South Soko route. As with the Black Point route, this is one order of magnitude below the Hong Kong EIAO individual risk criteria. There is a small point in the South Soko 2021F (Figure 6-12) contour where the Individual Risk is $1x10^{-5}$ per year. This point is almost imperceptible and resides over the water; therefore, the risk criteria is maintained. It is important to also remember that the point represents the risk to someone residing at that location for 24 hours, every day, for an entire year.

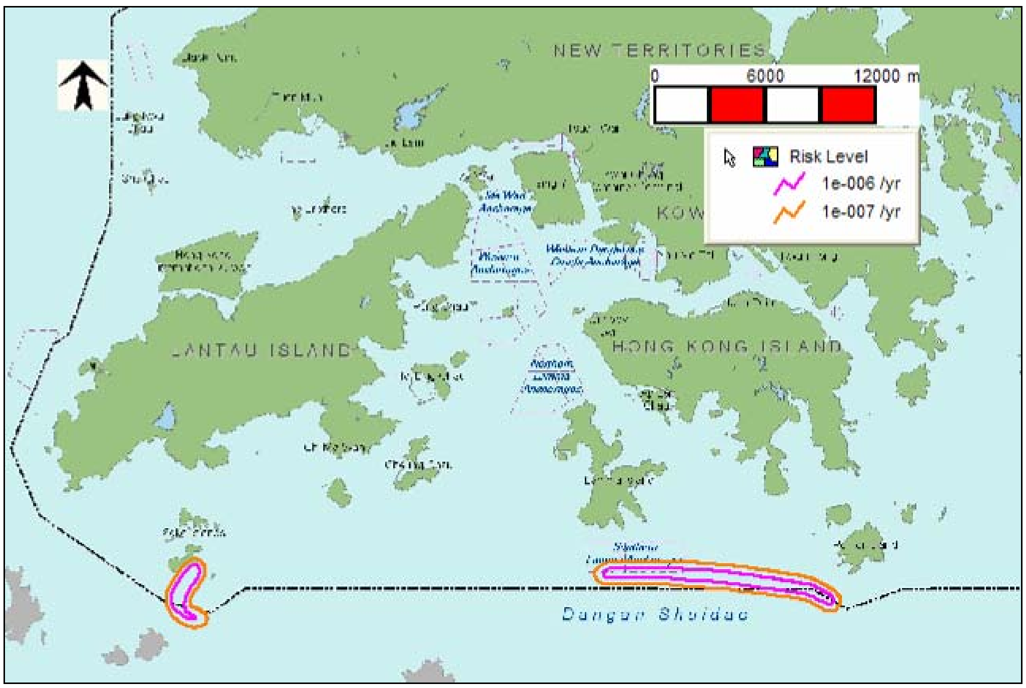


Figure 6-7 IR Contour of South Soko Route, 2011C (Large Carrier)

MANAGING RISK

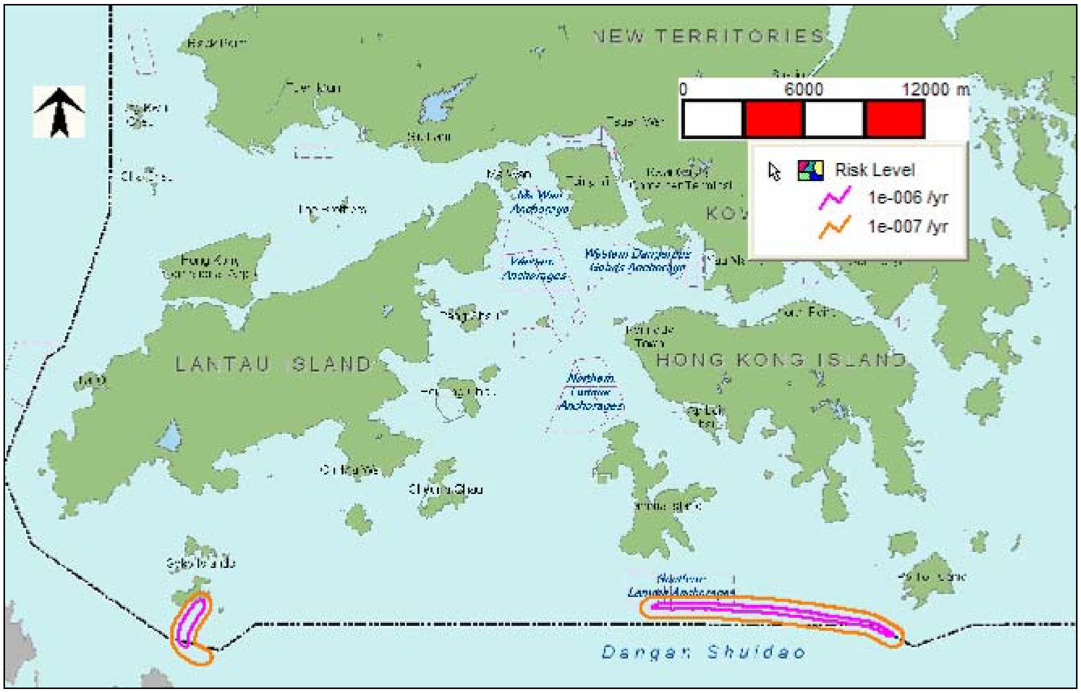


Figure 6-8 IR Contours of South Soko Route, 2021E (Large Carrier)

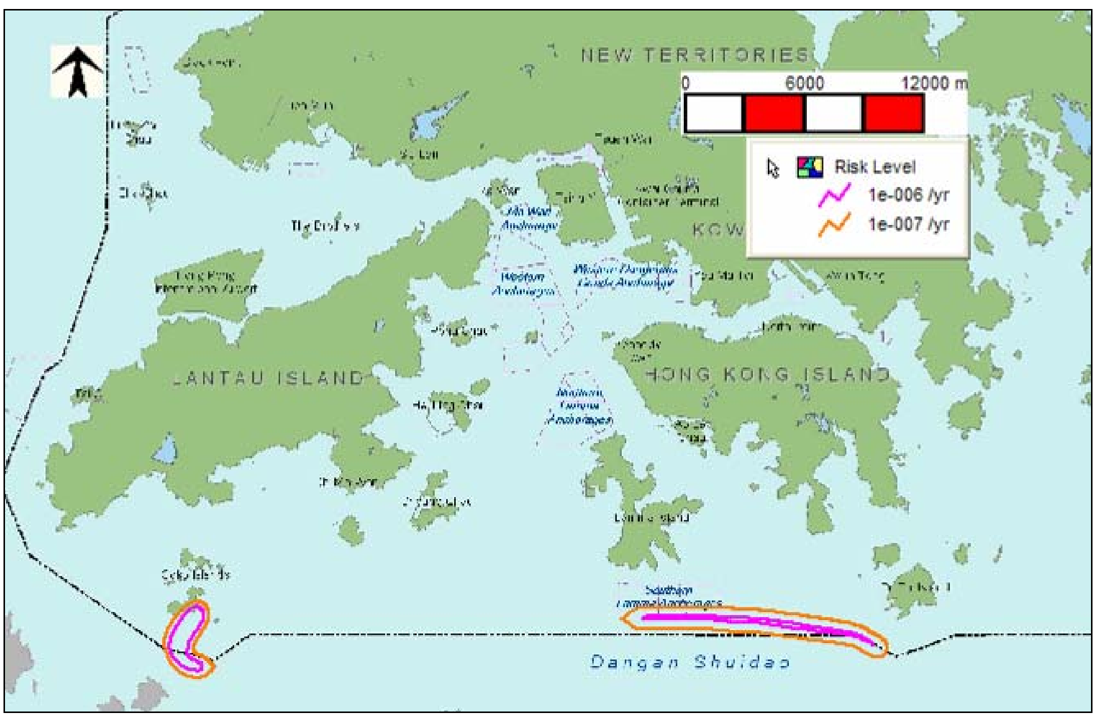


Figure 6-9 IR Contours of South Soko Route, 2021F (Large Carrier)

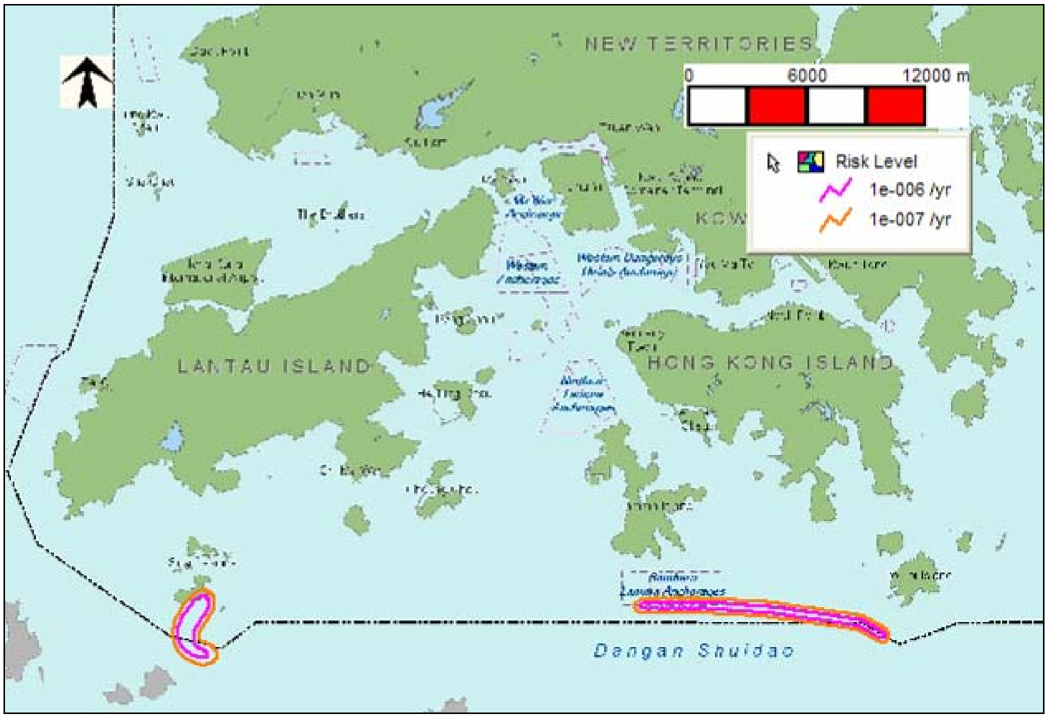


Figure 6-10 IR Contour of South Soko Route, 2011C (Small Carrier)

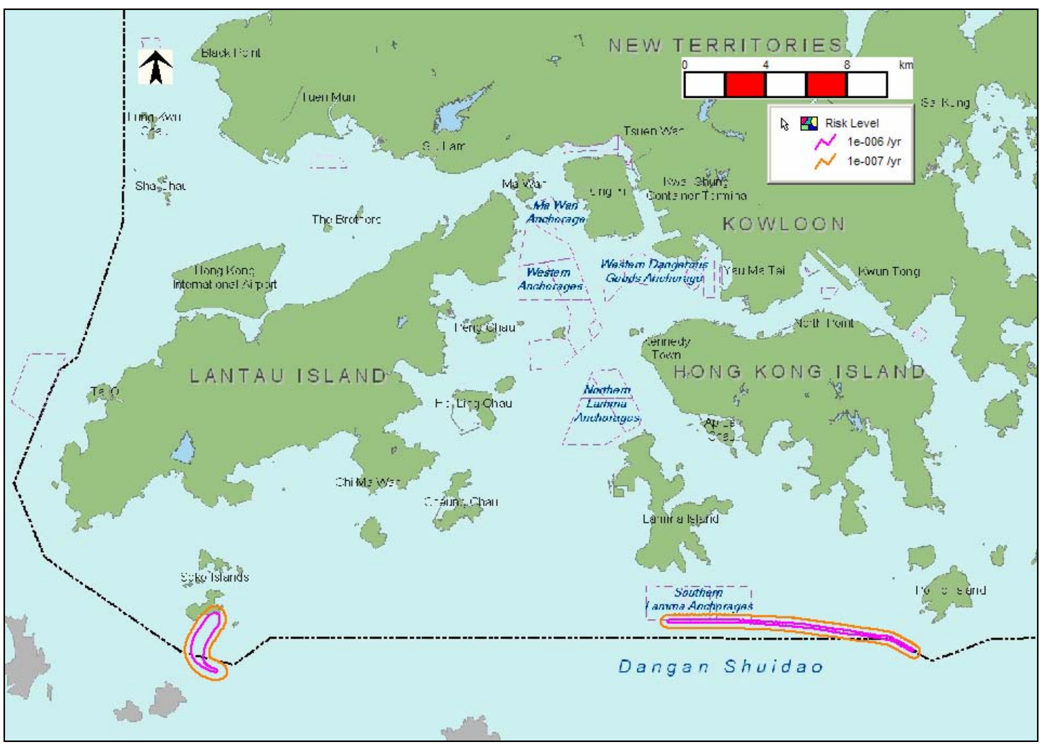


Figure 6-11 IR Contours of South Soko Route, 2021E (Small Carrier)

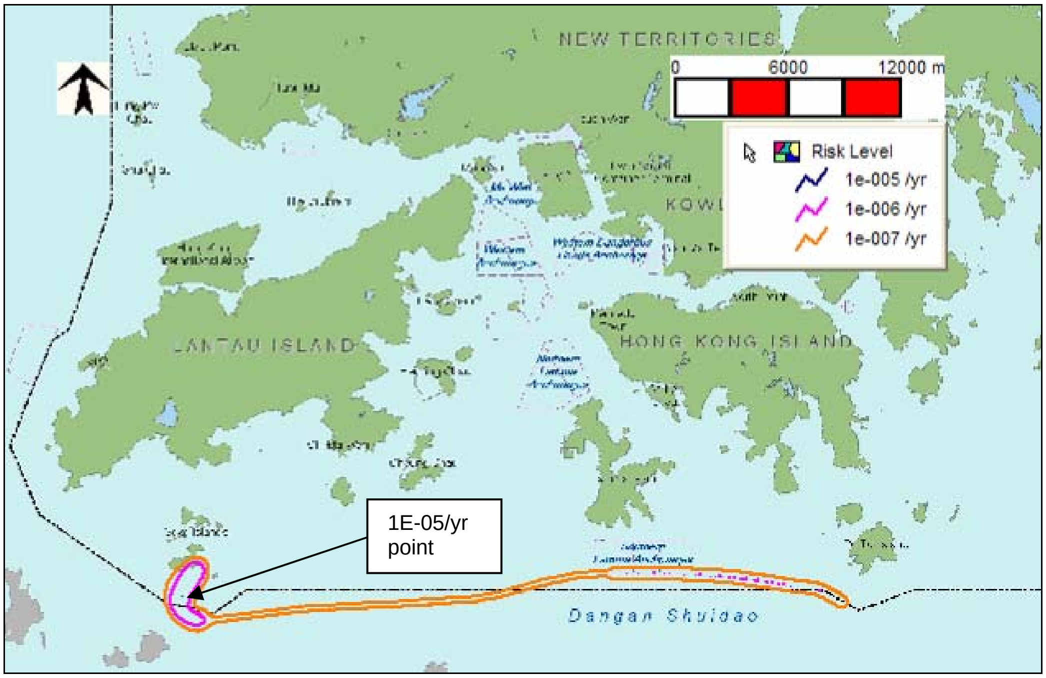


Figure 6-12 IR Contours of South Soko Route, 2021F (Small Carrier)

6.2 Societal Risk

Societal Risk is calculated and expressed in terms of FN curves – the cumulative frequency (F) of N or more potential fatalities occurring. Cumulative frequency is on the vertical axis, while number of potential fatalities is shown on the horizontal axis.

The Societal Risk for each segment is shown in relation to the Hong Kong EIAO societal risk criteria. The segments are each of a length of at least 7.3km as requested by the Hong Kong Government. This minimum length ensures that each segment is treated in a consistent manner. Refer to Table 3-1 and Figure 3-1 for segment details. In most cases, for both terminal locations and for the traffic scenario at 2011 and two cases at 2021, the FN curves are within the Hong Kong EIAO societal risk criteria acceptable region. For the Black Point segments BP4 and BP5, parts of the curves are within the EIAO societal risk criteria ALARP region.

6.2.1 Black Point Transit Route

The large LNG carrier case FN curves for the Black Point terminal location are presented in Figure 6-13, Figure 6-14, and Figure 6-15 for the 2011C, 2021E and 2021F cases, respectively. The small LNG carrier case FN curves for the Black Point terminal location are presented in Figure 6-16, Figure 6-17, and Figure 6-18 for the 2011C, 2021E and 2021F cases, respectively.

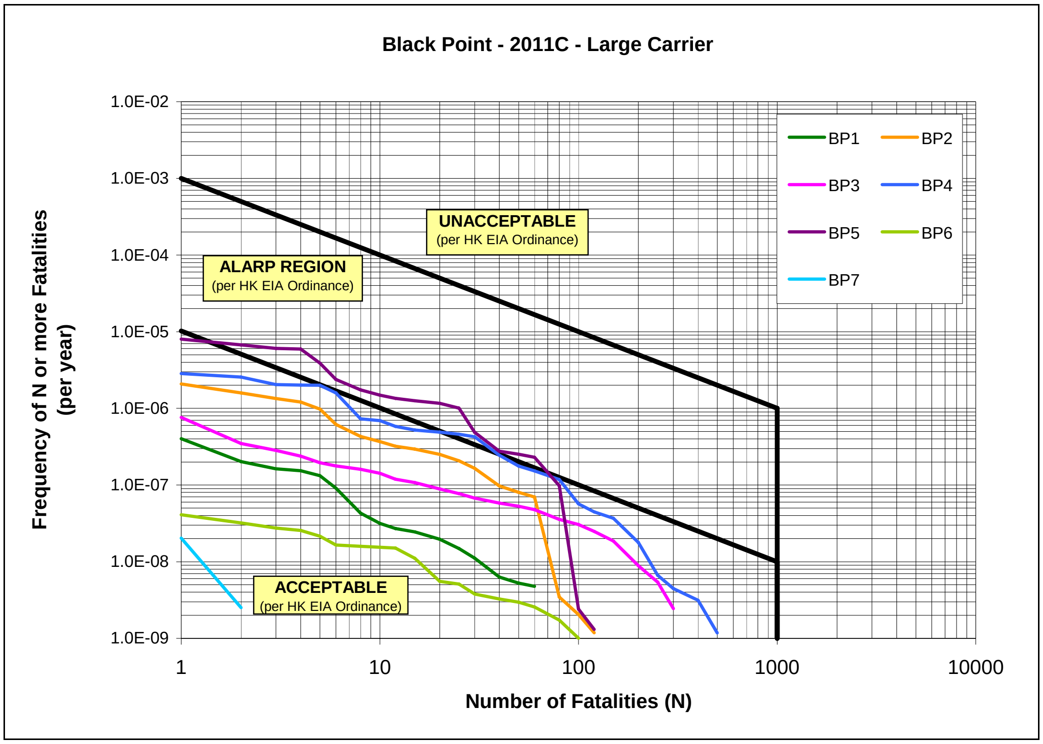


Figure 6-13 FN Curve for Black Point Route Segments, 2011C (Large Carrier)

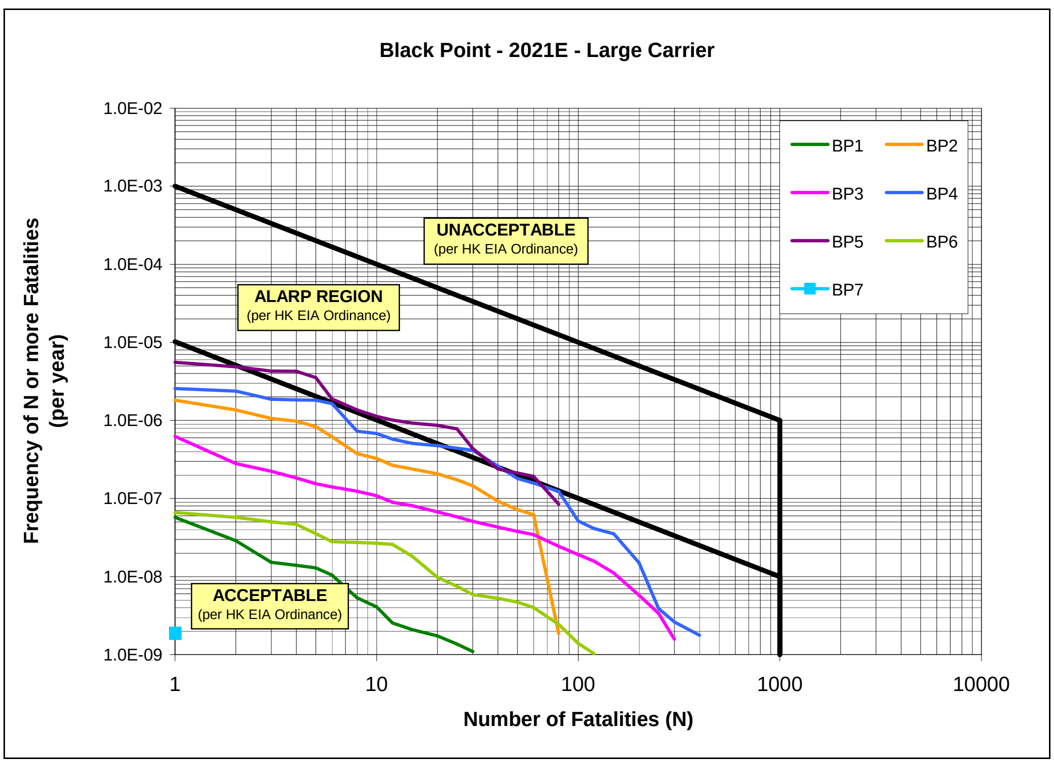


Figure 6-14 FN Curve for Black Point Route Segments, 2021E (Large Carrier)

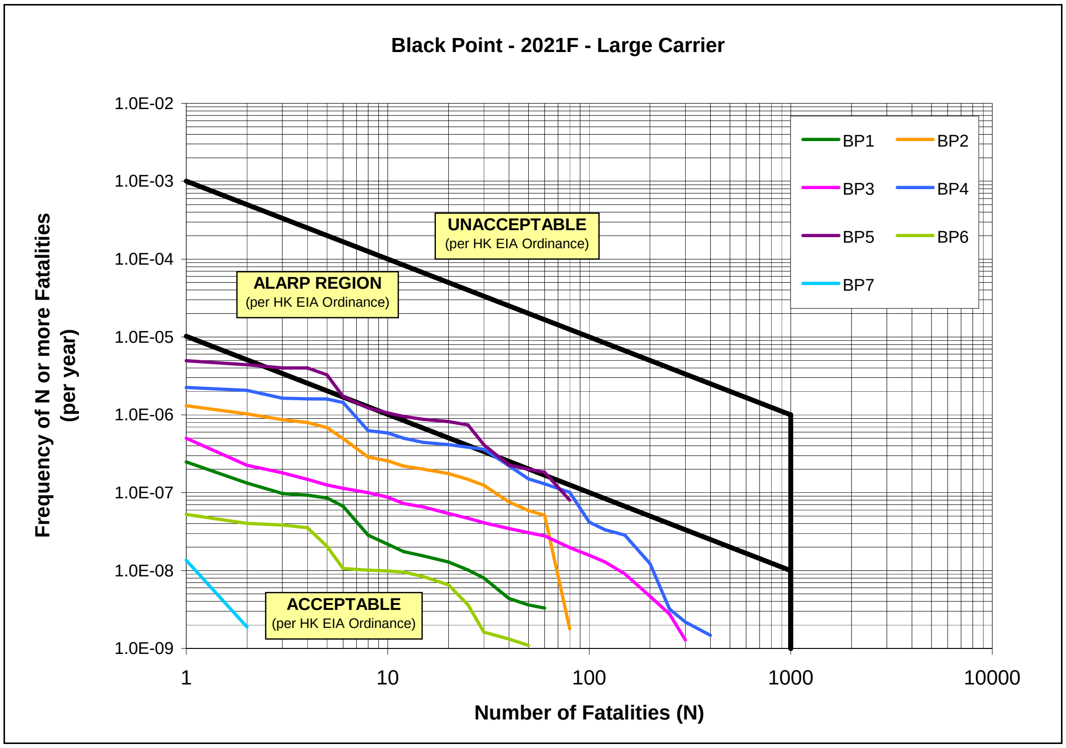


Figure 6-15 FN Curve for Black Point Route Segments, 2021F (Large Carrier)

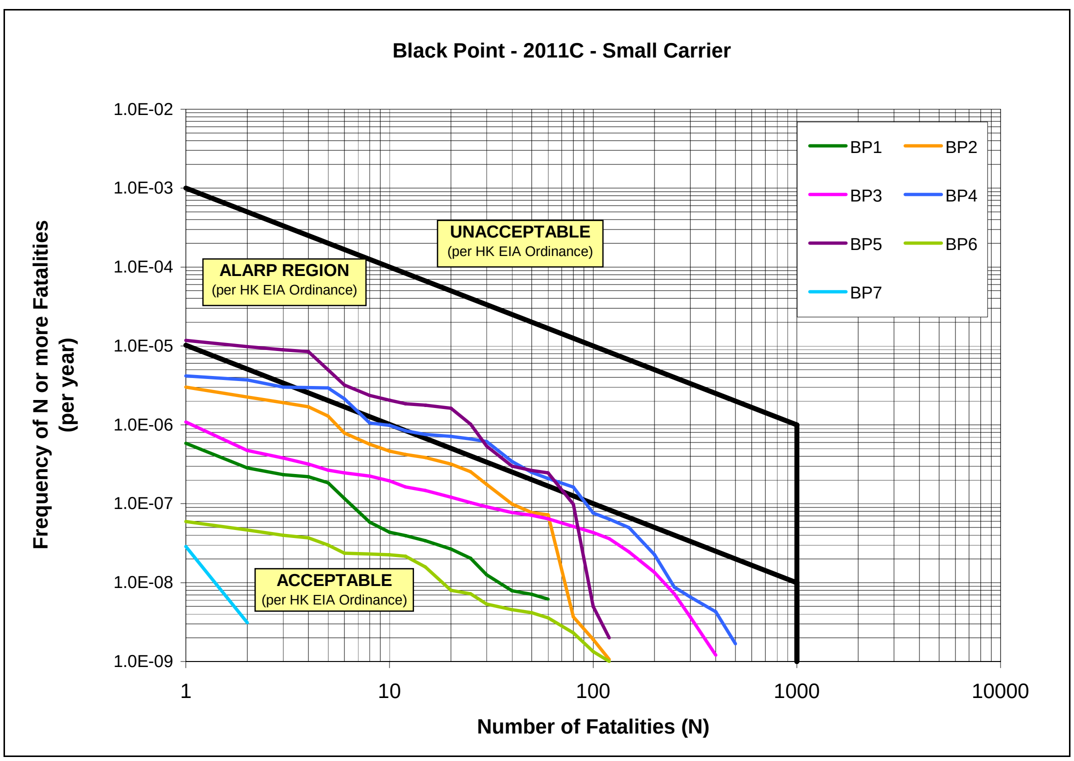


Figure 6-16 FN Curve for Black Point Route Segments, 2011C (Small Carrier)

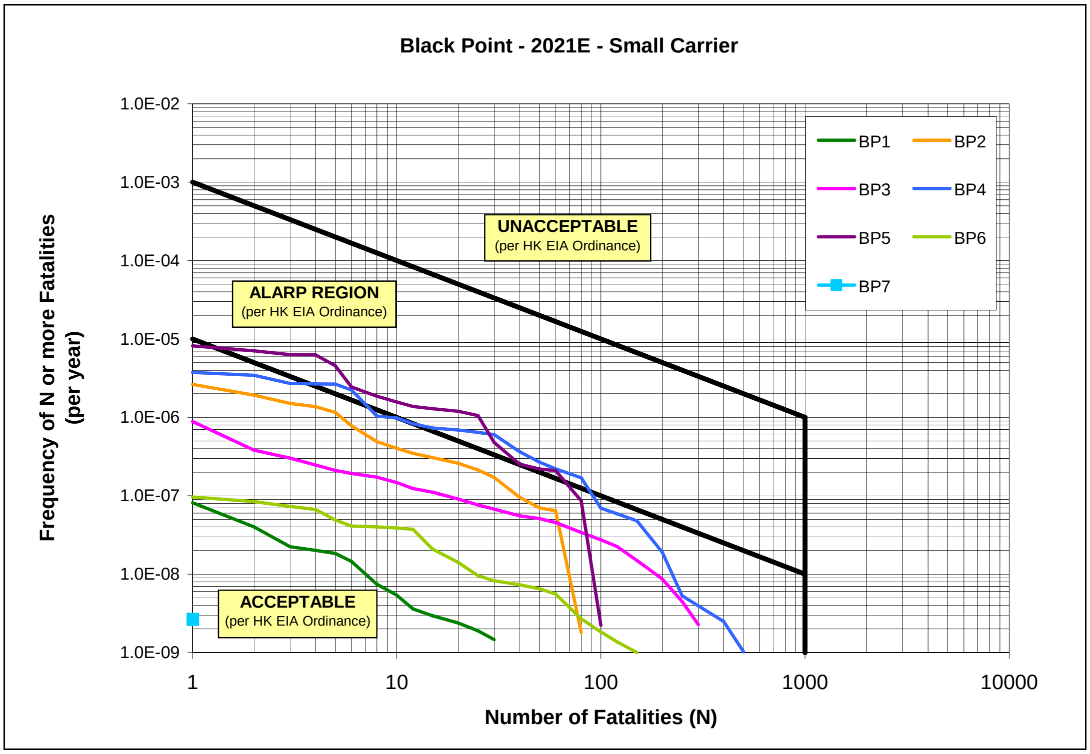


Figure 6-17 FN Curve for Black Point Route Segments, 2021E (Small Carrier)

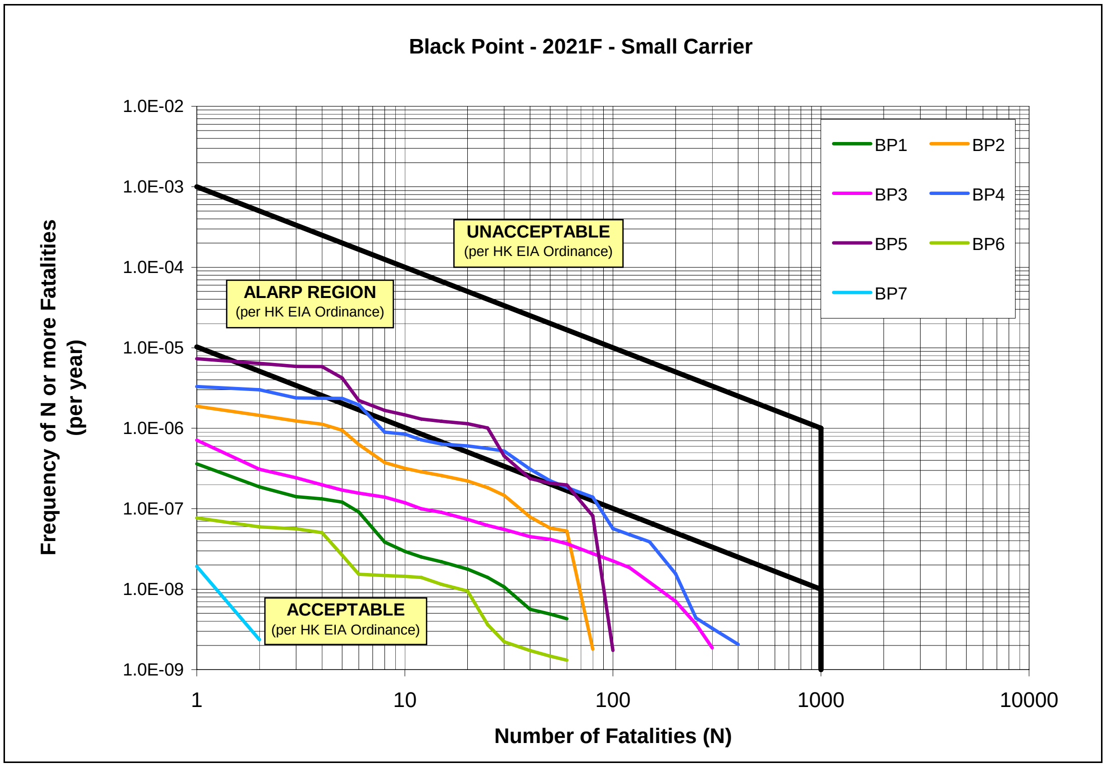


Figure 6-18 FN Curve for Black Point Route Segments, 2021F (Small Carrier)

6.2.2 South Soko Transit Route

The large LNG carrier case FN curves for the South Soko terminal location are presented in Figure 6-19, Figure 6-20, and Figure 6-21 for the 2011C, 2021E and 2021F cases, respectively. The small LNG carrier case FN curves for the South Soko terminal location are presented in Figure 6-22, Figure 6-23, and Figure 6-24, for the 2011C, 2021E and 2021F cases, respectively.

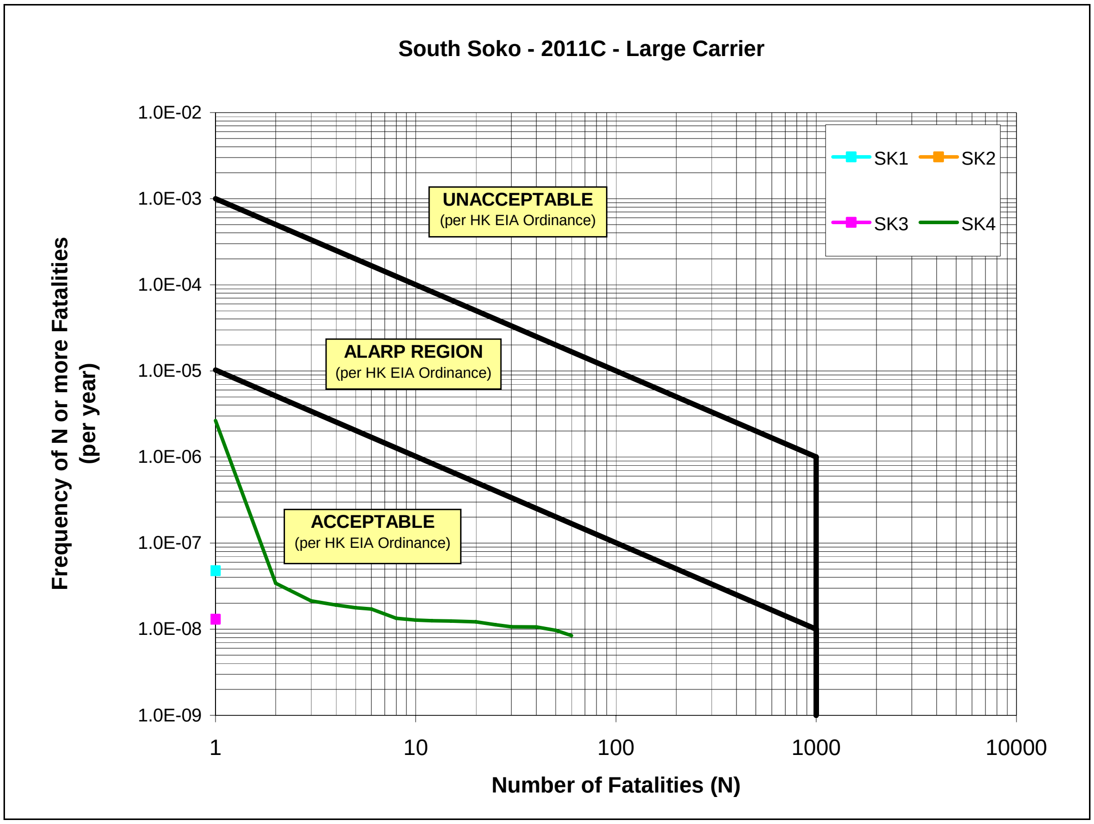


Figure 6-19 FN Curves for South Soko Route Segments, 2011C (Large Carrier)

MANAGING RISK

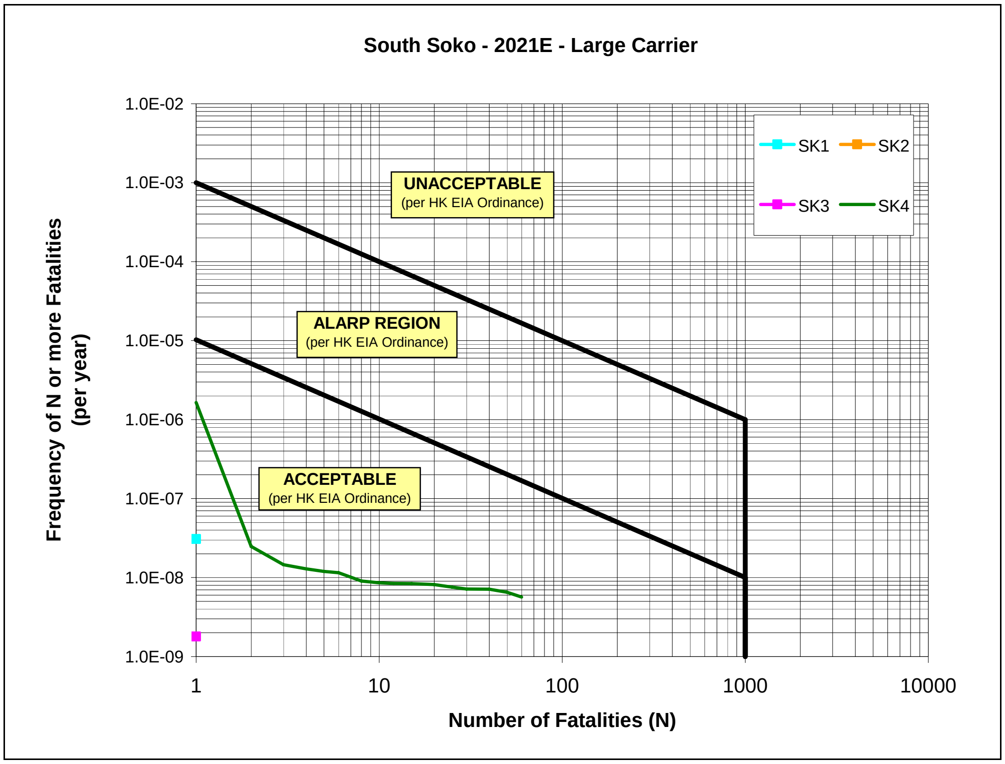


Figure 6-20 FN Curve for South Soko Route Segments, 2021E (Large Carrier)

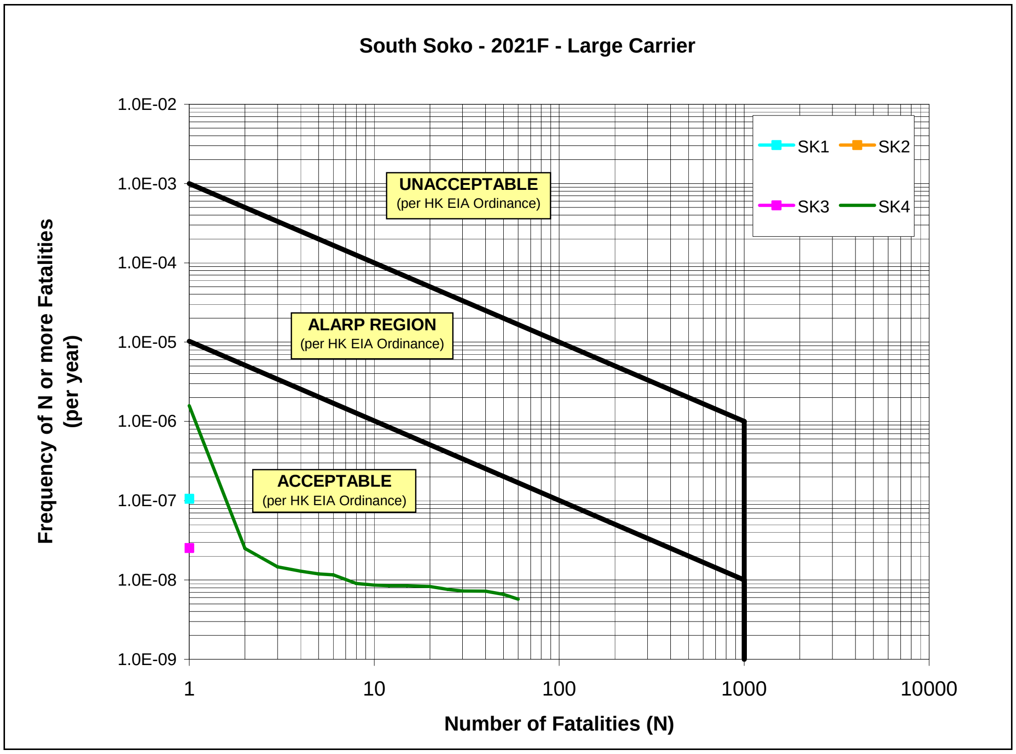


Figure 6-21 FN Curve for South Soko Route Segments, 2021F (Large Carrier)

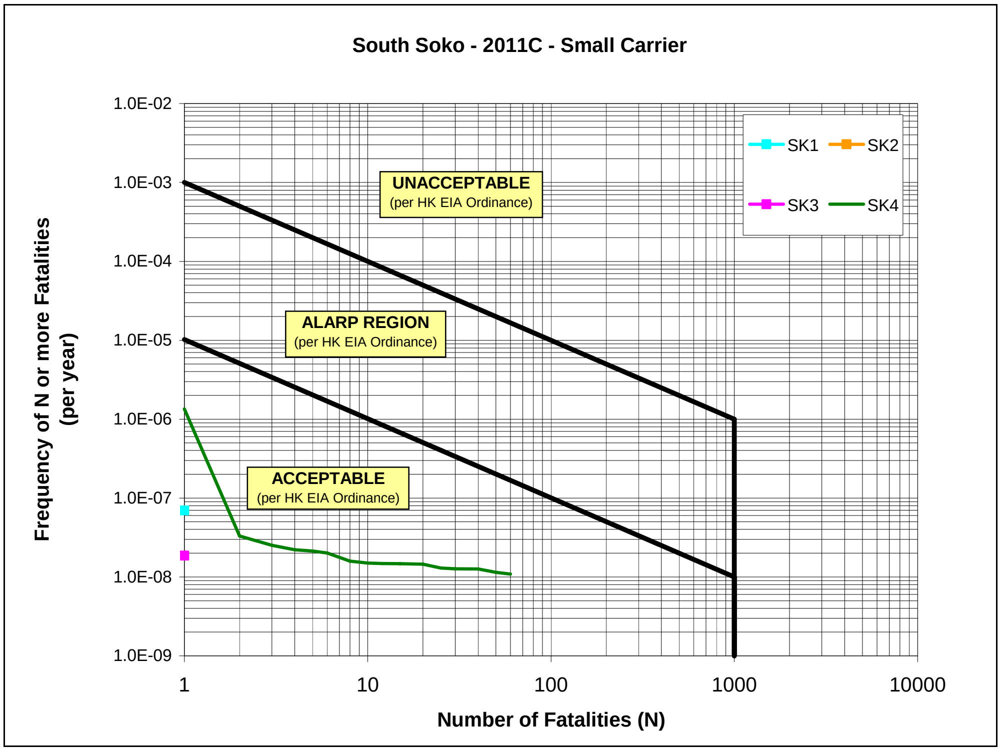


Figure 6-22 FN Curves for South Soko Route Segments, 2011C (Small Carrier)

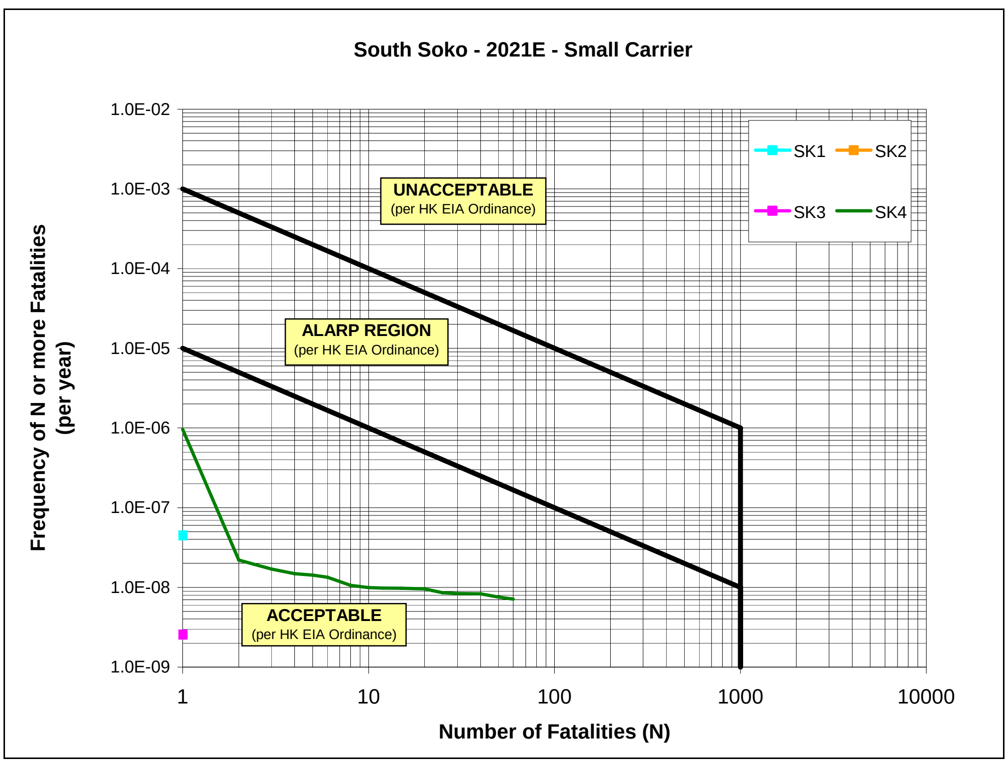


Figure 6-23 FN Curve for South Soko Route Segments, 2021E (Small Carrier)

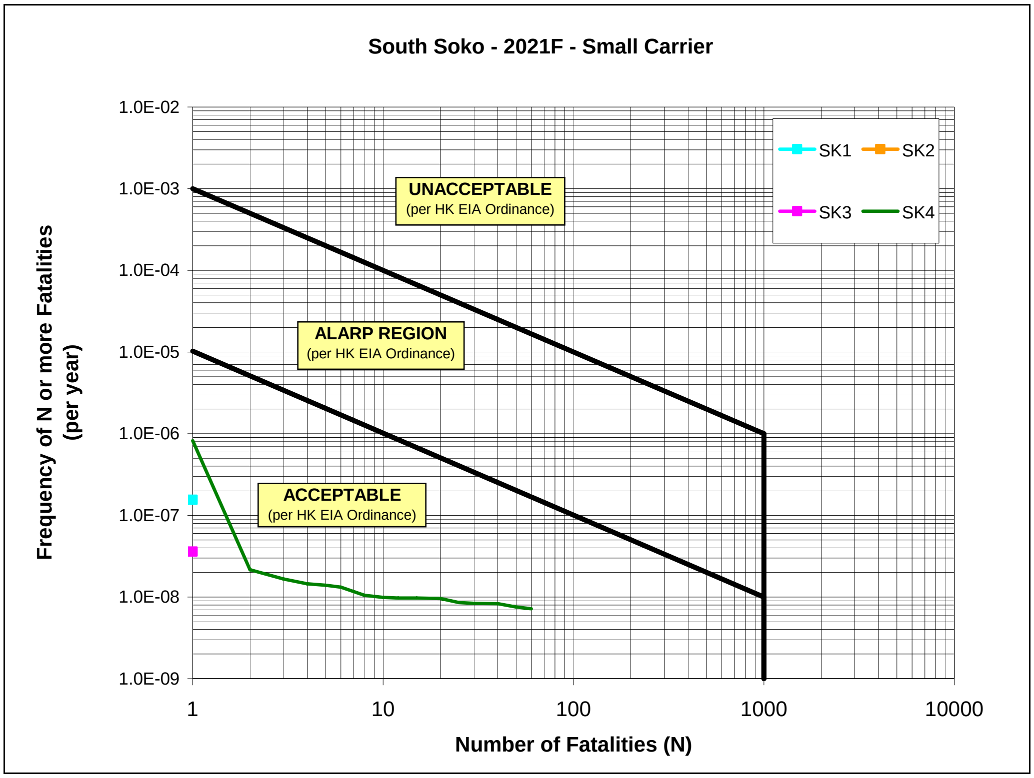


Figure 6-24 FN Curve for South Soko Route Segments, 2021F (Small Carrier)

6.3 Mitigation Cases for Black Point

The FN curves for the Black Point segments in all cases (2011 and 2021, large and small carriers) shows some of the route segments in the EIAO Ordinance ALARP region. This means that mitigation measures must be considered and applied in order to reduce the risk into the acceptable range. Several mitigation measures were considered that have been implemented at other ports around the world that receive LNG carriers and would involve restrictions on other marine traffic in the Ma Wan Channel. Implementation of these measures are beyond CAPCO's control. On the advice of the relevant authority, due to uncertainties regarding the level of safety improvement, the estimated impact to other port users, and the practicality of implementing these measures in the busy marine environment of Hong Kong, these measures are not considered implementable at this time.

7.0 Existing Risk Level at the Ma Wan Channel

The Ma Wan Channel is a strategic waterway linking Hong Kong and the Pearl River Delta. Incidents within this waterway are of key concern. The Study Brief entitled "ESB-126/2005 Liquefied Natural Gas (LNG) Receiving Terminal and Associated Facilities" dated June 2005 (ref. 02) stipulates that for the evaluation of the Black Point transit route, the existing risk of the Ma Wan Channel must also be assessed. The Study Brief stipulates in Section 3.7.9.2, the following regarding the existing risk study:

"For carrying out hazard assessment relating to marine transportation of the LNG, the Applicant shall assess the existing risk level at the Ma Wan Channel, among others, and identify practicable mitigation measures to avoid and eliminate the additional risk to the areas along the transportation route of the LNG carrier"

DNV evaluated the existing risk of dangerous goods transits through the Ma Wan Channel. This evaluation was undertaken to examine the relative importance of the additional risks associated with LNG transits versus the current risk levels. There are many unknown factors and uncertainties with regard to the assumptions employed in the study. More extensive analysis using the data that is currently not available to CAPCO would be needed to more accurately determine the existing risk levels at Ma Wan Channel. Based on the traffic records of the Marine Department, the transit of six dangerous cargos through the Ma Wan Channel was evaluated following the same procedure applied to the LNG MQRA but evaluated with 2006 traffic data. The dangerous goods cargos evaluated included the following:

- Oil
- Aviation Fuel
- Liquefied Petroleum Gases (LPG)
- Ammonia
- Toluene
- Chlorine

The study also evaluated the risk imposed by transiting the LNG carrier in the Ma Wan Channel with 2006 traffic data. Figure 7-1 presents the individual risk results for the DG vessel traffic in the Ma Wan Channel. The study concluded that the maximum individual risk from DG vessel traffic in the Ma Wan Channel is $1x10^{-05}$ per year. Figure 7-2 presents the societal risk profile generated for the combined DG and LNG carrier traffic, together with the societal risk profile of the DG and LNG carrier.

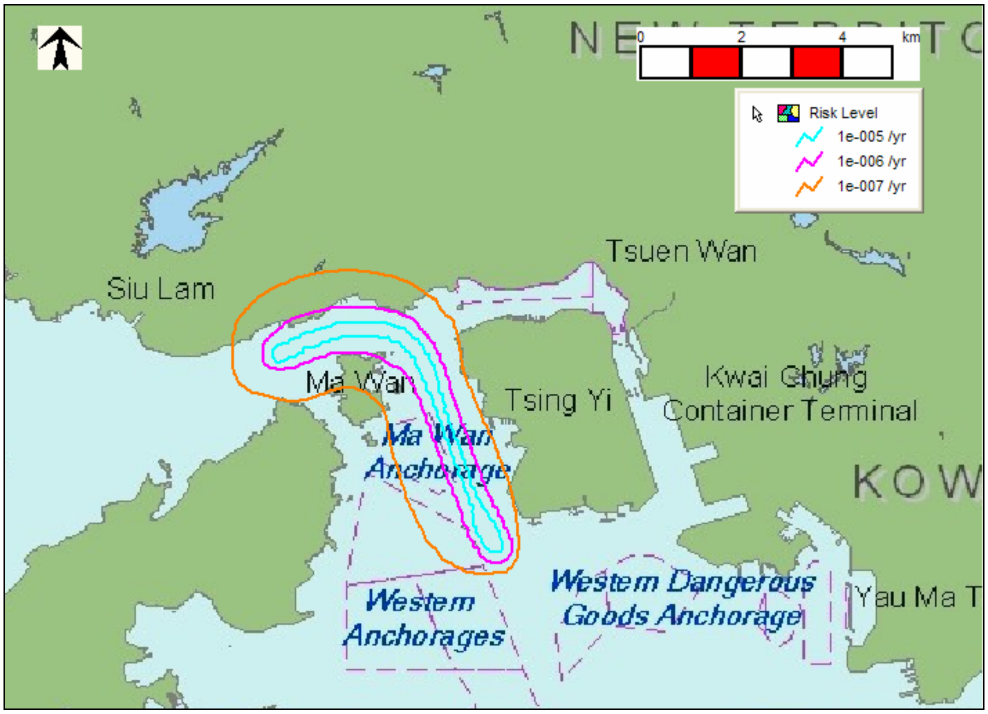


Figure 7-1 Individual Risk Contour for 2006 Existing Ma Wan Channel Dangerous Goods Traffic

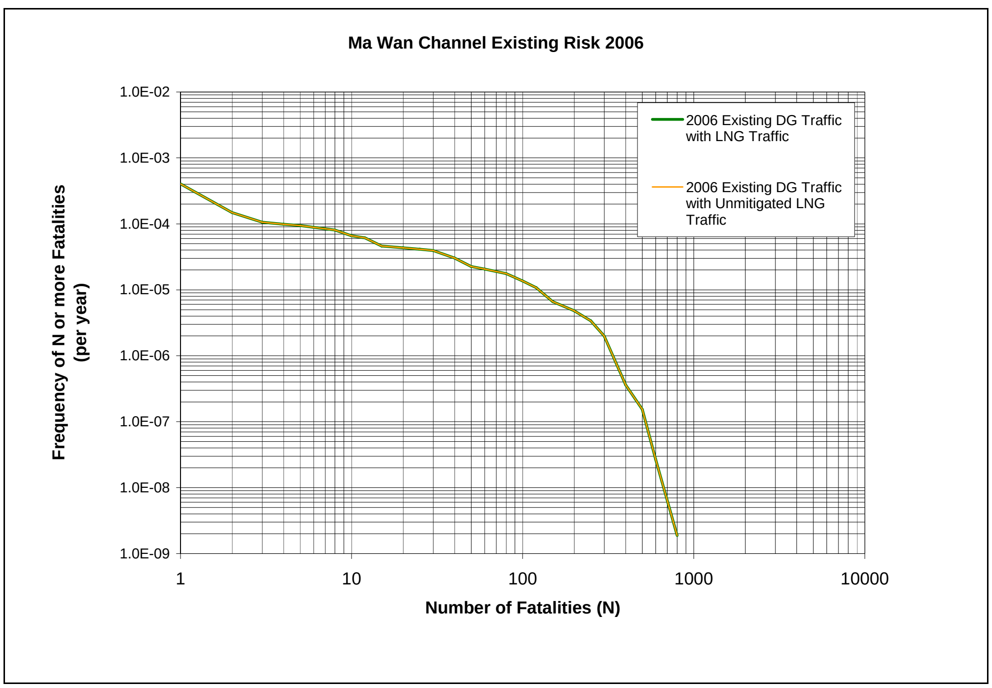


Figure 7-2 FN Curve for 2006 Existing Dangerous Goods Traffic and LNG Carrier Traffic in Ma Wan Channel

8.0 Conclusions and Recommendations

The individual risk results for the transit routes to both the Black Point and South Soko terminal locations, for the traffic scenario at 2011 and two cases at 2021, are in the acceptable region per the individual risk criterion set out in Annex 4 of the Technical Memorandum on the Environmental Impact Assessment Process (Hong Kong EPD), which is a level of 10^{-5} per year (one in 100,000 years) or less.

The societal risk results for the transit route segments to the South Soko terminal location, for the traffic scenario at 2011 and two cases at 2021, and for every sensitivity evaluated in Appendix III, lie in the acceptable region of the societal risk criteria curve defined in Annex 4 of the Hong Kong EPD Technical Memorandum on the Environmental Impact Assessment Process.

The societal risk results for the transit route segments to the Black Point terminal, for the traffic scenario at 2011 and two cases at 2021, mostly lie in the acceptable region of the societal risk criteria curve, as defined in Annex 4 with the exception of segments BP4 and BP5 which lie in the ALARP region. The difference in risk in these segments is due to busy marine traffic and high density population on the edge of the Ma Wan Channel. For the Ma Wan segments, ocean going vessel traffic is expected to grow from 19,000 vessels per year in 2005 to up to 60,000 vessels per year in 2021. In addition to ocean going vessels, river trade traffic exceeds 100,000 vessels per year. The population located along the Ma Wan channel is projected to approach 200,000 persons within 3 km of the transit route.

Several mitigation measures were considered that have been implemented at other ports around the world that receive LNG carriers. However, these measures would involve restrictions on other marine traffic in the Ma Wan Channel and implementation of these measures is beyond CAPCO's control. On the advice of the relevant authority, due to uncertainties regarding the level of safety improvement, the estimated impact to other port users, and the practicality of implementing these measures in the busy marine environment of Hong Kong, these measures are not considered implementable at this time.

The existing risk of dangerous goods transits through the Ma Wan Channel was evaluated using the best available data. There are many unknown factors and uncertainties with regard to the assumptions employed in the study. More extensive analysis using data that is currently not available to CAPCO would be needed to more accurately determine the existing risk levels at Ma Wan Channel.

Mitigating the marine societal risk through the Ma Wan Channel from ALARP to Acceptable is considered not implementable at this time due to the impact on busy marine traffic in the Hong Kong environment. The incremental risk of LNG transit through the Ma Wan Channel is avoided by the selection of the South Soko site, where the risk of the marine transit has been assessed as Acceptable along the entire route.

9.0 References

01 Hong Kong Environmental Protection Department, *"Environmental Impact Assessment Ordinance, Technical Memorandum on Environmental Impact Assessment Process."*

02 *Study Brief "ESB-126/2005 Liquefied Natural Gas (LNG) Receiving Terminal and Associated Facilities"* June 2005.

03 *CAPCO LNG PROJECT – Safeguards & Security Qualitative Risk Assessment*, April 2006.

04 *"Guidance on Risk Analysis and Safety Implications of a Large Liquefied Natural Gas (LNG) Spill Over Water,"* Sandia National Laboratories, December 2004.

05 *"LNG Marine Release Consequence Assessment*," DNV Report, Joint Sponsorship Project, April 2004.

06 *"Consequences of LNG Marine Incidents",* Pitblado, R., et. al., DNV, 19th Annual CCPS International Conference, Orlando, July 2004.

Appendix I –Table of Assumptions

Contents:

I Tables of Assumptions

Table I-1 HAZID LNG Transit Route Segments

BLACK POINT ROUTE	
Name	**Description**
Approach	Approach from entry to Hong Kong waters through pilot boarding to Ap Lei Chau (10km)
ALC-GI	South of Ap Lei Chau to Green Island in East Lamma Channel (11km)
Ma Wan 1	Western Fairway up to SW Tsing Yi (8km)
Ma Wan 2	Ma Wan approach west of Tsing Yi under bridge and around Ma Wan Island to location south of Brothers Point at Tai Lam Chung (5km)
Brothers Point	Brothers Point Channel south up to Urmston Road south of Tuen Mun River Trade Terminal (RTT) (9km)
Tuen Mun	Urmston Road from south of Tuen Mun River Trade Terminal to west of Castle Peak (5km)
Black Point	Around Castle Peak up to Black Point, including turning basin, berthing operation, and carrier at berth (7km)
SOUTH SOKO ROUTE	
Name	**Description**
Entry	From entry to Hong Kong waters, approach to pilot boarding at South Lamma DG Anchorage (13km)
Soko Approach	From pilot boarding area at South Lamma DG Anchorage, transit through PRC waters south of spoil grounds, to re-entry to Hong Kong (23km)
South Soko Point	Transit the approach channel, with tug assistance turn the carrier 180 deg and then berth the carrier to the Soko Island Terminal jetty (2km)

While the HAZID reviewed the LNG's carriers approach with respect to distinctive sections of channel, the MQRA risk analysis will use the segment approach presented in Table I-2 in order to provide the results of the analysis over a consistent length (in this case 7.3 km segment length minimum, as required by HK Government, a length consistent with prior risk studies at Ma Wan)..

Table I-2 LNG Transit Route Segments

BLACK POINT ROUTE	
Name	**Description**
BP7	From the point where the LNG carrier enters Hong Kong waters to the start of BP6, 10.17 km along the carrier transit route
BP6	7.51 km from end of BP5 along the carrier transit route
BP5	7.32 km from the end of BP4 along the carrier transit route
BP4	7.31 km from the end of BP3 along the carrier transit route
BP3	7.39 km from the end of BP2 along the carrier transit route
BP2	7.51 km from the end of BP1 along the carrier transit route
BP1	To Black Point terminal, 7.42 km along the carrier transit route
SOUTH SOKO ROUTE	
Name	**Description**
SK4	From the point where the LNG carrier enters Hong Kong waters to the start of SK3, 12.59 km along the carrier transit route
SK3	7.42 km from the end of SK2 along the carrier transit route
SK2	9.43 km from the end of SK1 along the carrier transit route
SK1	To South Soko terminal, 8.90 km along the carrier transit route

Table I-3 LNG Carrier Operation Basis

Description and Operations	Risk Assessment Basis
LNG Carrier Type	Membrane
LNG Carrier	1) Large Carrier: vessel capacity of 215,000 m^3 with 51 transits, and 43,000 m^3 single cargo tank capacity. 2) Small Carrier: vessel capacity of 145,000 m^3 with 75 transits, and 29,000m^3 single cargo tank capacity.
LNG Carrier during transit	Transit speed ranges from 4 to 12 knots Two pilots on board Two tug boats assist during transit. Two tug boats escort the LNG carrier during transit from Pilot Boarding Station (Ngan Chau, south of Ap Lei Chau for Black Point Approach, and south of the South Lamma Dangerous Goods Anchorage for South Soko Approach) For Black Point - Two additional tugboats will join in at Green Island For South Soko - Two additional tugboats will join prior to turn into dredged approach channel

Table I-4 Meteorological Data

Black Point – Stability and Wind Speed Category						
Day				Night		
B – 2.5m/s	F – 2.0 m/s	D – 3.0m/s	D – 7.0m/s	F – 2.0 m/s	D – 3.0m/s	D – 7.0m/s
19.79%	8.12%	10.23%	61.85%	24.95%	10.24%	64.81%

South Soko – Stability and Wind Speed Category						
Day				Night		
B – 2.5m/s	F – 2.0 m/s	D – 3.0m/s	D – 7.0m/s	F – 2.0 m/s	D – 3.0m/s	D – 7.0m/s
16.30%	6.74%	9.68%	67.28%	25.63%	9.70%	64.67%

Waglan Island – Stability and Wind Speed Category			
Day			
B – 2.9m/s	F – 2.2 m/s	D – 3.3m/s	D – 7.0m/s
20.24%	3.87%	14.35%	61.54%

Green Island – Stability and Wind Speed Category			
Day			
B – 2.8m/s	F – 2.1m/s	D – 3.3m/s	D – 7.0m/s
20.83%	5.09%	15.64%	58.44%

Ching Pak House Station – Stability and Wind Speed Category			
Day			
B – 3.1m.s	F – 2.2m/s	D – 3.3m/s	D – 7.0m/s
28.25%	8.78%	30.30%	32.67%

Tai Mo To Station – Stability and Wind Speed Category			
Day			
B – 3.0m.s	F – 2.3m/s	D – 3.3m/s	D – 7.0m/s
28.44%	7.72%	25.44%	38.39%

Table I-5 Waglan Island Station Meteorological Data (Daytime only)

Wind Direction	Stability and Windspeed (m/s) Category			
	B - 2.9	**F - 2.2**	**D - 3.3**	**D - 7**
N	0.75%	0.45%	1.24%	8.91%
NNE	2.87%	0.89%	3.27%	7.71%
ENE	4.08%	0.50%	2.12%	20.78%
E	4.17%	0.56%	2.09%	10.81%
ESE	1.85%	0.27%	1.06%	1.31%
SSE	1.28%	0.14%	0.90%	1.11%
S	1.08%	0.18%	0.80%	1.89%
SSW	1.96%	0.15%	0.98%	3.30%
WSW	1.12%	0.16%	0.77%	4.42%
W	0.58%	0.19%	0.46%	0.94%
WNW	0.28%	0.19%	0.40%	0.21%
NNW	0.21%	0.19%	0.25%	0.17%
Total	20.24%	3.87%	14.35%	61.54%

Table I-6 Green Island Station Meteorological Data (Daytime only)

Wind Direction	Stability and Windspeed (m/s) Category			
	B - 2.8	**F - 2.1**	**D - 3.3**	**D - 7.0**
N	0.61%	0.35%	1.20%	1.57%
NNE	1.20%	0.82%	2.22%	4.38%
ENE	2.32%	0.76%	2.45%	20.43%
E	1.52%	0.37%	1.28%	12.67%
ESE	0.33%	0.23%	0.40%	0.73%
SSE	0.24%	0.25%	0.33%	0.19%
S	6.38%	0.81%	3.24%	8.32%
SSW	3.25%	0.56%	1.62%	4.16%
WSW	1.54%	0.27%	0.70%	1.47%
W	1.46%	0.17%	0.52%	0.87%
WNW	1.27%	0.23%	0.76%	1.67%
NNW	0.71%	0.29%	0.93%	1.97%
Total	20.83%	5.09%	15.64%	58.44%

Table I-7 Ching Pak House (CPH) Station Meteorological Data (Daytime only)

Wind Direction	Stability and Windspeed (m/s) Category			
	B - 3.1	F - 2.2	D - 3.3	D - 7.0
N	0.97%	0.67%	0.95%	0.51%
NNE	1.37%	0.94%	2.37%	1.15%
ENE	1.96%	0.99%	3.89%	3.81%
E	1.28%	0.64%	2.79%	3.18%
ESE	2.35%	0.85%	4.39%	9.61%
SSE	5.50%	1.05%	4.02%	5.97%
S	7.44%	0.77%	4.28%	5.46%
SSW	1.63%	0.38%	1.39%	0.33%
WSW	0.58%	0.14%	0.30%	0.03%
W	1.78%	0.38%	1.13%	0.62%
WNW	1.26%	0.71%	1.77%	0.41%
NNW	2.13%	1.25%	3.02%	1.58%
Total	28.25%	8.78%	30.30%	32.67%

Table I-8 Tai Mo To Station (TMT) Meteorological Data (Daytime only)

Wind Direction	Stability and Windspeed (m/s) Category			
	B - 3.0	F - 2.3	D - 3.3	D - 7
N	2.49%	0.61%	3.01%	2.72%
NNE	1.90%	1.05%	2.69%	1.87%
ENE	1.36%	1.27%	2.64%	0.55%
E	2.26%	1.21%	3.49%	4.63%
ESE	3.52%	0.79%	3.93%	15.54%
SSE	1.89%	0.65%	1.94%	4.41%
S	1.08%	0.51%	1.13%	1.63%
SSW	1.40%	0.30%	1.01%	1.74%
WSW	1.24%	0.33%	1.06%	1.05%
W	4.20%	0.36%	1.51%	1.06%
WNW	5.83%	0.30%	1.79%	2.33%
NNW	1.26%	0.35%	1.23%	0.86%
Total	28.44%	7.72%	25.44%	38.39%

Table I-9 Black Point (Shau Chau Station) Meteorological Data

Wind Direction	Stability and Windspeed (m/s) Category						
	Day				Night		
	B - 2.5	F - 2.0	D - 3.0	D - 7.0	F - 2.0	D - 3.0	D - 7.0
N	2.48%	0.92%	1.37%	13.75%	2.08%	0.89%	9.93%
NNE	0.72%	0.61%	0.76%	4.38%	1.78%	0.84%	7.12%
ENE	0.55%	0.61%	0.59%	0.55%	1.89%	0.76%	0.95%
E	2.00%	1.57%	2.43%	6.07%	6.69%	2.97%	9.53%
ESE	1.68%	0.90%	1.32%	15.98%	3.82%	1.84%	20.08%
SSE	1.06%	0.61%	0.36%	3.12%	2.28%	0.60%	3.83%
S	2.43%	0.71%	0.65%	3.64%	1.81%	0.74%	3.88%
SSW	3.35%	0.86%	1.39%	9.04%	2.06%	1.01%	6.91%
WSW	0.07%	0.16%	0.05%	0.02%	0.23%	0.02%	0.04%
W	0.08%	0.09%	0.01%	0.01%	0.11%	0.00%	0.01%
WNW	1.58%	0.35%	0.21%	0.07%	0.62%	0.04%	0.05%
NNW	3.78%	0.74%	1.09%	5.22%	1.59%	0.53%	2.45%
Total	19.79%	8.12%	10.23%	61.85%	24.95%	10.24%	64.81%

Table I-10 South Soko (Cheung Chau Station) Meteorological Data

Wind Direction	Stability and Windspeed (m/s) Category						
	Day				Night		
	B - 2.5	F - 2.0	D - 3.0	D - 7.0	F - 2.0	D - 3.0	D - 7.0
N	1.57%	1.92%	1.31%	11.42%	6.05%	1.31%	13.14%
NNE	1.60%	0.94%	1.34%	4.21%	3.02%	1.20%	4.36%
ENE	0.81%	0.68%	0.92%	3.05%	3.26%	1.56%	5.02%
E	0.87%	0.65%	1.39%	14.86%	3.57%	2.19%	19.48%
ESE	3.18%	0.62%	1.38%	18.32%	2.02%	0.75%	9.32%
SSE	2.10%	0.44%	0.93%	2.92%	1.21%	0.36%	2.29%
S	2.41%	0.35%	0.72%	2.77%	1.35%	0.53%	3.47%
SSW	1.78%	0.27%	0.67%	4.97%	1.40%	0.58%	4.13%
WSW	0.89%	0.23%	0.44%	2.10%	1.20%	0.54%	1.80%
W	0.40%	0.27%	0.28%	0.79%	1.27%	0.41%	0.83%
WNW	0.22%	0.17%	0.09%	0.30%	0.61%	0.10%	0.25%
NNW	0.47%	0.22%	0.21%	1.57%	0.65%	0.18%	0.59%
Total	16.30%	6.74%	9.68%	67.28%	25.63%	9.70%	64.67%

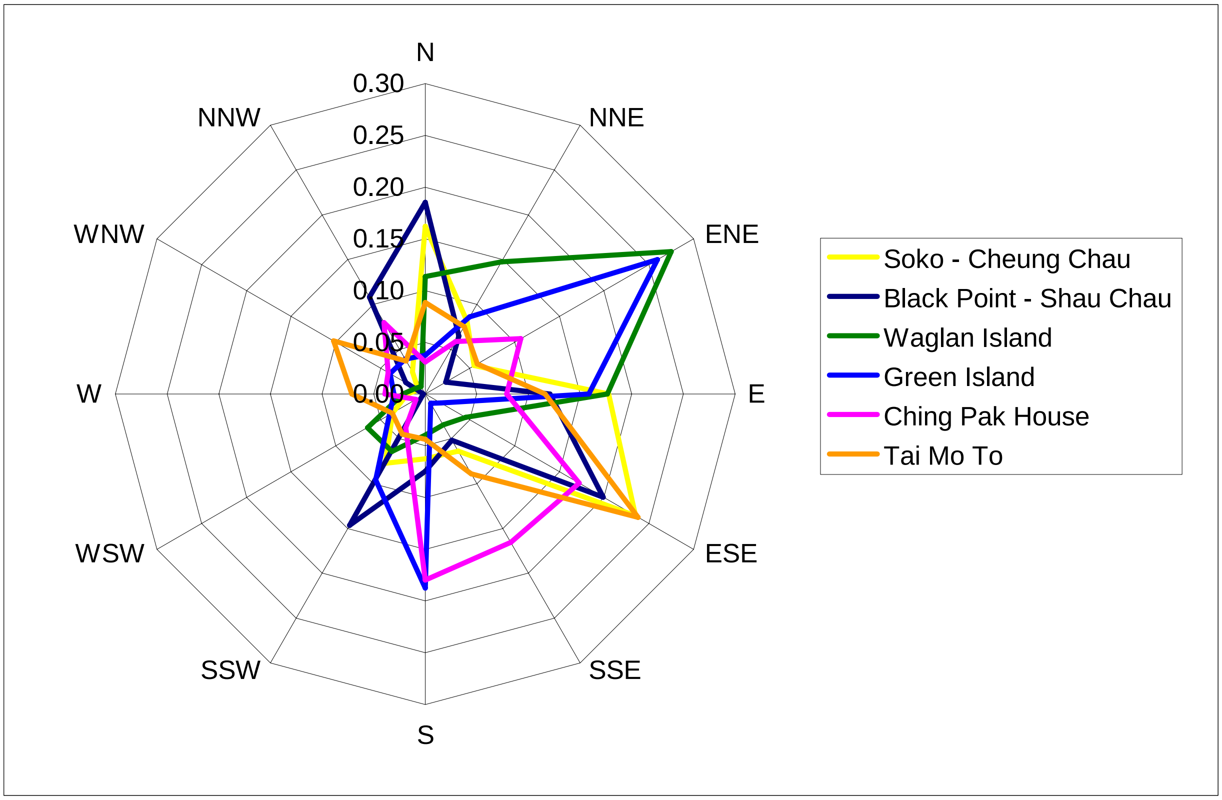


Figure I-1 Wind Rose Data for Six Weather Stations Considered

Table I-11 ERM Time Period Classification

Time Period	Definition	Hours in a week	Time Fraction
Night	7pm – 7am	84	0.500
Peak	Monday-Friday 7am-9am, 5pm-7pm Saturday 7am-9am, 1pm-3pm	24	0.143
Weekday	9am – 5pm (including Sat 9am-1pm)	44	0.262
Weekend Day	Saturday 3pm-7pm Sunday 7am-7pm	16	0.095
	Total	168	

Table I-12 PVS Zone Land Population Totals

PVS Zone	Provided by Hong Kong Government		ERM Analysis	
	2011	2021	2011	2021
001	51,726	53,849	77,838	72,514
002	0	0	0	0
003	48,603	48,741	54,077	50,547
012	7,082	7,201	14,230	13,899
041	2,668	3,128	3,257	3,670
042	6,433	6,778	36,534	35,168
043	15,188	14,976	21,964	20,806
044	14,795	14,483	16,783	16,265
045	43,132	39,040	53,699	48,012
046	17,001	15,412	28,705	18,170
047	43,839	40,772	64,495	55,575
048	50,432	47,949	66,764	60,242
049	13,625	42,751	98,333	129,589
051	6,299	6,155	3,250	3,183
052	5,393	5,163	9,941	8,600
151	45,871	47,058	44,332	45,326
152	72,859	69,752	71,805	67,744
153	37,541	36,048	32,253	30,854
154	56,491	53,018	55,057	51,589
155	222	91	11,039	3,594
156	31,361	33,270	58,770	60,775
157	9,316	10,426	41,702	41,077
158	15,182	14,718	29,793	26,597
161	6,068	5,979	10,637	8,992
162	35,407	33,673	34,738	33,032
163	0	0	30	30
227	9	16	0	27
230	34,645	33,980	28,451	27,544
233	0	0	0	0
234	0	0	936	720
239	2	1	1,129	435
240	0	0	374	288
247	0	0	5	5
251	4,094	4,212	8,835	8,622
258	0	0	16,946	13,254
259	969	1,669	7,140	10,054
284	5	5	5	5

PVS Zone	Provided by Hong Kong Government		ERM Analysis	
	2011	2021	2011	2021
327	3	3	554	468
338	9,999	8,599	20,190	16,277
TOTAL	**686,260**	**698,916**	**1,024,592**	**983,547**

Table I-13 Probabilities of Weather Conditions

	Probabilities of Weather Conditions			
Station/Weather	**B2.9**	**F2.2**	**D3.3**	**D7.0**
WGL	0.202	0.039	0.144	0.615
GI	0.208	0.051	0.156	0.584
CPH	0.283	0.088	0.303	0.327
TMT	0.284	0.077	0.254	0.384
SC	0.198	0.081	0.102	0.619
CCH	0.163	0.067	0.097	0.673
Average	**0.223**	**0.067**	**0.176**	**0.534**

Table I-14 Calculation of Cloud Height Weighted Average (m)

Distance Downwind (m):	Cloud Height (m)				Weighted Average (m)
	B 2.9	F 2.2	D 3.3	D 7.0	
50	16	15	15	13	14.2
100	15	13	13	12	12.9
150	22	13	13	13	15.0
200	32	24	22	19	22.8
250	33	30	32	24	27.8
300	30	30	35	28	29.8
350	24	26	35	31	29.8
400	18	23	33	32	28.4
450	11	20	32	33	27.0
500	0	18	30	33	24.1
550	0	17	28	32	23.1
600	0	16	26	31	22.2
650	0	15	24	30	21.2
700	0	14	21	29	20.1
750	0	13	18	28	19.0
800	0	12	12	26	16.8
850	0	10	4	24	14.2
900	0	0	8	22	13.1
950	0	0	6	19	11.2
1000	0	0	1	14	7.6
1050	0	0	0	7	7.0
1100	0	0	0	0	0.0
Average cloud height (m)	**22.3**	**18.2**	**20.4**	**23.8**	**22.5**

Table I-15 Land Daytime Population Data

SAFETI Indoor PVS sub-area	2011 Day Indoor Population	2021 Day Indoor Population	SAFETI Outdoor PVS sub-area	2011 Day Outdoor Population	2021 Day Outdoor Population
001	13530	14547	001	6335	5365
002	0	0	002	0	0
003-a	55	55	003	3940	3741
003-b	8179	7551			
012-1a	909	988	012-1	1283	1268
012-1b	19	19			
012-1c	0	0			
012-1d	2205	2161			
012-1e	23	24			
012-1f	1464	1448			
012-1g	0	0			
012-2	0	0	012-2	0	0
012-3	0	0	012-3	29	30
041-1a	423	438	041-1	350	371
041-1b	124	111			
041-2a	0	0	041-2a	0	0
041-2b	3	3	041-2b	30	35
041-2c	14	16	041-2c	41	48
041-2d	1	1	041-2d	0	0
042-a	612	625	042	5001	4179
042-b	0	0			
042-c	31	11			
042-d	0	0			
042-e	47	38			
042-f	868	815			
042-g	0	0			
042-h	0	0			
042-i	46	17			
042-j	58	20			
042-k	10	10			
042-l	96	101			
042-m	5364	4938			
042-n	200	159			
042-o	10	10			
042-p	5	5			
042-q	0	0			
042-r	8458	7696			
042-s	32	12			
042-t	0	0			

SAFETI Indoor PVS sub-area	2011 Day Indoor Population	2021 Day Indoor Population	SAFETI Outdoor PVS sub-area	2011 Day Outdoor Population	2021 Day Outdoor Population
042-u	82	45			
042-v	8	3			
043-a	108	104	043	1694	1587
043-b	668	640			
043-c	304	294			
043-d	20	20			
043-e	581	572			
043-f	405	399			
043-g	82	78			
043-h	561	553			
043-i	426	331			
043-j	771	585			
043-k	770	584			
044-a	207	156	044-a	84	76
044-b	69	52	044-b	8	6
044-c	2327	1702	044-c	1362	818
044-d	2	1	044-d	0	0
044-e	2	1	044-e	0	0
044-f	0	0	044-f	0	0
044-g	0	0	044-g	0	0
044-h	0	0	044-h	0	0
044-i	0	0	044-i	0	0
045	9266	8229	045	4372	3898
046-a	5164	3606	046	2175	1360
046-b	259	181			
046-c	0	0			
046-d	3	3			
047-1a	11446	10381	047-1	5146	4439
047-1b	164	127			
047-2	385	276	047-2	43	31
048-1a	7148	6437	048-1	5456	4966
048-1b	32	30			
048-1c	5	5			
048-1d	1410	1051			
048-2	45	42	048-2	52	49
049-1a	14060	18859	049-1	10468	13506
049-1b	6478	6478			
049-1c	153	390			
049-1d	10	32			

SAFETI Indoor PVS sub-area	2011 Day Indoor Population	2021 Day Indoor Population	SAFETI Outdoor PVS sub-area	2011 Day Outdoor Population	2021 Day Outdoor Population
049-2	0	0	049-2	0	0
049-3	0	0	049-3	0	0
049-4	8	8	049-4	14051	14414
051-1a	527	516	051-1	340	333
051-1b	403	395			
051-2	0	0	051-2	88	86
052-1a	1	1	052-1	837	789
052-1b	0	0			
052-1c	0	0			
052-1d	0	0			
052-1e	9	9			
052-1f	0	0			
052-1g	1324	1165			
052-1h	0	0			
052-2a	3	3	052-2	119	101
052-2b	187	177			
052-2c	2	2			
052-2d	3	3			
052-2e	0	0			
052-2f	0	0			
052-3a	2038	1501	052-3	0	0
052-3b	174	128			
052-3c	174	128			
052-4	20	19	052-4	23	22
151-a	3608	3615	151	3718	3800
151-b	253	260			
151-c	253	260			
151-d	506	519			
152-a	0	0	152	5763	5452
152-b	283	228			
152-c	193	142			
152-d	730	537			
152-e	0	0			
152-f	0	0			
152-g	561	537			
152-h	0	0			
152-i	620	508			
152-j	11	10			
152-k	5	5			

SAFETI Indoor PVS sub-area	2011 Day Indoor Population	2021 Day Indoor Population	SAFETI Outdoor PVS sub-area	2011 Day Outdoor Population	2021 Day Outdoor Population
152-l	977	893			
152-m	5173	4826			
152-n	1518	1410			
152-o	0	0			
153-a	4360	4129	153	2681	2557
153-b	1126	1081			
154-1a	1184	1111	154-1	635	596
154-1b	84	79			
154-2a	4501	4186	154-2	3892	3639
154-2b	84	79			
155-1a	1429	471	155-1	1015	331
155-1b	16	7			
155-1c	2	1			
155-1d	43	18			
155-1e	13	5			
155-1f	16	7			
155-1g	194	61			
155-1h	198	63			
155-1i	578	182			
155-1j	227	72			
155-1k	0	0			
155-1l	5	2			
155-1m	0	0			
155-1n	1452	465			
155-1o	65	21			
155-1p	0	0			
155-1q	5	2			
155-1r	11	4			
155-1s	5	2			
155-1t	177	61			
155-1u	5	2			
155-1v	973	308			
155-2	1	0	155-2	1	0
156-1a	51	52	156-1a	26	27
156-1b	168	147	156-1b	90	81
156-1c	211	223	156-1c	23	24
156-1d	4002	4100	156-1d	1195	1184
156-1f	703	603	156-1f	187	175
156-1g	949	784	156-1g	200	171

SAFETI Indoor PVS sub-area	2011 Day Indoor Population	2021 Day Indoor Population	SAFETI Outdoor PVS sub-area	2011 Day Outdoor Population	2021 Day Outdoor Population
156-1h	1325	1298	156-1h	639	651
156-1i	172	141	156-1i	21	17
156-1j	70	71	156-1j	56	57
156-1k	2189	2903	156-1k	1047	1140
156-1m	131	133	156-1m	111	110
156-1n	243	249	156-1n	167	170
156-1o	527	446	156-1o	240	226
156-1p	3761	3529	156-1p	1573	1590
156-1z	22	22	156-1z	23	24
156-2	93	94	156-2	104	107
156-3	215	180	156-3	40	36
156-4	215	180	156-4	40	36
156-5	193	157	156-5	21	17
156-6	0	0	156-6	3	2
156-7t	0	0	156-7	0	0
156-8u	0	0	156-8	3	2
157-1a	3321	2911	157-1	3487	3020
157-1b	193	166			
157-1c	6678	6633			
157-1d	0	0			
157-1e	5	5			
157-1f	2	1			
157-1g	215	172			
157-1h	227	178			
157-1i	2554	2254			
157-1j	2744	2401			
157-1k	7	4			
157-1l	0	0			
157-2	0	0	157-2	0	0
158-a	472	414	158	3037	2760
158-b	33	32			
158-c	102	89			
158-d	217	167			
158-e	880	660			
158-f	3113	2930			
158-g	0	0			
158-h	5931	4788			
158-i	1	1			
158-j	1	1			

SAFETI Indoor PVS sub-area	2011 Day Indoor Population	2021 Day Indoor Population	SAFETI Outdoor PVS sub-area	2011 Day Outdoor Population	2021 Day Outdoor Population
161-a	230	202	161	895	775
161-b	0	0			
161-c	2347	1873			
161-d	5	5			
161-e	5	5			
162	3231	3072	162	2886	2744
163-1	5	5	163-1	0	0
163-2	5	5	163-2	0	0
163-3	5	5	163-3	0	0
227-1a	0	5	227-1	0	2
227-1b	0	3			
227-1c	0	1			
227-2	0	0	227-2	0	0
227-3	0	0	227-3	0	0
230	6138	5858	230	2163	2093
233-a	0	0	233	0	0
233-b	0	0			
233-c	0	0			
234-a	0	0	234	53	41
234-b	257	197			
234-c	0	0			
239-1	54	21	239-1	4	2
239-10	172	66	239-10	21	8
239-11	0	0	239-11	0	0
239-12	0	0	239-12	0	0
239-13	0	0	239-13	0	0
239-14	0	0			
239-2	172	66	239-2	21	8
239-3	345	133	239-3	42	16
239-4	0	0	239-4	0	0
239-5	0	0	239-5	0	0
239-6	0	0	239-6	0	0
239-7	5	3	239-7	0	0
239-8	0	0	239-8	0	0
239-9	0	0	239-9	0	0
240	193	148	240	21	16
247-1	3	3	247-1	0	0
247-2a	0	0	247-2	0	0
247-2b	0	0			

SAFETI Indoor PVS sub-area	2011 Day Indoor Population	2021 Day Indoor Population	SAFETI Outdoor PVS sub-area	2011 Day Outdoor Population	2021 Day Outdoor Population
251-10	0	0	251-10	0	0
251-11	405	417	251-11	41	42
251-12	405	417	251-12	41	42
251-1a	62	55	251-1	389	350
251-1b	13	12			
251-1c	20	17			
251-1d	1	1			
251-1e	33	29			
251-1f	1	1			
251-1g	1	1			
251-1h	1	1			
251-1i	10	9			
251-1j	17	15			
251-1k	6	5			
251-1l	4	3			
251-1m	1	1			
251-1n	1337	1222			
251-1o	147	125			
251-1p	6	5			
251-1q	4	3			
251-1r	2	2			
251-1s	0	0			
251-2	7	6	251-2	2	2
251-3	1	1	251-3	0	0
251-4a	1	1	251-4	11	10
251-4b	6	5			
251-4c	24	21			
251-4d	6	5			
251-4e	5	4			
251-5a	0	0	251-5	11	9
251-5b	21	18			
251-5c	1	1			
251-5d	39	38			
251-5e	4	3			
251-6	47	37	251-6	5	4
251-7a	0	0	251-7	86	68
251-7b	193	152			
251-7c	4	4			
251-7d	582	462			

SAFETI Indoor PVS sub-area	2011 Day Indoor Population	2021 Day Indoor Population	SAFETI Outdoor PVS sub-area	2011 Day Outdoor Population	2021 Day Outdoor Population
251-8a	0	0	251-8	197	199
251-8b	0	0			
251-8c	32	28			
251-8d	21	18			
251-8e	28	25			
251-8f	0	0			
251-9	0	0	251-9	0	0
258-a	241	186	258	986	769
258-b	178	138			
258-c	5	5			
258-d	0	0			
258-e	0	0			
258-f	0	0			
258-g	11	11			
258-h	7254	5688			
258-i	0	0			
258-j	193	148			
258-k	385	296			
258-l	193	148			
258-m	193	148			
258-n	193	148			
259-1a	2965	3967	259-1	715	1116
259-1b	0	0			
259-1c	11	11			
259-2a	6	6	259-2	0	0
259-2b	6	6			
259-2c	6	6			
259-2d	26	26			
259-3	3	3	259-3	0	0
259-4a	100	100	259-4	0	0
259-4b	6	6			
259-5	3	3	259-5	0	0
259-6	3	3	259-6	0	0
259-7a	37	64	259-7	0	0
259-7b	11	18			
259-7c	5	9			
259-7d	5	9			
284-1	3	3	284-1	0	0
284-2	0	0	284-2	0	0

SAFETI Indoor PVS sub-area	2011 Day Indoor Population	2021 Day Indoor Population	SAFETI Outdoor PVS sub-area	2011 Day Outdoor Population	2021 Day Outdoor Population
327-1a	48	48	327-1	0	0
327-1b	5	5			
327-1c	42	42			
327-2a	0	0	327-2	0	0
327-2b	0	0			
327-3	193	148	327-3	21	16
327-4c	0	0	327-4	0	0
327-4d	0	0			
338-1a	12	10	338-1	1509	1184
338-1b	1	1			
338-1c	5372	4214			
338-1d	1	1			
338-1e	5	4			
338-1f	3	2			
338-1g	0	0			
338-1h	5	4			
338-1i	6	5			
338-1j	0	0			
338-2	578	382	338-2	64	42
338-3	34	23	338-3	4	3
FD10		4	FD10		5
FD14		41	FD14		48
FD15		36	FD15		41
FD2		90	FD2		105
FD23		180	FD23		209
FD24		59	FD24		68
FD25		12	FD25		14
FD26		23	FD26		27
FD27		2	FD27		3
FD28		1	FD28		1
FD29		1	FD29		1
FD3		159	FD3		184
FD30		356	FD30		412
FD4		71	FD4		82
FD5		29	FD5		34
FD6		94	FD6		109
FD7		345	FD7		400

Table I-16 Road Traffic Population Data

Highway	2011 & 2021 Population
Cheung Tsing Highway	1448
Cheung Tsing Tunnel	448
Lantau Link	1729
North West Tsing Yi Interchange	984
Tsing Long Highway	2929
Tuen Mun Road	8891

Table I-17 Marine Population Vessel Classes

Vessel Class	Assumed Velocity (m/s)	Assumed Population	Exposure Factor
Small Craft & Fast Launches	6	5	0.9
Fast Ferries	15	180	0.3
Tug & Tow	2.5	5	0.9
River trade vessels	6	5	0.3
Ocean-going vessels	6	21	0.1

Table I-18 Fast Ferry Population Data

Average Population per Vessel	Fraction of Trips
450 (largest ferries with max population)	0.0375
350 (typical ferry with max population)	0.0375
280 (80% capacity, peak hours, 4 hours a day)	0.225
175 (50% capacity, daytime operation, 9 hours a day)	0.525
105 (30% capacity, late evening, 4 hours a day)	0.125
35 (10% capacity, night time, 7 hours a day)	0.500

Table I-19 Marine Population Data for Underway Vessels Provided in the MIA Report (adjusted for Fast Ferry Populations)

Y	X	SAFETI Marine Population Area	2011 Population at Risk (per km^2)	2021 Population at Risk (per km^2)
D	1	M1-1	0	0
D	2	M1-2	0.08	0.10
D	3	M1-3	0.08	0.10
E	1	M2-1	0.03	0.04
E	2	M2-2	1.86	2.17
E	3	M2-3	8.03	8.98
E	4	M2-4	0.39	0.43
F	1	M3-1	0.10	0.11
F	2	M3-2	0.30	0.33
F	3	M3-3	7.43	8.45
F	4	M3-4	3.32	3.68
G	1	M4-1	0.10	0.11
G	2	M4-2	0.19	0.21
G	3	M4-3	0.72	0.84
G	4	M4-4	7.41	8.34
G	5	M4-5	6.98	7.86
G	6	M4-6	5.11	5.76
G	7	M4-7	3.70	4.19
G	8	M4-8	3.14	3.59
G	9	M4-9	3.26	3.77
H	1	M5-1	0.02	0.03
H	2	M5-2	0.02	0.03
H	3	M5-3	3.08	3.62
H	4	M5-4	5.14	6.04
H	5	M5-5	10.65	12.42
H	6	M5-6	0.74	0.87
H	7	M5-7	1.61	1.86
H	8	M5-8	2.33	2.66
H	9	M5-9	8.96	10.35
H	10	M5-10	3.55	4.05
I	1	M6-1	0.85	0.97
I	2	M6-2	3.11	3.66
I	3	M6-3	5.59	6.59
I	5	M6-5	5.90	6.80
I	7	M6-7	0.48	0.57
I	8	M6-8	2.92	3.43
I	9	M6-9	7.68	8.94
I	10	M6-10	21.87	25.47
I	12	M6-12	0.31	0.34
J	1	M7-1	0.73	0.84
J	2	M7-2	5.53	6.52
J	3	M7-3	0.03	0.04

Y	X	SAFETI Marine Population Area	2011 Population at Risk (per km^2)	2021 Population at Risk (per km^2)
J	7	M7-7	0.60	0.70
J	8	M7-8	3.85	4.51
J	9	M7-9	12.78	15.02
J	10	M7-10	3.91	4.42
K	1	M8-1	3.09	3.63
K	7	M8-7	5.54	6.52
K	8	M8-8	7.21	8.48
K	9	M8-9	0.71	0.78
K	10	M8-10	1.54	1.76
K	11	M8-11	1.91	2.16
K	12	M8-12	0.45	0.49
L	1	M9-1	9.62	11.24
L	2	M9-2	5.25	6.13
L	3	M9-3	5.82	6.83
L	4	M9-4	6.91	8.11
L	5	M9-5	5.95	6.97
L	6	M9-6	5.95	6.97
L	7	M9-7	5.17	6.03
L	8	M9-8	0.13	0.14
L	9	M9-9	0.61	0.67
L	10	M9-10	0.03	0.04
L	11	M9-11	1.15	1.34
L	12	M9-12	2.19	2.51
L	13	M9-13	0.32	0.35
M	1	M10-1	0.30	0.33
M	2	M10-2	0.82	0.90
M	3	M10-3	0.47	0.52
M	4	M10-4	0.03	0.04
M	5	M10-5	0.03	0.04
M	6	M10-6	0.03	0.04
M	7	M10-7	0.58	0.64
M	8	M10-8	0.58	0.63
M	9	M10-9	0.25	0.27
M	10	M10-10	0.18	0.20
M	11	M10-11	0.18	0.19
M	12	M10-12	0.76	0.87
M	13	M10-13	1.40	1.61
M	14	M10-14	0.06	0.07

Table I-20 Daytime and Nighttime Marine Population Data for Underway Vessels

SAFETI Marine Population Area	2011 Daytime Population at Risk (per km^2)	2011 Nighttime Population at Risk (per km^2)	2021 Daytime Population at Risk (per km^2)	2021 Nighttime Population at Risk (per km^2)
M1-1	0	0	0	0
M1-2	0.12	0.04	0.15	0.05
M1-3	0.12	0.04	0.15	0.05
M2-1	0.05	0.02	0.05	0.02
M2-2	2.80	0.93	3.25	1.08
M2-3	12.05	4.02	13.47	4.49
M2-4	0.59	0.20	0.65	0.22
M3-1	0.15	0.05	0.17	0.06
M3-2	0.45	0.15	0.49	0.16
M3-3	11.14	3.71	12.67	4.22
M3-4	4.98	1.66	5.52	1.84
M4-1	0.14	0.05	0.16	0.05
M4-2	0.28	0.09	0.31	0.10
M4-3	1.08	0.36	1.26	0.42
M4-4	11.12	3.71	12.51	4.17
M4-5	10.46	3.49	11.79	3.93
M4-6	7.66	2.55	8.64	2.88
M4-7	5.55	1.85	6.29	2.10
M4-8	4.71	1.57	5.39	1.80
M4-9	4.88	1.63	5.66	1.89
M5-1	0.04	0.01	0.04	0.01
M5-2	0.04	0.01	0.04	0.01
M5-3	4.62	1.54	5.43	1.81
M5-4	7.70	2.57	9.06	3.02
M5-5	15.97	5.32	18.64	6.21
M5-6	1.12	0.37	1.31	0.44
M5-7	2.41	0.80	2.79	0.93
M5-8	3.50	1.17	3.98	1.33
M5-9	13.45	4.48	15.52	5.17
M5-10	5.32	1.77	6.07	2.02
M6-1	1.28	0.43	1.46	0.49
M6-2	4.66	1.55	5.48	1.83
M6-3	8.39	2.80	9.88	3.29
M6-5	8.86	2.95	10.20	3.40
M6-7	0.72	0.24	0.86	0.29
M6-8	4.39	1.46	5.14	1.71
M6-9	11.52	3.84	13.41	4.47
M6-10	32.80	10.93	38.21	12.74
M6-12	0.47	0.16	0.51	0.17
M7-1	1.10	0.37	1.26	0.42
M7-2	8.29	2.76	9.77	3.26
M7-3	0.05	0.02	0.05	0.02

SAFETI Marine Population Area	2011 Daytime Population at Risk (per km^2)	2011 Nighttime Population at Risk (per km^2)	2021 Daytime Population at Risk (per km^2)	2021 Nighttime Population at Risk (per km^2)
M7-7	0.90	0.30	1.05	0.35
M7-8	5.77	1.92	6.76	2.25
M7-9	19.17	6.39	22.53	7.51
M7-10	5.86	1.95	6.63	2.21
M8-1	4.63	1.54	5.45	1.82
M8-7	8.31	2.77	9.79	3.26
M8-8	10.81	3.60	12.72	4.24
M8-9	1.06	0.35	1.16	0.39
M8-10	2.32	0.77	2.63	0.88
M8-11	2.87	0.96	3.25	1.08
M8-12	0.67	0.22	0.74	0.25
M9-1	14.43	4.81	16.87	5.62
M9-2	7.88	2.63	9.19	3.06
M9-3	8.73	2.91	10.25	3.42
M9-4	10.36	3.45	12.17	4.06
M9-5	8.92	2.97	10.46	3.49
M9-6	8.92	2.97	10.46	3.49
M9-7	7.75	2.58	9.05	3.02
M9-8	0.19	0.06	0.21	0.07
M9-9	0.91	0.30	1.00	0.33
M9-10	0.05	0.02	0.05	0.02
M9-11	1.73	0.58	2.01	0.67
M9-12	3.29	1.10	3.76	1.25
M9-13	0.48	0.16	0.53	0.18
M10-1	0.45	0.15	0.49	0.16
M10-2	1.24	0.41	1.36	0.45
M10-3	0.71	0.24	0.78	0.26
M10-4	0.05	0.02	0.05	0.02
M10-5	0.05	0.02	0.05	0.02
M10-6	0.05	0.02	0.05	0.02
M10-7	0.87	0.29	0.95	0.32
M10-8	0.86	0.29	0.95	0.32
M10-9	0.37	0.12	0.41	0.14
M10-10	0.27	0.09	0.30	0.10
M10-11	0.26	0.09	0.29	0.10
M10-12	1.14	0.38	1.31	0.44
M10-13	2.09	0.70	2.41	0.80
M10-14	0.10	0.03	0.11	0.04

Table I-21 Marine Population Data for Stationary Vessels Provided in the MIA Report

Y	X	SAFETI Marine Population Area	2011 Population at Risk (per km^2)	2021 Population at Risk (per km^2)
F	2	M3-2	6.08	6.29
G	3	M4-3	37.79	41.18
G	4	M4-4	10.85	11.79
G	5	M4-5	28.20	27.44
H	7	M5-7	6.38	7.28
H	8	M5-8	37.55	39.70
I	7	M6-7	2.95	3.16
I	8	M6-8	40.03	42.71
I	9	M6-9	35.76	38.30
J	7	M7-7	3.38	3.64
J	8	M7-8	3.38	3.64
J	9	M7-9	10.58	11.28
K	8	M8-8	13.73	14.69
K	9	M8-9	11.61	12.13
K	10	M8-10	76.67	71.10

Table I-22 Daytime and Nighttime Marine Population Data for Stationary Vessels

SAFETI Marine Population Area	2011 Daytime Population at Risk (per km^2)	2011 Nighttime Population at Risk (per km^2)	2021 Daytime Population at Risk (per km^2)	2021 Nighttime Population at Risk (per km^2)
M3-2	6.08	1.82	6.29	1.89
M4-3	37.79	11.34	41.18	12.36
M4-4	10.85	3.25	11.79	3.54
M4-5	28.20	8.46	27.44	8.23
M5-7	6.38	1.91	7.28	2.19
M5-8	37.55	11.26	39.70	11.91
M6-7	2.95	0.89	3.16	0.95
M6-8	40.03	12.01	42.71	12.81
M6-9	35.76	10.73	38.30	11.49
M7-7	3.38	1.01	3.64	1.09
M7-8	3.38	1.01	3.64	1.09
M7-9	10.58	3.17	11.28	3.38
M8-8	13.73	4.12	14.69	4.41
M8-9	11.61	3.48	12.13	3.64
M8-10	76.67	23.00	71.10	21.33

Table I-23 Total Marine Population Data without Fast Ferries during Daytime

Marine Population Area	2011 Population Density (per km^2)	2021 Population Density (per km^2)
M1-1	0.00	0.00
M1-2	0.02	0.02
M1-3	0.03	0.04
M2-1	0.05	0.05
M2-2	0.49	0.53
M2-3	5.33	5.85
M2-4	0.53	0.58
M3-1	0.09	0.10
M3-2	0.33	0.36
M3-3	4.79	5.20
M3-4	6.65	7.28
M4-1	0.14	0.16
M4-2	0.20	0.22
M4-3	0.17	0.19
M4-4	27.74	30.20
M4-5	19.86	21.60
M4-6	38.74	37.20
M4-7	7.53	8.27
M4-8	4.53	4.98
M4-9	2.69	2.95
M5-1	0.02	0.02
M5-2	0.02	0.02
M5-3	0.26	0.28
M5-4	0.45	0.49
M5-5	3.04	3.33
M5-6	0.13	0.15
M5-7	0.82	0.91
M5-8	12.32	14.50
M5-9	27.55	29.20
M5-10	4.03	4.44
M6-1	0.43	0.47
M6-2	0.30	0.33
M6-3	0.43	0.47
M6-5	6.05	6.62
M6-7	0.00	0.00
M6-8	2.43	2.62
M6-9	19.01	20.45
M6-10	22.92	24.61
M6-12	0.40	0.43
M7-1	0.19	0.20
M7-2	0.37	0.41
M7-3	0.16	0.18
M7-7	0.30	0.33

Marine Population Area	2011 Population Density (per km^2)	2021 Population Density (per km^2)
M7-8	2.39	2.61
M7-9	2.65	2.90
M7-10	10.79	11.77
M8-1	0.12	0.14
M8-7	0.39	0.43
M8-8	0.58	0.63
M8-9	6.77	7.37
M8-10	10.43	10.97
M8-11	101.00	94.02
M8-12	1.18	1.30
M9-1	1.71	1.87
M9-2	1.95	2.14
M9-3	0.86	0.94
M9-4	1.25	1.37
M9-5	0.96	1.05
M9-6	1.10	1.20
M9-7	1.31	1.43
M9-8	0.20	0.22
M9-9	0.91	1.00
M9-10	0.08	0.09
M9-11	1.44	1.60
M9-12	1.52	1.68
M9-13	0.62	0.68
M10-1	0.33	0.36
M10-2	0.78	0.85
M10-3	0.47	0.51
M10-4	0.06	0.06
M10-5	0.05	0.05
M10-6	0.05	0.05
M10-7	0.81	0.89
M10-8	0.86	0.95
M10-9	0.35	0.38
M10-10	0.18	0.20
M10-11	0.23	0.25
M10-12	0.57	0.63
M10-13	0.64	0.71
M10-14	0.12	0.14

Note: It is assumed that the population is 100% outdoors.

Table I-24 Fast Ferry Probabilities of Occurrence, 2011 Large Carrier

Corresponding Marine Population Block	Relevant Collision Frequency Segment	Fast Ferry Day Freq. of Occurrence (from BMT Analysis)	Probability Accounting for Intersecting Hazard			
			Grounding	Small Collision	Medium Collision	Large Collision
M2-2	BP	0.153	0.0016	0.0007	0.0084	0.0326
M2-3	BP	0.204	0.0021	0.0009	0.0113	0.0434
M3-3	BP	0.356	0.0037	0.0016	0.0197	0.0760
M3-4	BP	0.051	0.0014	0.0006	0.0072	0.0278
M4-3	BP	0.051	0.0005	0.0002	0.0028	0.0109
M4-4	½ BP & ½ TM2	0.255	0.0034	0.0014	0.0182	0.0702
M4-5	TM2	0.255	0.0055	0.0023	0.0296	0.1141
M4-6	TM2	0.204	0.0032	0.0014	0.0173	0.0667
M4-7	½ TM2 & ½ TM1	0.153	0.0059	0.0025	0.0312	0.1205
M4-8	½ MW4 & ½ MW3	0.153	0.0053	0.0022	0.0285	0.1100
M4-9	MW3	0.255	0.0093	0.0039	0.0497	0.1916
M5-3	BP	0.306	0.0032	0.0013	0.0169	0.0651
M5-4	½ TM2 & ½ BP	0.509	0.0053	0.0022	0.0281	0.1085
M5-5	TM2	0.917	0.0101	0.0043	0.0541	0.2087
M5-6	TM2	0.051	0.0005	0.0002	0.0029	0.0110
M5-7	½ TM1 & ½ TM2	0.102	0.0016	0.0007	0.0086	0.0333
M5-8	MW4	0.102	0.0025	0.0011	0.0135	0.0523
M5-9	MW2	0.611	0.0083	0.0035	0.0441	0.1700
M5-10	MW1	0.153	0.0039	0.0017	0.0209	0.0808
M6-5	TM2	0.407	0.0083	0.0035	0.0443	0.1710
M6-9	MW1	0.560	0.0059	0.0025	0.0313	0.1207
M6-10	MW1	1.833	0.0193	0.0081	0.1028	0.3966
M7-9	ALCGI	1.222	0.0128	0.0054	0.0682	0.2629
M7-10	ALCGI	0.102	0.0014	0.0006	0.0076	0.0292
M8-11	ALCGI	0.051	0.0007	0.0003	0.0036	0.0140
M9-12	Approach	0.051	0.0005	0.0002	0.0029	0.0111
M10-13	Approach & Soko Entry	0.051	0.0005	0.0002	0.0028	0.0109

Table I-25 Final Fast Ferry Point Location Probability of Occurrence, 2011 Large Carrier

Collision Frequency Segment	Grounding	Small Collision	Medium Collision	Large Collision
Black Point	0.017	0.007	0.089	0.345
TM2	0.035	0.015	0.187	0.721
TM1	0.004	0.002	0.020	0.077
MW4	0.005	0.002	0.028	0.107
MW3	0.012	0.005	0.064	0.247
MW2	0.008	0.003	0.044	0.170
MW1	0.029	0.012	0.155	0.598
ALCGI	0.015	0.006	0.079	0.306
Approach	0.0011	0.0004	0.006	0.022
Soko Entry	0.0005	0.0002	0.003	0.011

Table I-26 Night Land Population Data

SAFETI Indoor PVS sub-area	2011 Night Indoor Population	2021 Night Indoor Population	SAFETI Outdoor PVS sub-area	2011 Night Outdoor Population	2021 Night Outdoor Population
161-a	728	638	161	5	4
161-b	0	0			
161-c	1806	1546			
161-d	0	0			
161-e	0	0			
162	7558	7187	162	0	0
258-a	36	28	258	10	8
258-b	26	20			
258-c	0	0			
258-d	0	0			
258-e	0	0			
258-f	0	0			
258-g	0	0			
258-h	1395	1092			
258-i	0	0			
258-j	37	29			
258-k	75	58			
258-l	37	29			
258-m	37	29			
258-n	37	29			
259-1a	553	864	259-1	0	0
259-1b	0	0			
259-1c	2	2			
259-2a	1	1	259-2	0	0
259-2b	1	1			
259-2c	1	1			

SAFETI Indoor PVS sub-area	2011 Night Indoor Population	2021 Night Indoor Population	SAFETI Outdoor PVS sub-area	2011 Night Outdoor Population	2021 Night Outdoor Population
259-2d	5	5			
259-3	1	1	259-3	0	0
259-4a	18	18	259-4	0	0
259-4b	1	1			
259-5	1	1	259-5	0	0
259-6	1	1	259-6	0	0
259-7a	0	0	259-7	0	0
259-7b	0	0			
259-7c	0	0			
259-7d	0	0			
TOTAL	12357	11581	TOTAL	15	12

Table I-27 Total Marine Population Data without Fast Ferries during Nighttime

Marine Population Area	2011 Population Density (per km^2)	2021 Population Density (per km^2)
M1-1	0.00	0.00
M1-2	0.01	0.01
M1-3	0.01	0.01
M2-1	0.01	0.02
M2-2	0.19	0.21
M2-3	2.36	2.58
M2-4	0.21	0.23
M3-1	0.05	0.05
M3-2	0.14	0.15
M3-3	1.97	2.14
M3-4	2.88	3.15
M4-1	0.04	0.05
M4-2	0.08	0.09
M4-3	0.07	0.08
M4-4	9.82	10.72
M4-5	7.76	8.44
M4-6	13.01	12.82
M4-7	2.84	3.11
M4-8	1.88	2.07
M4-9	1.11	1.22
M5-1	0.00	0.01
M5-2	0.00	0.01
M5-3	0.08	0.08
M5-4	0.13	0.15
M5-5	0.91	1.00
M5-6	0.06	0.07
M5-7	0.32	0.35

Marine Population Area	2011 Population Density (per km^2)	2021 Population Density (per km^2)
M5-8	4.22	4.94
M5-9	10.67	11.37
M5-10	1.55	1.70
M6-1	0.13	0.14
M6-2	0.09	0.10
M6-3	0.13	0.14
M6-5	1.81	1.99
M6-7	0.00	0.00
M6-8	0.77	0.84
M6-9	7.84	8.48
M6-10	8.34	9.00
M6-12	0.12	0.13
M7-1	0.06	0.06
M7-2	0.11	0.12
M7-3	0.05	0.05
M7-7	0.09	0.10
M7-8	0.74	0.81
M7-9	0.90	0.99
M7-10	3.82	4.17
M8-1	0.04	0.04
M8-7	0.12	0.13
M8-8	0.17	0.19
M8-9	2.38	2.59
M8-10	3.71	3.93
M8-11	27.42	25.55
M8-12	0.35	0.39
M9-1	0.60	0.66
M9-2	0.59	0.64
M9-3	0.26	0.28
M9-4	0.37	0.41
M9-5	0.29	0.32
M9-6	0.33	0.36
M9-7	0.44	0.49
M9-8	0.06	0.06
M9-9	0.27	0.30
M9-10	0.02	0.03
M9-11	0.44	0.49
M9-12	0.59	0.66
M9-13	0.19	0.20
M10-1	0.14	0.15
M10-2	0.34	0.37
M10-3	0.18	0.20
M10-4	0.02	0.02
M10-5	0.01	0.02

Marine Population Area	2011 Population Density (per km^2)	2021 Population Density (per km^2)
M10-6	0.01	0.02
M10-7	0.26	0.29
M10-8	0.26	0.28
M10-9	0.11	0.12
M10-10	0.08	0.08
M10-11	0.07	0.08
M10-12	0.22	0.24
M10-13	0.30	0.33
M10-14	0.04	0.04

Table I-28 Marine Vessel Traffic Classes

Vessel Class	Assumed Velocity (m/s)	Assumed Vessel Area (m^2)
Small Craft & Fast Launches	6	75 (15m x 5m)
Fast Ferries	15	600 (50m x 12m)
Tug & Tow	2.5	2400 (120m x 20m)
Rivertrade Coastal vessels	6	2000 (100m x 20m)
Ocean-going vessels	6	21000 (350m x 60m)

Table I-29 Daytime Marine Ignition Source Data

Marine Population Area	2011 Operating Probability	2021 Operating Probability
M1-1	0	0
M1-2	1.8E-04	2.2E-04
M1-3	3.6E-04	4.4E-04
M2-1	7.2E-07	7.9E-07
M2-2	1.4E-04	1.6E-04
M2-3	3.8E-03	4.2E-03
M2-4	1.3E-04	1.4E-04
M3-1	5.6E-05	6.1E-05
M3-2	1.1E-04	1.2E-04
M3-3	8.6E-03	8.9E-03
M3-4	4.0E-03	4.4E-03
M4-1	2.2E-06	2.4E-06
M4-2	7.7E-05	8.4E-05
M4-3	2.6E-04	3.1E-04
M4-4	2.4E-02	2.4E-02
M4-5	1.5E-02	1.6E-02
M4-6	1.1E-02	1.1E-02
M4-7	5.4E-03	6.0E-03
M4-8	4.7E-03	5.4E-03
M4-9	1.7E-03	1.9E-03
M5-1	1.9E-05	2.1E-05

Marine Population Area	2011 Operating Probability	2021 Operating Probability
M5-2	1.9E-05	2.1E-05
M5-3	3.7E-05	4.2E-05
M5-4	5.0E-05	5.7E-05
M5-5	2.9E-04	3.4E-04
M5-6	4.3E-04	5.1E-04
M5-7	8.9E-04	1.0E-03
M5-8	9.6E-03	9.9E-03
M5-9	3.1E-02	3.2E-02
M5-10	4.4E-03	5.1E-03
M6-1	1.2E-04	1.3E-04
M6-2	3.8E-05	4.3E-05
M6-3	3.3E-05	3.8E-05
M6-5	1.3E-04	1.4E-04
M6-7	7.9E-06	9.4E-06
M6-8	2.5E-03	2.6E-03
M6-9	2.9E-02	2.9E-02
M6-10	1.9E-02	1.9E-02
M6-12	4.9E-04	5.4E-04
M7-1	1.8E-04	1.9E-04
M7-2	3.5E-05	4.1E-05
M7-3	2.5E-06	2.7E-06
M7-7	4.5E-05	5.0E-05
M7-8	2.0E-03	2.0E-03
M7-9	2.5E-03	2.7E-03
M7-10	1.0E-02	1.1E-02
M8-1	1.7E-04	1.9E-04
M8-7	1.2E-04	1.3E-04
M8-8	1.9E-04	2.1E-04
M8-9	8.4E-03	8.4E-03
M8-10	1.1E-02	1.2E-02
M8-11	1.1E-02	1.1E-02
M8-12	1.8E-05	1.9E-05
M9-1	4.6E-04	5.0E-04
M9-2	1.2E-04	1.3E-04
M9-3	4.2E-05	4.9E-05
M9-4	5.9E-05	6.9E-05
M9-5	4.1E-05	4.7E-05
M9-6	4.7E-05	5.4E-05
M9-7	2.2E-04	2.5E-04
M9-8	3.0E-06	3.2E-06
M9-9	1.4E-05	1.5E-05
M9-10	1.2E-06	1.4E-06
M9-11	2.3E-03	2.8E-03
M9-12	1.7E-03	2.0E-03

Marine Population Area	2011 Operating Probability	2021 Operating Probability
M9-13	9.3E-06	1.0E-05
M10-1	1.1E-04	1.2E-04
M10-2	4.4E-04	4.8E-04
M10-3	2.3E-04	2.5E-04
M10-4	8.6E-07	9.4E-07
M10-5	7.2E-07	7.9E-07
M10-6	7.2E-07	7.9E-07
M10-7	6.7E-05	7.3E-05
M10-8	1.3E-05	1.4E-05
M10-9	2.4E-05	2.7E-05
M10-10	1.0E-04	1.1E-04
M10-11	4.2E-05	4.6E-05
M10-12	8.8E-04	1.1E-03
M10-13	1.0E-03	1.2E-03
M10-14	1.8E-06	2.0E-06

Table I-30 Night Marine Ignition Source Data

Marine Population Area	2011 Operating Probability	2021 Operating Probability
M1-1	0	0
M1-2	6.1E-05	7.4E-05
M1-3	1.2E-04	1.5E-04
M2-1	2.4E-07	2.6E-07
M2-2	4.8E-05	5.2E-05
M2-3	1.3E-03	1.4E-03
M2-4	4.3E-05	4.7E-05
M3-1	1.9E-05	2.0E-05
M3-2	3.8E-05	4.2E-05
M3-3	2.7E-03	2.8E-03
M3-4	1.3E-03	1.5E-03
M4-1	7.2E-07	7.9E-07
M4-2	2.6E-05	2.8E-05
M4-3	8.7E-05	1.0E-04
M4-4	7.3E-03	7.4E-03
M4-5	4.7E-03	4.9E-03
M4-6	3.3E-03	3.4E-03
M4-7	1.8E-03	2.0E-03
M4-8	1.6E-03	1.8E-03
M4-9	5.7E-04	6.3E-04
M5-1	6.4E-06	7.0E-06
M5-2	6.4E-06	7.0E-06
M5-3	1.2E-05	1.4E-05
M5-4	1.7E-05	1.9E-05
M5-5	9.5E-05	1.1E-04

Marine Population Area	2011 Operating Probability	2021 Operating Probability
M5-6	1.4E-04	1.7E-04
M5-7	3.0E-04	3.5E-04
M5-8	2.9E-03	3.0E-03
M5-9	9.5E-03	9.6E-03
M5-10	1.5E-03	1.7E-03
M6-1	4.1E-05	4.5E-05
M6-2	1.3E-05	1.4E-05
M6-3	1.1E-05	1.3E-05
M6-5	4.3E-05	4.8E-05
M6-7	2.6E-06	3.1E-06
M6-8	7.6E-04	7.9E-04
M6-9	8.6E-03	8.7E-03
M6-10	5.8E-03	5.8E-03
M6-12	1.6E-04	1.8E-04
M7-1	5.9E-05	6.4E-05
M7-2	1.2E-05	1.4E-05
M7-3	8.2E-07	9.0E-07
M7-7	1.5E-05	1.7E-05
M7-8	6.0E-04	6.0E-04
M7-9	7.9E-04	8.3E-04
M7-10	3.1E-03	3.3E-03
M8-1	5.6E-05	6.2E-05
M8-7	4.0E-05	4.5E-05
M8-8	6.2E-05	6.9E-05
M8-9	2.5E-03	2.5E-03
M8-10	3.5E-03	3.6E-03
M8-11	3.3E-03	3.4E-03
M8-12	5.9E-06	6.5E-06
M9-1	1.5E-04	1.7E-04
M9-2	3.9E-05	4.4E-05
M9-3	1.4E-05	1.6E-05
M9-4	2.0E-05	2.3E-05
M9-5	1.4E-05	1.6E-05
M9-6	1.6E-05	1.8E-05
M9-7	7.5E-05	8.3E-05
M9-8	9.9E-07	1.1E-06
M9-9	4.6E-06	5.0E-06
M9-10	4.1E-07	4.5E-07
M9-11	7.8E-04	9.4E-04
M9-12	5.5E-04	6.6E-04
M9-13	3.1E-06	3.4E-06
M10-1	3.8E-05	4.2E-05
M10-2	1.5E-04	1.6E-04
M10-3	7.7E-05	8.4E-05

Marine Population Area	2011 Operating Probability	2021 Operating Probability
M10-4	2.9E-07	3.1E-07
M10-5	2.4E-07	2.6E-07
M10-6	2.4E-07	2.6E-07
M10-7	2.2E-05	2.4E-05
M10-8	4.3E-06	4.7E-06
M10-9	8.1E-06	8.8E-06
M10-10	3.4E-05	3.7E-05
M10-11	1.4E-05	1.5E-05
M10-12	2.9E-04	3.5E-04
M10-13	3.4E-04	4.0E-04
M10-14	6.2E-07	6.8E-07

Table I-31 Road Traffic Ignition Sources

Road	Ignition Probability	Time Period (s)	Cars per Day	Speed (kph)
Cheung Tsing Highway	0.40	60	97490	60
Cheung Tsing Tunnel	0	60	80250	60
Lantau Link	0.40	60	46980	60
North West Tsing Yi Interchange	0.40	60	43805	60
Tsing Long Highway	0.40	60	117260	60
Tuen Mun Road	0.40	60	90029	60

Table I-32 MQRA Scenarios

Route	Hazard No.	Title	HAZID Route Node	Potential Brach of containment of LNG Carrier?
Black Point	H1	Grounding	1-7	Yes
	H4	Powered Collision of another vessel into LNGC	1-7	Yes
South Soko	H1	Grounding	1-4	Yes
	H4	Powered Collision of another vessel into LNGC	1-4	Yes

Note: Although the Sandia Report suggests that grounding events do not pose public risk and there have been no existing loss of containment for grounding, this report includes grounding events in the analysis. The most credible scenario in the analysis was determined to be a small hole in the cargo tank (250mm) as the result of grounding event.

Table I-33 Modeled Scenarios

Event	Release Case	Consequences
Collision **Grounding**	**250 mm**	**Dispersion Cloud** **Pool Fire** **Flash Fire + Pool Fire**
Collision	**750 mm**	**Dispersion Cloud** **Pool Fire** **Flash Fire + Pool Fire**
Collision **Berthing**	**1500 mm**	**Dispersion Cloud** **Pool Fire** **Flash Fire + Pool Fire**

Table I-34 Study LNG Carrier Dimensions

LNG Carrier Tank Dimension	Small	Large
Carrier volume capacity (m^3)	145,000	215,000
Number of tanks	5	5
Max capacity per tank	29,000	43,000
Width (m)	33	40
Length (m)	35	40
Height (m)	25.5	26.875
Volume (m^3)	29,453	43,000
Carrier Tank Height under water (m)	10	10
LNG liquid head for release 0.5m above sea level (m)	15	16.4
LNG liquid head for release below sea level, 0.5m above bottom of tank (m)	24.5	25.875

Table I-35 Release Scenario Model Input

Inputs used for Large Carrier					
	Collision Releases			Grounding Release	Berth Release
Parameter	**Small**	**Medium**	**Large**		
Hole size (mm)	250	750	1500	250	1500
Inventory (kg)	1.11E7	1.11E7	1.11E7	1.76E7	1.11E7
Release Rate (kg/s)	223.9	2015	8060	159.8	8060
Discharge Velocity (m/s)	10.74	10.74	10.74	7.66	10.74
Final Temperature (°C)	-165	-165	-165	-165	-165
Duration of Discharge (s)	3600	3600	3600	3600	3600
Droplet Diameter (mm)	10	10	10	10	10
Direction of Release	Horizontal	Horizontal	Horizontal	Horizontal	Horizontal
Elevation (m)	0.5	0.5	0.5	0	0.5
Input used for Small Carrier					
	Collision Releases			Grounding Release	Berth Release
Parameter	**Small**	**Medium**	**Large**		
Hole size (mm)	250	750	1500	250	1500
Inventory (kg)	7.36E6	7.36E6	7.36E6	1.20E7	7.36E6
Release Rate (kg/s)	214.4	1930	7720	146	7720
Discharge Velocity (m/s)	10.28	10.28	10.28	7	10.28
Final Temperature (°C)	-165	-165	-165	-165	-165
Duration of Discharge (s)	3600	3600	3600	3600	3600
Droplet Diameter (mm)	10	10	10	10	10
Direction of Release	Horizontal	Horizontal	Horizontal	Horizontal	Horizontal
Elevation (m)	0.5	0.5	0.5	0	0.5

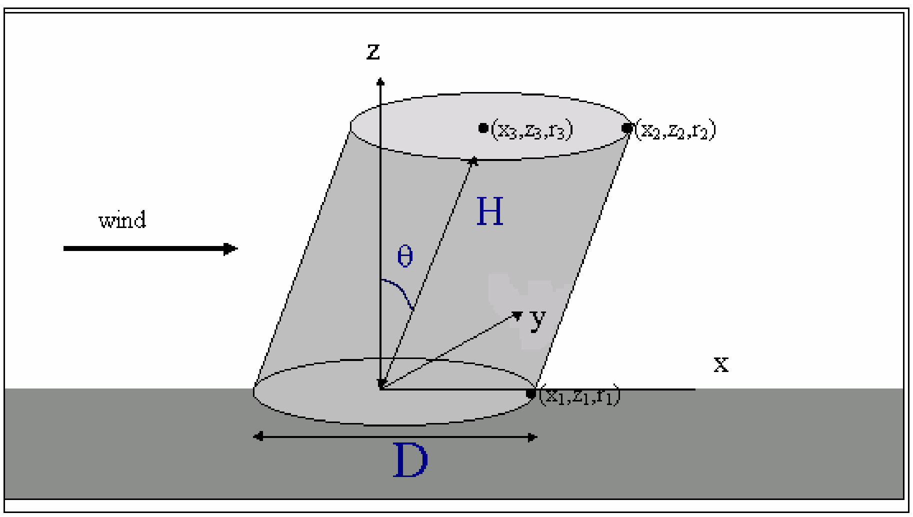


Figure I-2 Pool Fire Flame Shape

Note: The height of the fire plume is listed as a "fundamental assumption" in the Study Brief, section 3.7.9.4. This data is not an input assumption or parameter in SAFETI but instead is a data point generated as a result of the consequence modeling. The height of the fire plume, and the resulting radiation from it, is then considered in SAFETI when estimating the consequence impact and hazard to life in terms of individual risk and the EIAO FN curve.

Table I-36 Black Point Route Collision Frequency Data – 2011C – Large Carrier (215,000 m^3)

Penetration Energy (MJ)	Release Size	Sub-Segment Collision Frequency per year per m									
		Approach	ALCGI	MW1	MW2	MW3	MW4	TM1	TM2	BP	Total
<1.4	-	1E-10	1E-10	5E-10	8E-10	2E-09	2E-09	1E-09	9E-10	3E-10	8E-09
1.4 – 99	-	1E-10	3E-10	4E-09	3E-09	3E-09	4E-09	3E-09	3E-09	5E-10	2E-08
99 - 110	Small	6E-13	2E-12	2E-10	7E-11	0E+00	4E-11	8E-11	4E-11	7E-12	4E-10
110 - 150	Medium	5E-12	2E-12	5E-10	1E-10	0E+00	1E-10	1E-10	1E-10	2E-11	1E-09
> 150	Large	7E-12	3E-12	1E-09	2E-10	0E+00	2E-10	9E-11	3E-10	5E-11	2E-09
Total (/yr/m)		**3E-10**	**4E-10**	**6E-09**	**4E-09**	**5E-09**	**6E-09**	**5E-09**	**4E-09**	**9E-10**	**3E-08**
Release Total (/yr/m)		1E-11	6E-12	2E-09	4E-10	0E+00	3E-10	3E-10	5E-10	7E-11	4E-09

Table I-37 Black Point Route Collision Frequency Data – 2011C – Small Carrier (145,000 m^3)

Penetration Energy (MJ)	Release Size	Sub-Segment Collision Frequency per year per m									
		Approach	ALCGI	MW1	MW2	MW3	MW4	TM1	TM2	BP	Total
<1.4	-	2E-10	1E-10	8E-10	1E-09	3E-09	3E-09	2E-09	1E-09	5E-10	1E-08
1.4 – 99	-	2E-10	4E-10	5E-09	4E-09	4E-09	6E-09	5E-09	4E-09	8E-10	3E-08
99 - 110	Small	9E-13	3E-12	2E-10	1E-10	0E+00	5E-11	1E-10	5E-11	1E-11	6E-10
110 - 150	Medium	7E-12	3E-12	8E-10	2E-10	0E+00	2E-10	2E-10	2E-10	3E-11	2E-09
> 150	Large	1E-11	4E-12	2E-09	3E-10	0E+00	3E-10	1E-10	5E-10	7E-11	3E-09
Total (/yr/m)		**4E-10**	**6E-10**	**9E-09**	**6E-09**	**7E-09**	**9E-09**	**7E-09**	**6E-09**	**1E-09**	**5E-08**
Release Total (/yr/m)		2E-11	1E-11	3E-09	6E-10	0E+00	5E-10	4E-10	7E-10	1E-10	5E-09

Table I-38 South Soko Route Collision Frequency Data – 2011C – Large Carrier (215,000 m^3)

Penetration Energy (MJ)	Release Size	Sub-Segment Collision Frequency per year per m				
		Entry	Approach1	Approach2	Soko	Total
<1.4	-	1E-10	3E-10	5E-10	1E-10	1E-09
1.4 - 99	-	1E-09	5E-10	3E-09	3E-09	8E-09
99 - 110	Small	3E-10	8E-12	1E-10	5E-10	9E-10
110 - 150	Medium	8E-10	5E-11	6E-10	9E-10	2E-09
> 150	Large	3E-09	5E-11	2E-09	5E-09	9E-09
Total (/yr/m)		**5E-09**	**9E-10**	**6E-09**	**1E-08**	**2E-08**
Release Total (/yr/m)		4E-09	1E-10	2E-09	6E-09	1E-08

Table I-39 South Soko Route Collision Frequency Data – 2011C – Small Carrier (145,000 m^3)

Penetration Energy (MJ)	Release Size	Sub-Segment Collision Frequency per year per m				
		Entry	Approach1	Approach2	Soko	Total
<1.4	-	2E-10	4E-10	7E-10	2E-10	2E-09
1.4 - 99	-	2E-09	8E-10	5E-09	4E-09	1E-08
99 - 110	Small	4E-10	1E-11	2E-10	8E-10	1E-09
110 - 150	Medium	1E-09	8E-11	9E-10	1E-09	4E-09
> 150	Large	4E-09	8E-11	2E-09	7E-09	1E-08
Total (/yr/m)		**8E-09**	**1E-09**	**9E-09**	**1E-08**	**3E-08**
Release Total (/yr/m)		6E-09	2E-10	3E-09	9E-09	2E-08

Table I-40 Black Point Route Collision Frequency Data – 2021E – Large Carrier (215,000 m^3)

Penetration Energy (MJ)	Release Size	Sub-Segment Collision Frequency per year per m									
		Approach	ALCGI	MW1	MW2	MW3	MW4	TM1	TM2	BP	Total
<1.4	-	9E-11	2E-10	1E-09	2E-09	2E-09	3E-09	1E-09	2E-09	5E-10	1E-08
1.4 – 99	-	9E-11	3E-10	4E-09	5E-09	3E-09	6E-09	5E-09	4E-09	5E-10	3E-08
99 - 110	Small	5E-14	6E-14	1E-10	5E-11	0E+00	6E-11	2E-11	4E-11	2E-13	3E-10
110 - 150	Medium	3E-13	5E-12	4E-10	2E-10	0E+00	2E-10	5E-11	1E-10	7E-12	9E-10
> 150	Large	3E-13	4E-12	1E-09	3E-10	0E+00	1E-10	1E-10	2E-10	4E-12	2E-09
Total (/yr/m)		**2E-10**	**5E-10**	**7E-09**	**8E-09**	**5E-09**	**9E-09**	**6E-09**	**6E-09**	**1E-09**	**4E-08**
Release Total (/yr/m)		6E-13	9E-12	1E-09	5E-10	0E+00	3E-10	2E-10	4E-10	1E-11	3E-09

Table I-41 Black Point Route Collision Frequency Data – 2021E – Small Carrier (145,000 m^3)

Penetration Energy (MJ)	Release Size	Sub-Segment Collision Frequency per year per m									
		Approach	ALCGI	MW1	MW2	MW3	MW4	TM1	TM2	BP	Total
<1.4	-	1E-10	3E-10	2E-09	3E-09	3E-09	5E-09	2E-09	2E-09	8E-10	2E-08
1.4 – 99	-	1E-10	5E-10	6E-09	8E-09	4E-09	9E-09	7E-09	6E-09	7E-10	4E-08
99 - 110	Small	7E-14	9E-14	2E-10	8E-11	0E+00	1E-10	3E-11	7E-11	2E-13	4E-10
110 - 150	Medium	4E-13	7E-12	5E-10	3E-10	0E+00	2E-10	7E-11	2E-10	1E-11	1E-09
> 150	Large	4E-13	6E-12	1E-09	4E-10	0E+00	1E-10	1E-10	3E-10	5E-12	2E-09
Total (/yr/m)		**3E-10**	**8E-10**	**1E-08**	**1E-08**	**7E-09**	**1E-08**	**9E-09**	**9E-09**	**2E-09**	**6E-08**
Release Total (/yr/m)		8E-13	1E-11	2E-09	7E-10	0E+00	5E-10	2E-10	6E-10	2E-11	4E-09

Table I-42 South Soko Route Collision Frequency Data – 2021E – Large Carrier (215,000 m^3)

Penetration Energy (MJ)	Release Size	Sub-Segment Collision Frequency per year per m				
		Entry	Approach1	Approach2	Soko	Total
<1.4	-	4E-10	6E-10	1E-09	6E-10	3E-09
1.4 - 99	-	5E-09	9E-10	8E-09	1E-08	2E-08
99 - 110	Small	2E-10	2E-12	3E-10	4E-10	9E-10
110 - 150	Medium	9E-10	9E-12	1E-09	2E-09	4E-09
> 150	Large	1E-09	6E-12	7E-10	3E-09	5E-09
Total (/yr/m)		**8E-09**	**2E-09**	**1E-08**	**2E-08**	**4E-08**
Release Total (/yr/m)		2E-09	2E-11	2E-09	5E-09	9E-09

Table I-43 South Soko Route Collision Frequency Data – 2021E – Small Carrier (145,000 m^3)

Penetration Energy (MJ)	Release Size	Sub-Segment Collision Frequency per year per m				
		Entry	Approach1	Approach2	Soko	Total
<1.4	-	6E-10	9E-10	2E-09	8E-10	4E-09
1.4 - 99	-	7E-09	1E-09	1E-08	2E-08	4E-08
99 - 110	Small	3E-10	3E-12	4E-10	6E-10	1E-09
110 - 150	Medium	1E-09	1E-11	1E-09	3E-09	5E-09
> 150	Large	2E-09	9E-12	1E-09	4E-09	7E-09
Total (/yr/m)		**1E-08**	**2E-09**	**2E-08**	**2E-08**	**5E-08**
Release Total (/yr/m)		4E-09	3E-11	3E-09	7E-09	1E-08

Table I-44 Black Point Route Collision Frequency Data – 2021F – Large Carrier (215,000 m^3)

Penetration Energy (MJ)	Release Size	Sub-Segment Collision Frequency per year per m									
		Approach	ALCGI	MW1	MW2	MW3	MW4	TM1	TM2	BP	Total
<1.4	-	1E-10	4E-11	5E-10	1E-09	2E-09	2E-09	1E-09	6E-10	3E-10	7E-09
1.4 – 99	-	1E-10	2E-10	3E-09	2E-09	4E-09	2E-09	2E-09	2E-09	3E-10	2E-08
99 - 110	Small	7E-13	6E-13	2E-10	5E-11	0E+00	2E-11	2E-11	3E-11	4E-12	3E-10
110 - 150	Medium	3E-12	7E-12	2E-10	2E-10	0E+00	1E-10	1E-10	6E-11	1E-11	7E-10
> 150	Large	4E-12	6E-13	9E-10	2E-10	0E+00	8E-11	7E-11	2E-10	3E-11	2E-09
Total (/yr/m)		**2E-10**	**2E-10**	**5E-09**	**4E-09**	**5E-09**	**4E-09**	**3E-09**	**3E-09**	**7E-10**	**3E-08**
Release Total (/yr/m)		8E-12	8E-12	1E-09	4E-10	0E+00	2E-10	2E-10	3E-10	4E-11	3E-09

Table I-45 Black Point Route Collision Frequency Data – 2021F – Small Carrier (145,000 m^3)

Penetration Energy (MJ)	Release Size	Sub-Segment Collision Frequency per year per m									
		Approach	ALCGI	MW1	MW2	MW3	MW4	TM1	TM2	BP	Total
<1.4	-	2E-10	5E-11	7E-10	1E-09	2E-09	2E-09	2E-09	9E-10	4E-10	1E-08
1.4 – 99	-	2E-10	2E-10	4E-09	4E-09	6E-09	3E-09	3E-09	3E-09	5E-10	2E-08
99 - 110	Small	1E-12	8E-13	3E-10	7E-11	0E+00	3E-11	4E-11	4E-11	6E-12	5E-10
110 - 150	Medium	5E-12	1E-11	3E-10	2E-10	0E+00	2E-10	2E-10	8E-11	2E-11	1E-09
> 150	Large	6E-12	8E-13	1E-09	3E-10	0E+00	1E-10	1E-10	3E-10	4E-11	2E-09
Total (/yr/m)		**3E-10**	**3E-10**	**7E-09**	**6E-09**	**8E-09**	**6E-09**	**5E-09**	**4E-09**	**1E-09**	**4E-08**
Release Total (/yr/m)		1E-11	1E-11	2E-09	6E-10	0E+00	3E-10	3E-10	4E-10	7E-11	4E-09

Table I-46 South Soko Route Collision Frequency Data – 2021F – Large Carrier (215,000 m^3)

Penetration Energy (MJ)	Release Size	Sub-Segment Collision Frequency per year per m				
		Entry	Approach1	Approach2	Soko	Total
<1.4	-	1E-10	6E-10	1E-09	5E-10	2E-09
1.4 - 99	-	1E-09	1E-09	7E-09	7E-09	2E-08
99 - 110	Small	2E-10	3E-11	4E-10	3E-10	9E-10
110 - 150	Medium	5E-10	1E-10	1E-09	3E-09	4E-09
> 150	Large	1E-09	9E-11	3E-09	1E-08	1E-08
Total (/yr/m)		**3E-09**	**2E-09**	**1E-08**	**2E-08**	**4E-08**
Release Total (/yr/m)		2E-09	2E-10	4E-09	1E-08	2E-08

Table I-47 South Soko Route Collision Frequency Data – 2021F – Small Carrier (145,000 m^3)

Penetration Energy (MJ)	Release Size	Sub-Segment Collision Frequency per year per m				
		Entry	Approach1	Approach2	Soko	Total
<1.4	-	2E-10	9E-10	2E-09	8E-10	4E-09
1.4 - 99	-	2E-09	2E-09	1E-08	1E-08	2E-08
99 - 110	Small	3E-10	4E-11	6E-10	5E-10	1E-09
110 - 150	Medium	7E-10	2E-10	2E-09	4E-09	6E-09
> 150	Large	2E-09	1E-10	4E-09	1E-08	2E-08
Total (/yr/m)		**5E-09**	**3E-09**	**2E-08**	**3E-08**	**6E-08**
Release Total (/yr/m)		3E-09	3E-10	6E-09	2E-08	3E-08

A variable factor ranging from 0 (for bow-on collisions) to 0.65 (for beam-on collisions) was included in the release frequencies presented in the above tables to account for the exposure of the cargo tanks in the event of a collision.

Table I-48 Black Point Route Relation of Frequency and Risk Analysis Segmentations

Risk Analysis Segments	Frequency Analysis Segments (Data presented in the form of segment length [km])									Total
	Approach	ALCGI	MW1	MW2	MW3	MW4	TM1	TM2	BP	
BP1									7.41	7.41
BP2								6.32	1.19	7.51
BP3						1.38	1.38	4.62		7.39
BP4			0.79	2.97	2.96	0.59				7.31
BP5		3.17	4.15							7.32
BP6		7.51								7.51
BP7	9.78	0.40								10.18
Total	9.78	11.07	4.94	2.97	2.96	1.98	1.38	10.94	8.60	**54.63**

Table I-49 South Soko Route Relation of Frequency and Risk Analysis Segmentations

Risk Analysis Segments	Frequency Analysis Segments (Data presented in the form of segment length [km])				Total
	Entry	Approach1	Approach2	Soko	
SK1		5.08	1.50	2.32	8.90
SK2		9.43			9.43
SK3		7.42			7.42
SK4	12.59				12.59
Total	12.59	21.93	1.50	2.32	**38.34**

The following table presents the grounding analysis performed by BMT, developed from a review of historic local grounding incidents for vessels of 200m length or greater.

Table I-50 Route Node Grounding Frequencies

Node	Section Length (km)	Annual Transit	Grounding /Year	Grounding / Year / km	Grounding / km / transit
Approach	9.8	16,000	0	9×10^{-3}	5×10^{-7}
ALCGI	11	15,400	0.25		6×10^{-7}
Western Fairway	7.9	14,700	0		6×10^{-7}
Ma Wan	4.9	4,400	0.25	5×10^{-2}	1×10^{-5}
Brothers	9.2	4,400	0	2×10^{-2}	5×10^{-6}
Tuen Mun	5.1	4,400	0		5×10^{-6}
Black Point	6.6	4,400	0.5		5×10^{-6}

Table I-51 Route Node Grounding Release Frequencies – Large Carrier (215,000 m^3)

Node	Grounding / km / transit	LNG transits / yr	Grounding / km / yr	Factors Applied	2011 Grounding releases / km / yr	2021 Grounding releases / km / yr
Approach	5E-07	51	3E-05	*Containment breach*	3E-07	3E-07
ALCGI	6E-07		3E-05	0.025	4E-07	4E-07
Western Fairway	6E-07		3E-05	*Tug Presence*	4E-07	4E-07
Ma Wan	1E-05		5E-04	0.5	7E-06	7E-06
Brothers	5E-06		3E-04		3E-06	3E-06
Tuen Mun	5E-06		3E-04		3E-06	3E-06
Black Point	5E-06		3E-04		3E-06	3E-06
TOTAL	**3E-05**		1E-03		**2E-05**	**2E-05**

Table I-52 Route Node Grounding Release Frequencies – Small Carrier (145,000 m^3)

Node	Grounding / km / transit	LNG transits / yr	Grounding / km / yr	Factors Applied	2011 Grounding releases / km / yr	2021 Grounding releases / km / yr
Approach	5E-07	75	2E-05	*Containment breach*	5E-07	5E-07
ALCGI	6E-07		2E-05	0.025	5E-07	5E-07
Western Fairway	6E-07		2E-05	*Tug Presence*	6E-07	6E-07
Ma Wan	1E-05		4E-04	0.5	1E-05	1E-05
Brothers	5E-06		2E-04		5E-06	5E-06
Tuen Mun	5E-06		2E-04		5E-06	5E-06
Black Point	5E-06		2E-04		5E-06	5E-06
TOTAL	**3E-05**		1E-03		3E-05	3E-05

Table I-53 Black Point Grounding Release Frequency Input – Large Carrier (215,000 m^3)

MQRA Nodes	Grounding Nodes	Length Fraction to Split Nodes	Grounding Release Frequency / m / yr	Length Effectiveness Factor	2011 Grounding Release Freq / m / yr	2021 Grounding Release Freq / m / yr
n1	N1	1	3E-10	0.283	1E-10	1E-10
n2	N2	1	4E-10	0.911	3E-10	3E-10
n3	N3	0.62	2E-10	0.720	2E-10	2E-10
n4	N3	0.38	1E-10	0.800	1E-10	1E-10
n5	N4	0.60	4E-09	0.933	4E-09	4E-09
n6	N4	0.40	3E-09	0.950	3E-09	3E-09
n7	N5	0.15	5E-10	1.000	5E-10	5E-10
n8	N5, N6	0.85, 0.62	5E-09	0.982	5E-09	5E-09
n9	N6, N7	0.38, 1.00	5E-09	0.557	3E-09	3E-09
				TOTAL	2E-08	2E-08

Table I-54 Black Point Grounding Release Frequency Input – Small Carrier (145,000 m^3)

MQRA Nodes	Grounding Nodes	Length Fraction to Split Nodes	Grounding Release Frequency / m / yr	Length Effectiveness Factor	2011 Grounding Release Freq / m / yr	2021 Grounding Release Freq / m / yr
n1	N1	1	5E-10	0.283	1E-10	1E-10
n2	N2	1	5E-10	0.911	5E-10	5E-10
n3	N3	0.62	3E-10	0.720	2E-09	2E-09
n4	N3	0.38	2E-10	0.800	2E-10	2E-10
n5	N4	0.60	6E-09	0.933	6E-09	6E-09
n6	N4	0.40	4E-09	0.950	4E-08	4E-08
n7	N5	0.15	8E-10	1.000	8E-10	8E-10
n8	N5, N6	0.85, 0.62	7E-09	0.982	7E-10	7E-10
n9	N6, N7	0.38, 1.00	7E-09	0.557	4E-09	4E-09
				TOTAL	2E-08	2E-08

Table I-55 South Soko Grounding Release Frequency Input – Large Carrier (215,000 m^3)

MQRA Nodes	Grounding Nodes	Grounding Release Frequency / m / yr	Length Effectiveness Factor	2011- Grounding Release Freq / m / yr	2021 Grounding Release Freq / m / yr
SK1	SK1	7E-09	0.00	0E+00	0E+00
SK2a	SK2	7E-09	0.00	0E+00	0E+00
SK2b	SK2	7E-09	0.500	4E-09	4E-09
SK3	SK3	7E-09	0.391	3E-09	3E-09
			Total	7E-09	7E-09

Table I-56 South Soko Grounding Release Frequency Input – Small Carrier (145,000 m^3)

MQRA Nodes	Grounding Nodes	Grounding Release Frequency / m / yr	Length Effectiveness Factor	2011- Grounding Release Freq / m / yr	2021 Grounding Release Freq / m / yr
SK1	SK1	1E-08	0.00	0E+00	0E+00
SK2a	SK2	1E-08	0.00	0E+00	0E+00
SK2b	SK2	1E-08	0.500	5E-09	5E-09
SK3	SK3	1E-08	0.391	4E-09	4E-09
			Total	1E-08	1E-08

BMT also performed an analysis to evaluate the risk of a passing vessel colliding with the carrier, while the carrier is at berth at Black Point or South Soko terminals. It was determined that the frequency of an event at the Black Point berth was $2x10^{-8}$ and $4x10^{-8}$ per year in 2011 and 2021 respectively. The frequency of impact at the South Soko berth was evaluated to be $1x10^{-17}$ and $2x10^{-17}$ per year in 2011 and 2021, respectively.

Table I-57 SAFETI Parameters for 2011C Case

Parameter	Value	Unit	Remark
Dispersion Parameters			
Expansion zone length/source diameter ratio	0.01		
Near Field Passive Entrainment Parameter	1		
Jet Model			Morton et.al.
Jet entrainment coefficient alpha1	0.17		
Jet entrainment coefficient alpha2	0.35		
Drag coefficient between plume and air	0		
Dense cloud parameter gamma (continuous)	0		
Dense cloud parameter gamma (instant)	0.30		
Dense cloud parameter k (continuous)	1.15		
Dense cloud parameter k (instantaneous)	1.15		
Modeling of instantaneous expansion			Standard Method
Maximum Cloud/Ambient Velocity Difference	0.1		
Maximum Cloud/Ambient Density Difference	0.015		
Maximum Non-passive entrainment fraction	0.3		
Maximum Richardson number	15		
Distance multiple for full passive entrainment	2		
Core Averaging Time	18.75	s	
Ratio instantaneous/continuous sigma-y	1		
Ratio instantaneous/continuous sigma-z	1		
Droplet evaporation thermodynamics model			Rainout, Non-equilibrium
Droplet equation solution method			Synchronized
Drop/expansion velocity for inst. release	0.8		
Expansion energy cutoff for droplet angle	690	J/kg	
Coefficient of Initial Rainout	0		
Flag to reset rainout position			Do not reset rainout position

Parameter	Value	Unit	Remark
Richardson Number for passive transition above pool	0.015		
Pool Vaporization entrainment parameter	1.5		
Ground Drag Model			New (Recommended)
Drag coefficient between plume and ground	1.5		
Richardson number criterion for cloud lift-off	-20		
Flag for Heat/Water vapor transfer			Heat and Water
Surface over which the dispersion occurs	Water		
Minimum temperature allowed	-262.1	degC	
Maximum temperature allowed	626.9	degC	
Minimum release velocity for cont. release	0.1	m/s	
Minimum Continuous Release Height	0	m	
Maximum distance for dispersion	50,000	m	
Maximum height for dispersion	1,000	m	
Minimum cloud depth	0.02	m	
Flag for mixing height			Constrained
Model In Use			Best Estimate
Calculate Lee Length			Calculate
Calculate Lee Half-Width			Calculate
Calculate Lee Height			Calculate
Calculate K-Factor			Calculate
Calculate Switch Distance			Calculate
Maximum Initial Step Size	10	m	
Minimum Number of Steps per Zone	5		
Factor for Step Increase	1.2		
Maximum Number of Output Steps	1,000		
Flag for finite duration correction			QI without Duration Adjustment
Quasi-instantaneous transition parameter	0.8		
Accuracy for integration of dispersion	0.001		
Accuracy for droplet integration	0.001		
Minimum integration step size (Instantaneous)	0.1	s	
Minimum integration step size (Continuous)	0.1	m	
Maximum integration step size (Instantaneous)	1,000	s	
Maximum integration step size (Continuous)	100	m	
Criterion for halting dispersion model			Risk based
Discharge Parameters			
Continuous Critical Weber number	12.5		
Instantaneous Critical Weber number	12.5		
Venting equation constant	24.82		
Relief valve safety factor	1.2		
Minimum RV diameter ratio	1		
Critical pressure greater than flow phase	3.447E4	N/m^2	
Maximum release velocity	500	m/s	
Minimum drop diameter allowed	0.00001	mm	

Parameter	Value	Unit	Remark
Maximum drop diameter allowed	10	mm	
Default Liquid Fraction	1	fraction	
Continuous Drop Slip factor	1		
Instantaneous Drop Slip factor	1		
Pipe-Fluid Thermal Coupling	0		
Number of Time Steps	100		
Maximum Number of Data Points	1,000		
Droplet Method	1.00		
Input Flash Mechanism			Do not force correlation
Tolerance	1E-6		
Excess Flow Valve velocity head losses	0		
Non-Return Valve velocity head losses	0		
Shut-Off Valve velocity head losses	0		
Frequency of bends in long pipes	0	/m	
Frequency of couplings in long pipes	0	/m	
Frequency of junctions in long pipes	0	/m	
Line length	10	m	
Pipe roughness	4.57E-5	m	
Default volume changes	26,280	/yr	
Elevation	1	m	
Atmospheric Expansion Method			Closest to Initial Conditions
Tank Roof Failure Model Effects			Instantaneous Effects (default)
Jet Fire Parameters			
Maximum SEP for a Jet Fire	400	kW/m2	
Jet Fire Averaging Time	20	s	
Jet fire radiation intensity level 1	7.3	kW/m2	
Jet fire radiation intensity level 2	14.4	kW/m2	
Jet fire radiation intensity level 3	20.9	kW/m2	
Rate Modification Factor	3		
Jet Fire Maximum Exposure Duration	30	s	
Jet fire radiation dose level 1	1,270,000		
Jet fire radiation dose level 2	5,800,000		
Jet fire radiation dose level 3	25,100,000		
Jet fire radiation probit level 1	2.73		
Jet fire radiation probit level 2	3.72		
Jet fire radiation probit level 3	7.50		
Jet fire radiation lethality level 1	0.01	fraction	
Jet fire radiation lethality level 2	0.5	fraction	
Jet fire radiation lethality level 3	0.9	fraction	
Calculate Dose			Unselected
Calculate Probit			Unselected
Calculate Lethality			Selected
Crosswind Angle	0	deg	

Parameter	Value	Unit	Remark
Shell Calculation Method			DNV Recommended
Use Johnson Method If Horizontal			Use Johnson
Pool Fire Parameters			
Minimum pool duration for pool fire risk (Inst. Releases)	10	s	
Minimum pool duration for pool fire risk (Cont. Releases)	10	s	
Pool fire radiation intensity level 1	7.3	kW/m2	
Pool fire radiation intensity level 2	14.4	kW/m2	
Pool fire radiation intensity level 3	20.9	kW/m2	
Pool Fire Maximum Exposure Duration	30	s	
Pool fire radiation dose level 1	1,270,000		
Pool fire radiation dose level 2	5,800,000		
Pool fire radiation dose level 3	25,100,000		
Pool fire radiation probit level 1	2.73		
Pool fire radiation probit level 2	3.72		
Pool fire radiation probit level 3	7.50		
Pool fire radiation lethality level 1	0.01	fraction	
Pool fire radiation lethality level 2	0.5	fraction	
Pool fire radiation lethality level 3	0.9	fraction	
Calculate Dose			Unselected
Calculate Probit			Unselected
Calculate Lethality			Selected
Fireball and BLEVE Blast Parameters			
Maximum SEP for a BLEVE	400	kW/m2	
Radiation Dose for BLEVE risk calculations	5,783,770		
Fireball radiation intensity level 1	7.3	kW/m2	
Fireball radiation intensity level 2	14.4	kW/m2	
Fireball radiation intensity level 3	20.9	kW/m2	
Mass Modification Factor	3		
Fireball Maximum Exposure Duration	30	s	
Fireball radiation dose level 1	1,270,000		
Fireball radiation dose level 2	5,800,000		
Fireball radiation dose level 3	25,100,000		
Fireball radiation probit level 1	2.73		
Fireball radiation probit level 2	3.72		
Fireball radiation probit level 3	7.50		
Fireball radiation lethality level 1	0.01	fraction	
Fireball radiation lethality level 2	0.5	fraction	
Fireball radiation lethality level 3	0.9	fraction	
Calculate Dose			Unselected
Calculate Probit			Unselected
Calculate Lethality			Selected
Temperature of fireball	2000	degK	
Calculation method for fireball			DNV Recommended

Parameter	Value	Unit	Remark
Ground Reflection			Ground Burst
Ideal Gas Modeling			Model as real gas
Flammables Parameters			
Height for calculation of flammable effects	0	m	
Flammable result grid step in X-direction	10	m	
LFL fraction to finish	0.85		
Flammable angle of inclination	0	deg	
Flammable inclination			Variable
Flammable mass calculation method			Mass between LFL and UFL
Flammable Base averaging time	18.75	s	
Radiation level for Jet/Pool Fire Risk	35.5	kW/m2	
Cut Off Fraction	0.001	fraction	
UFL Multiple	1		
Cut Off Time for Short Continuous Releases	20	s	
Observer type radiation modelling flag			Planar
Probit A	-38.48		
Probit B	2.56		
Probit N	1.333		
Height for reports			Centerline Height
Angle of Orientation	0	deg	
Relative Tolerance for radiation calculations	0.01	fraction	
Number of Lethality Ellipses	4.00		
Radiation Ellipse Interpolation			Intensity
Minimum Probability of Death	0.01	fraction	
Explosion Parameters			
Over Pressure Level 1	2068	N/m2	
Over Pressure Level 2	13,790	N/m2	
Over Pressure Level 3	20,680	N/m2	
Explosion Location Criterion			Cloud Front (LFL Fraction)
Minimum explosive mass	0	kg	
Min Explosion Energy	5,000,000	kJ	
Explosion Efficiency	0.1	fraction	
MPACT explosion higher damage zone coefficient	0.03		
MPACT explosion lower damage zone coefficient	0.06		
Explosion efficiency	0.1	fraction	
Air or Ground burst			Air burst
Early Explosion Mass Modification Factor	3		
Critical Separation Ratio	0.5		
Cloud Shape of Area Integration			Elliptical
Flammable Mass Calculation Type			Area Weighted Mass Integral
Explosion Type Calculation Method			Polynomial Curve-Fit Equations
Number of Blast Curve Discretization Points	30,000		

Parameter	Value	Unit	Remark
General Parameters			
Maximum release duration	3,600	s	
Height for concentration output	0	m	
Rotation	0	deg	
Minimum Z	0	m	
Maximum Z	1	m	
Pool Vaporization Parameters			
Toxics Cut-off rate for pool evaporation	0.001	kg/s	
Flammable Cut-off rate for pool evaporation	0.1	kg/s	
Concentration Power	1		
Maximum number of pool evaporation rates	10.00		
Pool minimum thickness	0.005	M	
Surface thermal conductivity	2.21	J/m.s.degK	
Surface roughness factor	2.634		
Surface thermal diffusivity (per second)	9.48E-07	m2/s	
Type of Bund Surface			Deep Open Water
Bund Height	0	m	
Bund Failure Modeling			Bund cannot fail
Toxics Parameters (Not Used)			
Toxics: minimum probability of death	0.001		
Toxics: height for calculation of effects	0	m	
Toxics: results grid step in Y-direction	2.5	m	
Toxics: results grid step in X-direction	25	m	
Multi-comp. toxic calc. method			Mixture Probit
Toxic Averaging Time (New Parameter)	600	s	
Probit calculation method			Use Probit
Building Exchange Rate	35,040	/yr	
Tail Time	1,800	s	
Do Indoor Calcs			Unselected
Wind dependent exchange rate			Case specified
Weather Parameters			
Atmospheric pressure	1.013E5	N/m2	
Atmospheric molecular weight	28.97		
Atmospheric specific heat at constant pressure	1,004	J/kg.degK	
Wind speed reference height (m)	10	m	
Temperature reference height (m)	0	m	
Cut-off height for wind speed profile (m)	1	m	
Wind speed profile			Power Law
Atmospheric Temperature and Pressure Profile			Temp.Logarithmic; Pres.Linear
Atmospheric temperature	9.85	degC	
Relative humidity	0.7	fraction	
Surface Roughness Parameter	0.043		
Surface Roughness Length	0.0009121	m	

Parameter	Value	Unit	Remark
Roughness or Parameter			Parameter
Dispersing surface temperature	9.85	degC	
Default surface temperature of bund	9.85	degC	
Solar radiation flux	500	W/m2	
Building exchange rate	4	/hr	
Tail Time	1,800	s	
Surface Type			
Mixing layer height for Pasquil Stability A	1300	m	
Mixing layer height for Pasquil Stability A/B	1080	m	
Mixing layer height for Pasquil Stability B	920	m	
Mixing layer height for Pasquil Stability B/C	880	m	
Mixing layer height for Pasquil Stability C	840	m	
Mixing layer height for Pasquil Stability C/D	820	m	
Mixing layer height for Pasquil Stability D	800	m	
Mixing layer height for Pasquil Stability E	400	m	
Mixing layer height for Pasquil Stability F	100	m	
Mixing layer height for Pasquil Stability G	100	m	
Event Tree Probabilities			
Probability of a BLEVE	1	fraction	
Probability of a Pool Fire	1	fraction	
Toxic Probability	1	fraction	
Continuous no Rainout Immediate Ignition	0.8	fraction	
Continuous no Rainout Long Duration Horizontal Fraction	0.6	fraction	
Continuous no Rainout Long Duration Horizontal Jet Fire	1	fraction	
Continuous no Rainout Long Duration Vertical Jet Fire	1	fraction	
Continuous no Rainout Short Duration Fraction	0	fraction	
Continuous no Rainout Short Duration BLEVE	0	fraction	
Continuous no Rainout Short Duration Flash Fire	0	fraction	
Continuous no Rainout Short Duration Explosion	0	fraction	
Continuous no Rainout Delayed Ignition Flash Fire	1	fraction	
Continuous no Rainout Delayed Ignition Explosion	0	fraction	
Continuous with Rainout Immediate Ignition	Collision – 0.8 Grounding – 0.2	fraction	
Continuous with Rainout Long Duration Horizontal Fraction	0.6	fraction	
Continuous with Rainout Long Duration Horizontal Jet Fire	0	fraction	
Continuous with Rainout Long Duration Horizontal Pool Fire	1	fraction	
Continuous with Rainout Long Duration Horizontal Jet Fire with Pool Fire	0	fraction	
Continuous with Rainout Long Duration Vertical Pool Fire	1	fraction	
Continuous with Rainout Long Duration Vertical Jet Fire	0	fraction	
Continuous with Rainout Short Duration Fraction	0	fraction	
Continuous with Rainout Long Duration Vertical Jet Fire with Pool Fire	0	fraction	

Parameter	Value	Unit	Remark
Continuous with Rainout Short Duration BLEVE with Pool Fire	0	fraction	
Continuous with Rainout Short Duration BLEVE alone	0	fraction	
Continuous with Rainout Short Duration Flash Fire with Pool Fire	0	fraction	
Continuous with Rainout Short Duration Flash Fire Alone	0	fraction	
Continuous with Rainout Short Duration Explosion with Pool Fire	0	fraction	
Continuous with Rainout Short Duration Explosion Alone	0	fraction	
Continuous with Rainout Short Duration Pool Fire	0	fraction	
Continuous with Rainout Residual Pool Fire	0.15	fraction	
Continuous with Rainout Delayed Ignition Flash Fire	1	fraction	
Continuous with Rainout Delayed Ignition Explosion	0	fraction	
Instantaneous no Rainout Immediate Ignition	0.8	fraction	
Instantaneous no Rainout BLEVE	1	fraction	
Instantaneous no Rainout Immediate Flash Fire	0	fraction	
Instantaneous no Rainout Immediate Explosion	0	fraction	
Instantaneous no Rainout Delayed Ignition Flash Fire	0.95	fraction	
Instantaneous no Rainout Delayed Ignition Explosion	0.05	fraction	
Instantaneous with Rainout Immediate Ignition	0.8	fraction	
Instantaneous with Rainout BLEVE with Pool Fire	1	fraction	
Instantaneous with Rainout BLEVE Alone	0	fraction	
Instantaneous with Rainout Immediate Flash Fire with Pool Fire	0	fraction	
Instantaneous with Rainout Immediate Flash Fire Alone	0	fraction	
Instantaneous with Rainout Immediate Explosion with Pool Fire	0	fraction	
Instantaneous with Rainout Immediate Explosion Alone	0	fraction	
Instantaneous with Rainout Immediate Pool Fire Alone	0	fraction	
Instantaneous with Rainout Residual Pool Fire	0.15	fraction	
Instantaneous with Rainout Delayed Ignition Flash Fire	0.95	fraction	
Instantaneous with Rainout Delayed Ignition Explosion	0.05	fraction	
Immediate Ignition	0.1	fraction	
Explosion Given Ignition	0.5	fraction	
Long Duration Jet Fire	0.5	fraction	
Short Duration Any Ignition of Cloud	0.5	fraction	
Short Duration Ignition of Cloud with Pool Fire	0	fraction	
Long Duration Horizontal Jet Fire with Pool	0	fraction	
Long Duration Vertical Jet Fire with Pool	0	fraction	
Short Duration Fraction for Effects	0	fraction	
Short Duration BLEVE not Flash Fire	0.5	fraction	
General Risk Parameters			
Use Free Field Modeling			No
Distance to Site Boundary	0	m	
Include Effects of Late Pool Fire			No
Minimum Case Frequency	1E-12		
Minimum Event Probability	1E-12		
Fraction of Population Outdoors for Societal Risk	0.1	fraction	

Parameter	Value	Unit	Remark
Fraction of Population Outdoors for Individual Risk	1	fraction	
Maximum Number of Subsquares across Ellipse	10		
Maximum Number of Subdivisions per Square	5		
Factor for Toxic F-N Spread	2		
Set Calculation Grid Size			No
Grid Bounds Minimum X (input)	-1,000	m	
Grid Bounds Maximum X (input)	1,000	m	
Grid Bounds Minimum Y (input)	-1,000	m	
Grid Bounds Maximum Y (input)	1,000	m	
Grid calculation method			Number of cells
MPACT cell size	10	m	
Maximum number of MPACT cells	100,000		
Aversion Index	1.20		
Outdoor Population Omega Factor	0.000168		
Indoor Population Omega Factor	0.000168		
Number of wind subdivisions per sector	1.00		
Method for handling Indoor/Outdoor Risk			Indoor and outdoor risk calculations
Inter-ellipse interpolation method			Weighted
Heavy Explosion Damage Outdoors	1	fraction	
Heavy Explosion Damage Indoors	1	fraction	
Light Explosion Damage Outdoors	0	fraction	
Light Explosion Damage Indoors	0.025	fraction	
Flash Fire Outdoors	1	fraction	
Flash Fire Indoors	0.1	fraction	
Fireball Societal Radiation Criteria Zone Outdoors	1	fraction	
Fireball Societal Radiation Criteria Zone Indoors	1	fraction	
Fireball Individual Radiation Criteria Zone Outdoors	1	fraction	
Fireball Individual Radiation Criteria Zone Indoors	1	fraction	
Fireball Societal Flammable Probit Zone Outdoors	0.14	fraction	
Fireball Societal Flammable Probit Zone Indoors	0	fraction	
Fireball Individual Flammable Probit Zone Outdoors	1	fraction	
Fireball Individual Flammable Probit Zone Indoors	0	fraction	
Jet Fire Societal Radiation Criteria Zone Outdoors	1	fraction	
Jet Fire Societal Radiation Criteria Zone Indoors	1	fraction	
Jet Fire Individual Radiation Criteria Zone Outdoors	1	fraction	
Jet Fire Individual Radiation Criteria Zone Indoors	1	fraction	
Jet Fire Societal Flammable Probit Zone Outdoors	0.14	fraction	
Jet Fire Societal Flammable Probit Zone Indoors	0	fraction	
Jet Fire Individual Flammable Probit Zone Outdoors	1	fraction	
Jet Fire Individual Flammable Probit Zone Indoors	0	fraction	
Pool Fire Societal Radiation Criteria Zone Outdoors	1	fraction	
Pool Fire Societal Radiation Criteria Zone Indoors	1	fraction	
Pool Fire Individual Radiation Criteria Zone Outdoors	1	fraction	

Parameter	Value	Unit	Remark
Pool Fire Individual Radiation Criteria Zone Indoors	1	fraction	
Pool Fire Societal Flammable Probit Zone Outdoors	0.14	fraction	
Pool Fire Societal Flammable Probit Zone Indoors	0	fraction	
Pool Fire Individual Flammable Probit Zone Outdoors	1	fraction	
Pool Fire Individual Flammable Probit Zone Indoors	0	fraction	
Toxics Outdoors	1	fraction	
Toxics Indoors	1	fraction	
Plant Parameters			
Length of In-Unit Pipes	10	m	
Path Factor for Inter-Unit Pipes	1.414		
Maximum Spacing Between Failures	50	m	
Maximum Pipe Inventory as a Fraction of Upstream Inventory	0.25	fraction	
Size for Leak Cases (as fraction of Pipe Diameter)	0.1	fraction	
Minimum Detection Time	3,600	s	
Normal Gas Flow Velocity	20	m/s	
Normal Liquid Flow Velocity	1	m/s	
Probability of Non-Ignition	0.5	fraction	
Minimum Volume Changes per Step	0.15		
Maximum Volume Changes per Step	0.5		
Bend Frequency for In Unit Pipes	0.2	/m	
Coupling Frequency for In Unit Pipes	0.5	/m	
Junction Frequency for In Unit Pipes	0.1	/m	
Probability First Valve Fails to Close on Demand	0.01		
Minimum Event Frequency for Generated Models	6.496E-07	/AvgeYear	
Smallest Leak Detectable as Fraction of Normal Flowrate	0.1	fraction	
Time to Shut Non-Return Valves	5	s	
Time to Shut Excess Flow Valves	5	s	
Calculate Rupture Cases			Yes
Divide Base Failure Rate Equally Along Length of Pipe			Yes
Prevent Flashing in Pipes			Yes

Appendix II – Hazard Register and List of Modeled Scenarios

Contents:

II Hazard Register and List of Modeled Scenarios

This appendix analyzes the potential hazards identified in the HAZID session documents as part of the MQRA. This analysis was conducted by the DNV team following the MQRA HAZID session using the HAZID log sheets as well as research on specific topics as required

Hazard Registers are presented for the potential hazards. Each Hazard Register begins with a description of the potential hazard, causes, consequences and safeguards. Then a typical risk assessment potential scenario is developed. In this potential scenario development, the frequency of the scenario is considered. Where the frequency is less than the lower bound of the Hong Kong EIAO criteria ($1x10^{-9}$ /year), the scenario is not considered credible. The conclusion on the credibility of the scenario is provided in the risk evaluation section of the Hazard Register. Those scenarios that are credible will then be considered in the MQRA risk analysis. The Hazard Registers are not listed in order of priority.

II.1 High-Energy Ship Collision

A powered high-energy ship collision of a large ship at near right angles into the side of the LNG carrier is estimated to be a worst-case scenario. Breach of containment is possible if the collision energy is sufficiently high. Such a scenario could possibly lead to fire, potentially affecting populations on the water as well as onshore. The fire would be fought by existing fire fighting equipment that is standard on an LNG carrier. These include, but are not limited to, automatic fire detection and suppression, manual fire fighting equipment together with the water deluge that coats the entire deck and outer hull of a carrier in the event of an emergency.

This potential scenario will be evaluated along the entire transit route to both Black Point and South Soko. Three areas of particular concern were identified for the Black Point route.

- Node 3, the Western Fairway, crossing vessel traffic in and out of Victoria Harbor and the Kwai Chung container terminal.
- Node 4, the Ma Wan Fairway, with a turn greater than 90 degrees to the west; potential to meet vessel traffic from opposite direction at the entrance or exit of the channel (traffic control restricting the passage of two ships greater than 170m LOA or 9.5m draft or more in the channel at one time).
- Node 7, Turning Basin at the approach to the turning basin located beside the main shipping route from Shenzhen errant vessel contact during turning maneuver off the berth.

Along the South Soko Island route, a single area of concern was identified.

- Node 1 (well away from onshore population) where the LNG carrier would have to turn across the outbound vessel traffic from Hong Kong and the Pearl River Delta.

II.2 Collisions between Gas Carriers

Along the route of the LNG carrier, it has been considered whether it is possible for two gas carriers to be in the channel at the same time. This situation is not anticipated for South Soko.
Considering the volumes of LNG to be delivered, it is not anticipated that two LNG carriers (one inbound, one outbound) would be transiting Hong Kong waters at the same time. In the

unexpected event that this did occur, the transit of the inbound carrier would be delayed until the outbound carrier had cleared the southeast entry to the Ma Wan channel.

Considering a collision scenario between an inbound LNG carrier and an LPG vessel, traffic management safeguards are in place to assist in the minimization of vessel collisions.

II.3 LNG Carrier Grounding

The Hong Kong waters involved in this study have a relatively low incidence of grounding. This is due to the presence of very wide channels and deep water. Nonetheless, the bottom of the transit route can be rocky and there is heavy population along some portions of the route, in particular along the west and north sides of the Ma Wan Fairway (Node 4, Black Point route), on Castle Peak Road, where the LNG carrier must make a greater than 90 degree turn to the west. There is also some concern in Node 5 of the Black Point route where the LNG carrier must pass through the narrowest point of the channel (310 meters) through buoys CP4 and CP5. The use of tugs are anticipated to greatly reduce this risk.

Grounding will be addressed in the detailed analysis in the MQRA.

II.4 Tsing Ma Bridge

At Node 4 of the Black Point route, the LNG carrier will be passing under the Tsing Ma Bridge, a heavily traveled bridge connecting Tsing Yi Island to Lantau and linking Chep Lap Kok Airport to the population centers of Hong Kong. It is understood that the supports of the bridge are set on islands, meaning that a scenario where an LNG Carrier drifts toward the supports would lead to a grounding scenario, prior to the LNG Carrier colliding with the bridge or the supports.

When an LNG carrier is nominated for discharge in Hong Kong it will be known that there is an air draft restriction under the Tsing Ma bridge. Information on air draft will be part of the precharter exchange on carrier particulars between the owner/operator and the charterer and will be determined prior to approving the LNG carrier for the intended voyage

This scenario will be included in the detailed analysis of grounding scenarios as part of the MQRA.

II.5 Hazard Register – Black Point

Black Point Hazard No. H1: Grounding

Description:	Grounding of LNG carrier. Channels in Hong Kong are wide and groundings are infrequent. Delineated fairways within Hong Kong waters permit two way traffic. Frequency of grounding for ocean going vessels is less than that for collisions. From Green Island, the LNG carrier will have two passive tug escorts, with an additional two tugs on standby to the north of Ma Wan Island to provide emergency response under and near the Tsing Ma bridge. In addition, two pilots, with local knowledge of the shipping routes and traffic patterns, will be onboard for the entire transit. This will serve to further reduce the probability of grounding.	
Nodes:	Node 1-3: Areas consist of delineated fairways with two way traffic; rocky bottom; some identified shoals outside the fairways. Node 4: Potential grounding while transiting Ma Wan Fairway during 90 degree turn to west after Tsing Ma bridge. Node 5: Narrowest channel width (310 meters) between CP 4/CP 5. Node 6-7: Muddier bottom, particularly at node 7; traffic avoidance while crossing over into turning basin; turning carrier with four tugs and berthing maneuver.	
Causes:	1. Environmental Factors 2. Steering into Known Obstacles (Operational Error) 3. Loss of Navigation Ability (Power failure, etc.) 4. Inadequate Navigational Aids / Uncharted Obstacles 5. Tug Boat Operational Error 6. Mooring Failure (causing carrier drift from jetty)	
Consequence:	Breach of outer hull, water ingress into ballast tanks. Worst case scenario would be penetration through the double hull and cargo tank resulting in breach of containment, leading to an accidental LNG release to sea. That would result in a vapor cloud forming, which if ignited would result in a flash fire and/or pool fire event, potentially affecting onshore population. NOTE: Kinetic energy of the impact is a governing factor in determining whether both outer and inner hulls would be penetrated which may lead to a breach of the containment.	
Safeguards:	1. Environmental Factors	The LNG carrier is equipped with advanced navigational systems such as DGPS, radar and communication systems. Monitoring of traffic by VTS (Vessel Traffic System) and where appropriate, providing traffic control. e.g. Ma Wan Channel. LNG carrier has double bottom. LNG cargo tank area is divided into five subdivisions. A pressure relief (venting) system is installed on each of the LNG cargo tanks. Weather forecasting and port typhoon warning system. Published Marine Department tidal window for Ma Wan transit.
	2. Steering into Known Obstacles	Minimum of two officers on bridge during port approach and transit. VTS information for approaching 14 specified areas at a distance 3 minutes ahead. Two pilots onboard LNG carrier. Port passage plan. Bridge resource management.
	3. Loss of Navigational Ability	Redundant power supply for critical instrumentation and redundant steering motors.

	4. Inadequate Navigational Aids / Hidden Obstacles	Channel boundaries for two way traffic are identified on navigational charts with recent updates provided through Notices to Mariners Some shallows outside of the channel may not be marked. Local incident reporting system for sunken vessels, vessels removed if sunk in delineated fairway. LNG carrier has ECDIS (Electronic Chart Display Information System). Pilot(s) have local knowledge. Port Passage Plan
	5. Tug Boat Operational Error	Tugs used are of required type and bollard pull. Tug boat crews are trained for emergency scenarios. Tug(s) made fast to optimize retarding and directional changes during Ma Wan transit. Dimension and delineation of turning basin per LNG industry standards with allowance for maneuver with designated number of tugs.
	6. Mooring failure	Mechanical integrity program for mooring lines. Tension monitoring system for mooring lines (provided on jetty).
Typical Risk Assessment Potential Scenario:	Grounding of LNG carrier due to e.g. electrical power or propulsion failure. Breach of the outer hull, water ingress into void space, potential heating of LNG cargo, boil-off exceeds capacity of boil-off handling system with release to atmosphere via the venting system. Vapor cloud formed due to emergency venting, potential ignition of vapor cloud.	
Risk Evaluation:	Scenario will be assessed further in MQRA due to potential for breach of LNG containment.	

Black Point Hazard No. H2: Ship Collision - Powered Collision of LNG carrier into another vessel

Description:	The LNG carrier is sharing the delineated fairways with several other vessels. Collision can include bow to bow contact or side impact in areas of cross traffic. Typical types of vessels are container vessels, bulk carriers, tankers, ferries, fishing boats and recreation crafts.	
Nodes:	Nodes 1-2: Generally moderate vessel traffic, with very little cross traffic. Node 3: Western Fairway has considerable cross traffic, with high speed ferries to outlying islands, vessels leaving Victoria Harbour, and vessels leaving Kwai Chung container terminal. Node 4: Ma Wan Fairway has high traffic and a 90 degree turn, with limited visibility; one way traffic applies to ships with 170m LOA or 9.5m draft or more. Node 5-6: Increased river trade traffic and high cross traffic of small vessels. Otherwise, generally wide navigable channels and good visibility of traffic. Node 7: LNG carrier proceeding into turning basin. Potential for bow and side collision.	
Cause:	1. Failure to follow collision avoidance regulations. 2. Environmental Factors. 3. Loss of Navigational Ability / Radar.	
Consequence:	Collision impact into another vessel could cause damage to the bow or the hull of the LNG carrier, however considered unlikely to cause breach of cargo containment. Dropped object(s) from the other vessel considered unlikely to breach the cargo containment. Possible fire event if the collision is with the other vessel carrying dangerous cargo. Loss of small craft, i.e. fishing boat, river traffic, recreation vessel. Potential injuries and/or fatalities of crew regardless of type of struck vessel.	
Safeguards:	1. Failure to Follow Collision Avoidance Regulations	The LNG carrier is equipped with advanced navigational aids such as Differential Global Positioning System (DGPS), radar with Automatic Radar Plotting Aid (ARPA) and communication systems. Monitoring of traffic by VTS (Vessel Traffic System) Forward collision bulkhead for the LNG carrier. A water spray system installed on the front of the accommodation on the LNG carrier protects the cargo space and tank covers to prevent any fire escalation. Fire water/foam would normally be available on other vessel involved in the collision, especially if carrying dangerous cargo. A passive tug boat is normally required for ocean going vessels, particularly through Ma Wan Fairway. Presence and intervention from tug(s) or Marine Department surveillance boat north of Ma Wan could reduce the probability of a collision with subsequent potential for grounding. Training of crew as required by regulations and company policy. Two officers on bridge during port approach and transit.
	2. Environmental Factors	Loaded LNG carrier transits only during day light. Transit in compliance with prescribed environmental limits. Two pilots onboard LNG carrier.
	3. Loss of Navigational Ability / Radar	Redundant electrical power supply for critical instrumentation and redundant steering motors. Two or more independent radar systems.
Typical Risk Assessment Potential Scenario:	LNG carrier collides with another vessel due to human error or non-compliance with COLREGS on struck vessel. When involving a small craft such as river, fishing or recreational type, capsizing is possible due to the impact velocity. Depending on the circumstances, LNG carrier personnel could provide assistance in rescuing personnel in the water using a rescue craft, as well as provide medical treatment if necessary until assistance from shore is available. The design of the carrier incorporates a forward collision bulkhead and double hull, thereby preventing a breach of containment.	
Risk Evaluation:	This scenario will be assessed in the MQRA as it is part of the collision frequencies that will be provided by BMT.	

Black Point Hazard No. H3: Ship Collision – Drifting Collision

Description:	Another vessel drifting into the LNG carrier, or the LNG carrier drifting into another vessel. The LNG carrier is sharing the delineated fairways with several other vessels. Typical types of vessels are container, bulk carriers, tankers, ferries, fishing boats and recreation crafts. Based on their deadweight, smaller vessels would not require a pilot.	
Nodes:	Node 1-2: Approach to pilot boarding area and transit up East Lamma Channel. Potential for several anchored vessels south of Lamma Island; LNG carrier may have to anchor to await available pilot. Node 3: Transiting vessels and cross traffic; container vessels anchor along Western Fairway to pick up cargo from barges. Node 4-5: Ma Wan Fairway and transit to Urmston Road; heavier traffic with few large vessels anchored in area. Node 6: Urmston Road up west side of mainland, with increased river trade traffic from China, but few vessels anchored. Node 7: LNG carrier turning basin.	
Cause:	1. Dragging Anchor. 2. Propulsion Power Failure. 3. Not maintaining efficient bridge watch.	
Consequence:	Low impact energy, superficial damage to LNG carrier. Considered unlikely to cause breach of LNG cargo containment. Could cause severe damage to, or even loss of small craft. Potential personnel injuries on both struck and striking vessel. However, it is considered unlikely that any debris would lead to breach of LNG cargo containment.	
Safeguards:	1. Dragging Anchor	Automated anchor watch system (ARPA). Alarm on GPS. Bridge continuously manned and position verified while anchored.
	2. Power Failure	Redundant electrical power supply for critical instrumentation and redundant steering motors. Presence and intervention from tug boats could reduce the probability and potential impact of a collision or grounding.
	3. Not maintaining efficient bridge watch	Bridge continuously manned and position verified while anchored.
Typical Risk Assessment Potential Scenario:	LNG carrier dragging anchor or drifting following a breakdown in propulsion system causing collision with other vessel type. Other vessel type drifted into LNG carrier. At drifting speeds, there is not sufficient energy that could be generated in a collision that would lead to a breach of LNG containment. The collision bulkhead and forecastle of the carrier together with its double hull and bottom safeguard against breach of LNG containment from a drifting collision.	
Risk Evaluation:	Drifting collisions would not lead to a breach of LNG containment and hence will not be assessed in the MQRA.	

Black Point Hazard No. H4: Ship Collision - Powered Collision of another vessel into the LNG carrier

Description:	Another ship colliding into the side of the LNG carrier, i.e. typical bow to side collision. The LNG carrier is sharing the delineated fairways with several other vessels. Typical types of vessels are container, bulk carriers, tankers, ferries, fishing boats and recreation crafts. Based on their deadweight, smaller vessels would not have a pilot onboard.	
Nodes:	Nodes 1-2: Limited cross traffic of large vessels; large numbers of vessels approaching Hong Kong waters (total of 40,000 ocean going transits per year in all approaches); main approach to Hong Kong. East Lamma Channel has no cross traffic of ocean going vessels. Node 3: Western Fairway is crossed by multiple ferry routes, vessels entering and exiting Victoria Harbour, and container ships exiting Kwai Chung container port. In addition, many ocean going vessels anchor along the Western Fairway to take on cargo and then re-enter the channel. Node 4: Ma Wan Fairway transits the Tsing Ma bridge and turns 90 degrees to the west on a limited visibility turn; potential for impact with vessels smaller than the 170 meter LOA or 9.5m draft or more limit for one way traffic and also larger vessels that are not aware of oncoming traffic. Node 5-6: Limited cross traffic of ocean going vessels, but many smaller vessels (private, ferries, river trade) crossing channel regularly. Potential for collision with ocean going vessel attempting to maneuver around smaller vessels. Node 7: LNG carrier turning basin. Potential for side collision, although limited by shallow water depths in area surrounding turning basin.	
Cause:	1. Failure to Follow Collision Avoidance Regulations 2. Loss of Navigational Ability / Power Failure 3. Environmental Factors	
Consequence:	Depending on the size, displacement, design speed and angle of the striking vessel, into the side of the LNG carrier, the result could be severe damage to both vessels. Worst case scenario would be penetration through the double hull and cargo tank resulting in breach of containment, leading to an accidental LNG release to sea. This could result in fire on the carrier or, without immediate ignition, a vapour cloud forming, potentially affecting populated areas.	
Safeguards:	1. Failure to Follow Collision Avoidance Regulations	The LNG carrier is equipped with advanced navigational aids such as Differential Global Positioning System (DGPS), radar with Automatic Radar Plotting Aid (ARPA) and communication systems. Monitoring of traffic by (Vessel Traffic System) (VTS) and where appropriate, providing for ship traffic control within Hong Kong waters. Forward collision bulkhead for the LNG carrier. A water spray system is installed on the front of the accommodation to protect the cargo space and tank covers on the LNG carrier to prevent any fire escalation. Fire water/foam would normally be available on other vessel involved in the collision especially if carrying dangerous cargo. A passive tug boat is normally required for ocean going vessels, particularly through Ma Wan Fairway and Ma Wan Channel. Presence and intervention from tug(s) or Marine Department surveillance boat north of Ma Wan could reduce the probability of a collision with subsequent grounding.
	2. Loss of Navigational Ability / Power Failure	Redundant electrical power supply for critical instrumentation and redundant steering motors.

	3. Environmental Factors	Based on the intended initial practice, loaded vessel transit only during day light. Two pilots onboard LNG carrier.
Typical Risk Assessment Potential Scenario:	Weather conditions/ human error resulting in another vessel colliding into the side of the LNG carrier. The collision impact could result in major damage, and fatalities/injuries on both vessels. If the impact energy is high from a combination of displacement, speed and striking angle, such a scenario could lead to penetration through the double hull and cargo tank resulting in breach of containment, and leading to an accidental LNG release to sea. This would result in a pool fire or vapor cloud, potentially affecting populated areas.	
Risk Evaluation:	Scenario will be assessed further in MQRA due to potential for breach of LNG containment.	

Black Point Hazard No. H5: Ship Collision (Striking) – Powered Collision of LNG vessel into obstructions

Description:	LNG carrier colliding into obstructions such as Black Point jetty or other marine structures along the route. However two pilots with local knowledge will be onboard for the entire transit. This knowledge will reduce the probability of striking known obstructions.	
Nodes:	Nodes 1-3: No fixed obstruction in the area. Potential impact to the vessels anchored along the Western Fairway. Node 4: Transit under the Tsing Ma bridge and around several smaller anchored vessels. Suspension bridge width approximately 1,200 meters ensures supports are outside the navigable channel and are protected; small vessels can anchor in the area, limited visibility 90 degree turn to the west midway through the delineated Ma Wan Fairway. Nodes 5-6: Fewer obstacles in this more open area, but still could encounter fishing vessels or other small anchored vessels. Risk of contact with navigational buoys or fishing nets also present in this area. Node 7: LNG carrier turning basin. Risk of impact to jetty, with damage to LNG carrier and jetty.	
Cause:	1. Tug Boat Equipment Failure or Human Error. 2. Loss of Navigational Ability / Electrical Power or Propulsion Failure 3. Environmental Factors	
Consequence:	Striking the jetty at an angle during the berthing manoeuvre is likely to damage the bow of the LNG carrier; however damage to cargo tank (LNG) containment is unlikely. Jetty could be rendered inoperable. Possible fire if anchored dangerous goods vessel is struck.	
Safeguards:	1. Tug Boat Operational Error	Tugs used are of required type and bollard pull. Tug boat crews are trained for emergency scenarios. Tug(s) made fast to optimize retarding and directional changes during Ma Wan transit. Dimension and delineation of turning basin per LNG industry standards with allowance for maneuver with designated number of tugs.
	2. Loss of Navigational Ability / Power Failure	Redundant electrical power supply for critical instrumentation and redundant steering motors.
	3. Environmental Factors	Loaded vessel transit only during day light. 2 pilots onboard LNG carrier.
Typical Risk Assessment Potential Scenario:	Fishing nets and buoys could result in fouling of propeller with loss of propulsion, or loss of steering, with either possibly leading to grounding or collision. LNG carrier impacts jetty while attempting to berth. Jetty could be rendered inoperable, with commercial impact on LNG availability for the generating facility. The LNGC impact into the jetty during berthing which would be at very low speeds and under tug control; therefore, the energy of collision would not be large enough to cause a breach of LNG containment.	
Risk Evaluation:	This eventuality is included within the frequencies of grounding of the LNG Carrier, and hence will be assessed in the MQRA.	

Black Point Hazard No. H6: Sinking / Foundering

Description:	Structural failure of laden LNG carrier, eventually leading to capsize/sinking. Typically occurring in combination with extreme weather. Due to causes other than collision, grounding, etc. Carrier will maneuver to avoid extreme weather.
Nodes:	General issue.
Cause:	Material defect, fatigue, extreme environmental loads, corrosion, exceeded permissible shear and bending moments.
Consequence:	Potentially leading to delayed breach of LNG containment with eventual release of all cargo into the surrounding water.
Safeguards:	LNG Carrier design in accordance with International Gas Carrier (IGC) regulations and classification requirements. The IMO International Code for the Construction and Equipment of Ships Carrying dangerous Chemicals in Bulk (Chapter 17) and amendments 1996, specifies hazard type, tank type, tank vents and tank environmental control aimed at making ships structurally sound in continuously averse conditions. Seaworthiness inspections every 5 years. Annual certificate for handling hazardous liquids. The cargo tank is divided into five subdivisions. Forecast of extreme weather provides avoidance action.
Typical Risk Assessment Potential Scenario:	Extreme weather impacts LNG carrier. Structural failure of hull, eventually leading to foundering/capsize. Release of all LNG cargo is possible. Circumstances and availability of emergency services will dictate successful evacuation of carrier personnel. This scenario is dependent on extreme weather. An LNGC is designed according to significant wave height and period criteria. At sea the vessel encounters waves of up to 10 meters crest to trough and is able to maneuver in this significant heave amplitude without experiencing structural damage. For overall strength, a ship's hull must be capable of withstanding design values of still water and wave induced loads within specified stress criteria. Within the Hong Kong harbor transit area, waves in excess of 5m have not been achieved even in a typhoon. The capability of modern weather prediction would allow an LNGC to avoid operating in severe conditions above the design criteria. Also, in the 40 years of operation of LNGCs, a sinking event has never occurred. The LNG carrier is expected to be classified by a classification society. Classification is carried out in order to contribute to the development and implementation of technical standards for the protection of life, property and the environment according to the International Association of Classification Societies. A classification society periodically inspects the LNG carrier during the design and construction phases and in the years of operation thereafter. Classification rules are developed to contribute to the structural strength and integrity of essential parts of the carrier's hull and its appendages, and the reliability and the function of the propulsion and steering systems, power generation and those other features and auxiliary systems which have been built into the carrier in order to maintain essential services on board for the purpose of safe operation of the carrier.
Risk Evaluation:	Given the typhoon sea states in the Hong Kong transit area and the design of LNGCs, this scenario is not credible.

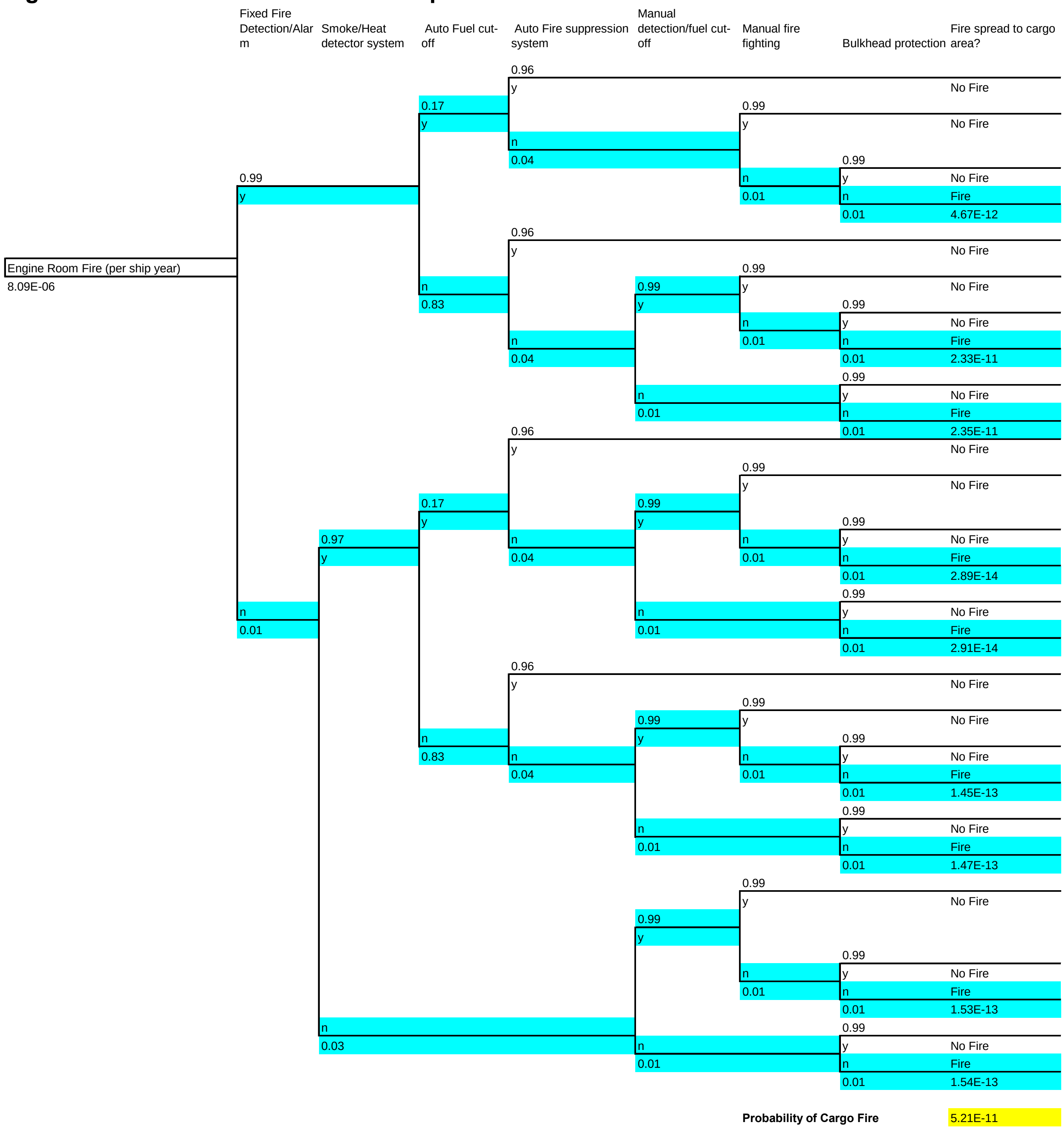
Black Point Hazard No. H7: Breach of Cargo Containment

Description:	The forces of sloshing due to environmental loads could cause damage to and/or possible loss of membrane structural integrity.
Nodes:	General issue.
Cause:	Material defect, fatigue, extreme environmental loads, corrosion, overfilling/overpressure of tanks. Non compliance with prescribed cargo tank liquid operating levels while underway.
Consequence:	Breach of LNG containment; accumulation of LNG in hold spaces resulting in embrittlement of steel. Potential release of LNG to the sea.
Safeguards:	Double containment barrier of cargo tank. Leak detection system installed between the two membrane barriers. Materials used for membrane construction have a very high corrosion resistance. Procedures exist for gradual warming and cooling of cargo containment. Carrier tanks will be full on the inbound voyage; hence there will not be a sloshing issue. If discharge is interrupted (e.g. environmental conditions) and the carrier has to leave the jetty with a partial cargo, the allowable tank liquid levels are prescribed to avoid sloshing. Design basis of LNG tanks per current practice (IGC code) which ensures that the secondary containment is able to contain the whole volume of the primary containment should it fail. In accordance with reference 05, the base failure rate of a full containment atmospheric tank (catastrophic failure of both inner and outer containers) is set at 1.0E10-08 per year. This applies to land-based atmospheric tanks. In the absence of available failure rates for LNG vessel containers (no breach of containment occurrences to date) the double containment failure rate for land-based atmospheric tanks is applied. The frequency of exposure is calculated as the number of hours LNG vessels are present in the Hong Kong transit area with a full laden cargo. The conservative estimate for transit per vessel is estimated to be between 2.5 and 3 hours. Taking the longer of the two time periods and dividing by the number of hours in a year yields: 75 trips into harbor per year x 3 hours / 8760 hours per year = 2.6E10-02 The total frequency of failure of a double containment cargo tank in the Hong Kong transit area is: 1.0E10-08 x 2.6E10-02 = 2.6E10-10 per year (based on onshore failure frequency)
Typical Risk Assessment Potential Scenario:	The sloshing scenario is dependent on the LNGC loading and the sea states. The LNGC always inbound transits in a full condition, such that sloshing will not occur. Weather windows are monitored to ensure that transit and discharge can take place safely. During typhoon conditions in the Hong Kong transit areas, wave heights of greater than 5m have not been experienced. Given the unforeseen need to leave the berth before fully unloading, the LNGC can conduct an internal cargo transfer between tanks to fill/empty tanks such that sloshing would not be a potential hazard.
Risk Evaluation:	Given the typhoon sea states in the Hong Kong transit area, the passage plans for weather windows, and the ability to conduct intra-ship cargo transfers between tanks, this scenario is not viewed as credible. If there would be a potential for failure, this would have been small and occurred in the open seas given the increased load to the carrier in these conditions and not in Hong Kong Harbour. In the 10,000 tank years for LNG sea vessels this has not occurred. Failure of a double containment cargo tank is an order of magnitude below the lower bound of the Hong Kong EIAO criteria and thus is not considered credible.

Black Point Hazard No. H8: Fire and Explosion

Description:	Fire/explosion on LNG carrier during transit. Potential spreading to other areas. Leakage of fuel piping system, impinging on hot surface, e.g. diesel generator causes fire. Resulting flammable gas vapors can contact electrical equipment that is not intrinsically safe causing an explosion.
Nodes:	General issue.
Cause:	1. Leakage or rupture of fuel system in engine room 2. Accommodation fire/explosion 3. Fire in cargo handling 4. Fire in storage area 5. Boiler explosion 6. Fire on neighboring vessel
Consequence:	Loss of power, loss of steering, potential fatalities. Potential escalation to living quarters and LNG cargo tanks.
Safeguards:	Double wall piping for fuel supply lines in engine room. Engine room air exchange frequency. Redundant electrical power supply for critical instrumentation and redundant steering motors. Fire suppression in engine room; diesel driven fire pump located outside of engine room. The living quarters and engine room are separated by means of firewalls. The LNG cargo tank is located away from the engine room, hence low escalation probability. Double wall diesel oil tank. Training in compliance with boiler re-firing procedures
Typical Risk Assessment Potential Scenario:	An event tree has been developed as shown in Figure 1 to illustrate the probability of this scenario. The event tree considers the layers of protection that would typically exist on an LNG carrier. These include fixed fire detection, smoke/heat detection, automatic fuel cut-off, automatic fire suppression, manual detection/fuel shut off, manual fire firefighting and bulkhead protection. From the event tree, which has been derived from internationally recognized databases on accidents (Eknes M., Kvien M. H., "Historical risk levels in the maritime industry", Report No. 99-2028, Rev 01, October 1999) and reliability of equipment (OREDA – Offshore Reliability Data Handbook), it can be seen that the probability of an engine room fire escalating to the cargo areas is seen of the order of 5E-11 per ship year. This is two orders of magnitude below the lower bound of the EIAO-FN curve' hence this scenario is not considered credible and will not be considered further. This event tree supports the experience that in 40 years of LNG history, this event has not occurred.
Risk Evaluation:	Based on the event tree and historical events, this scenario is not credible.

Figure II-1 – Event Tree for Fire and Explosion



Black Point Hazard No. H9: Aircraft Impact into LNG Carrier During Takeoff/Landing from Chep Lap Kok Airport

Description:	Impact on LNG carrier during takeoff or landing of aircraft at Chep Lap Kok Airport (relevant for Nodes 4 – 5 of Black Point route)
Nodes:	Nodes 4-5: Only nodes of concern are those on flight path near runways.
Cause:	Failure on aircraft during takeoff or landing while crossing over vessel traffic route.
Consequence:	Immediate fire on carrier from jet fuel with potential for breach of LNG containment.
Safeguards:	Modern airport with most recent aircraft landing assistance devices; separation of channel from end of runway is more than 5 km.
Typical Risk Assessment Potential Scenario:	According to an Airclaims report (ref. 01), the frequency of fatal accidents (excluding hostile attacks and personal accidents) on large commercial jets, worldwide, during 1990-2002 was estimated as 6.2E-07 per flight. The following elements are taken into account in assessing the risk of the aircraft accident event: – Number of flights at Hong Kong International Airport (HKIA) in 2011 is estimated to be 1080 flights per day, equivalent to 394,000 flights per year. – Frequency of crashes (i.e. events where the aircraft impacts on the ground, water or another object and loses overall structural integrity), should apply a modification factor of 1.26 (ref. 02). – There is a downward trend in the frequencies of 4.5% per year (ref. 01). Given that the frequency of 6.2E-07 per flight corresponds to the middle of the plot between 1990 to 2002, the frequency at the end of the data period (2002) is estimated to be 0.74 of the frequency above. Extrapolating this further to 2011, assuming half of the downward trend per year (to be conservative), yields another reduction, to 0.6 of the frequency above. – The normal flight path is departure from HKIA at Chep Lap Kok heading East Northeast towards Ma Wan and the mainland. The flight path is directly above the identified Node 5 and Node 6 of the Black Point route. The length of the flight path before turning is estimated to be 20km and the length of the exposed passage is about 6km. The flight corridor is estimated to be 1 to 1.5km and the wingspan of commercial air plan is about 60m. The fraction of exposed passage is therefore estimated to be 0.018 (=6/20 x 0.06). – The average length of flight was 1.8 hours or equivalent to 900km (at an average cruise speed of 500 km/hr). By applying a linear correlation and considering the exposed passage length of 6km, the time fraction of an airplane flight above the exposed passage is in the region of 0.007. – The transit time of the LNG carrier within the exposed passage is estimated to be 17 minutes (at a transit speed of 12 knots) or equivalent to 0.002 per year (with 75 arrivals per year). – The aircraft may have a change in direction during an accident, either due to loss of control or pilot last minute action, and it is estimated that only 1% probability it will remain on the exposed passage. – The overall frequency is therefore estimated as 4.7E-10 per year (= 6.2E-07 x 394,000 x 1.26 x 0.6 x 0.018 x 0.007 x 0.002 x 0.01). The result showed that the likelihood of an aircraft impact on an LNG carrier is remote and poses risk that is below the Hong Kong EIAO criteria.
Risk Evaluation:	An analysis of this event was carried out, and the frequency of occurrence was calculated to be below $1x10^{-9}$. This frequency falls below the lower bound of the EIAO criteria, and thus, this scenario is not considered credible and will not be developed further in the MQRA.

II.6 Hazard Register – South Soko

South Soko Hazard No. H1: Grounding

Description:	Grounding of LNG carrier. Channels in Hong Kong are very wide and groundings are infrequent. Delineated fairways within Hong Kong waters permit two-way traffic. Frequency of grounding for ocean going vessels is less than that for collisions. For the approach to South Soko, the LNG carrier will have four passive tug escorts. In addition, two pilots with local knowledge of the shipping routes and traffic patterns will be onboard for the entire transit. This will serve to further reduce the probability of grounding.	
Nodes:	Nodes 1-2: Areas consist of wide approach channel with entrance channel delineated; rocky bottom; some shoals in way of spoil ground. Node 3: Dredged channels around Soko islands; 250 m approach channel to turning basin and jetty.	
Causes:	1. Environmental Factors 2. Steering into Known Obstacles 3. Loss of Navigation Ability (Power failure, etc.) 4. Inadequate Navigational Aids / Uncharted Obstacles 5. Tug Boat Operational Error 6. Mooring Failure (causing carrier drift from jetty)	
Consequence:	Breach of outer hull, water ingress into ballast tanks. Worst case scenario would be breaching of double wall containment and cargo tank, leading to an accidental LNG release to sea. That would result in a vapor cloud forming, which if ignited would results in a flash fire and/or pool fire event, potentially affecting onshore population in closest proximity to South Soko. NOTE: Kinetic energy of the impact is a governing factor in determining whether both outer and inner hulls would be penetrated which may lead to a breach of the containment.	
Safeguards:	1. Environmental Factors	The LNG carrier is equipped with advanced navigational systems such as DGPS, radar and communication systems. Monitoring of traffic by VTS (Vessel Traffic System) LNG carrier has double bottom. LNG cargo tank area is divided into five subdivisions. A pressure relief (venting) system is installed on each of the LNG cargo tanks. Weather forecasting and port typhoon warning system. Published Marine Department tidal window for Ma Wan transit.
	2. Steering into Known Obstacles	Minimum of two officers on bridge during port approach and transit. VTS automated warning system for approaching 14 specified areas at a distance 3 minutes ahead.. Two pilots onboard LNG carrier. Port passage plan. Bridge resource management.
	3. Loss of Navigational Ability	Redundant power supply for critical instrumentation and redundant steering motors.
	4. Inadequate Navigational Aids / Hidden Obstacles	Channel boundaries for two way traffic are identified on navigational charts with recent updates provided through Notices to Mariners Some shallows outside of the channel may not be marked. Local incident reporting system for sunken vessels; vessels removed if sunk in delineated fairway. LNG carrier has ECDIS (Electronic Chart Display Information System). Pilot(s) have local knowledge. Port Passage Plan.
	5. Tug Boat Operational Error	Tugs used are of required type and bollard pull. Tug boat crews are trained for emergency scenarios. Dimension and delineation of turning basin per LNG industry standards with allowance for maneuver with designated number of tugs.
	6. Mooring failure	Mechanical integrity program for mooring lines. Tension monitoring system for mooring lines (provided on jetty).

Typical Risk Assessment Potential Scenario:	Grounding of LNG carrier due to e.g. electrical or propulsion power failure. Breach of the outer hull, water ingress into void space, potential heating of LNG cargo, boil-off exceeds capacity of boil-off handling system with release to atmosphere via the venting system. Vapor cloud formed due to emergency venting, potential ignition of vapor cloud.
Risk Evaluation:	Scenario will be assessed further in MQRA due to potential for breach of LNG containment.

South Soko Hazard No. H2: Ship Collision - Powered Collision of LNG carrier into another vessel

Description:	The LNG carrier is sharing the delineated fairways with several other vessels. Collision can include bow to bow contact or side impact in areas of cross traffic. Typical types of vessels are container vessels, bulk carriers, tankers, ferries, fishing boats and recreation crafts.	
Nodes:	Nodes 1-2: Generally moderate vessel traffic; LNG carrier must cross outbound channel on approach to the South Lamma DG Anchorage to pick up pilot. Passage through PRC waters south of HK dumping area; passage near to new vessel traffic separation scheme near Soko islands. Number of vessels is uncertain as information is not as good for traffic outside HK waters. Node 3: Dredged channel around South Soko; few vessels in the area, mostly fishing vessels and other small craft.	
Cause:	1. Failure to follow collision avoidance regulations. 2. Environmental Factors. 3. Loss of Navigational Ability / Radar.	
Consequence:	Collision impact into another vessel could cause damage to the bow or the hull of the LNG carrier, however considered unlikely to cause breach of cargo containment. Dropped object(s) from the other vessel considered unlikely to breach the cargo containment. Possible fire event if the collision is with the other vessel carrying dangerous cargo. Loss of small craft, i.e. fishing boat, river traffic, recreation vessel. Potential injuries and/or fatalities of crew regardless of type of struck vessel.	
Safeguards:	1. Failure to Follow Collision Avoidance Regulations	The LNG - carrier is equipped with advanced navigational aids such as Differential Global Positioning System (DGPS), radar with Automatic Radar Plotting Aid (ARPA) and communication systems. Monitoring of traffic by VTS (Vessel Traffic System) and where appropriate, providing for traffic control within Hong Kong waters Forward collision bulkhead for the LNG carrier. A water spray system installed on the front of the accommodation on the LNG carrier protects the cargo space and tank covers to prevent any fire escalation. Fire water/foam would normally be available on other vessel involved in the collision, especially if carrying dangerous cargo. Training of crew as required by regulations and company policy. Two officers on bridge during port approach and transit.
	2. Environmental Factors	Based on the intended initial practice, loaded LNG carrier transit only during day light. Two pilots onboard LNG carrier.
	3. Loss of Navigational Ability / Radar	Redundant electrical power supply for critical instrumentation and redundant steering motors. Two or more independent radar systems.
Typical Risk Assessment Potential Scenario:	LNG carrier collides with another vessel due to human error or non-compliance with COLREGS on struck vessel. When involving a small craft such as river, fishing or recreational type, capsizing is possible due to the impact velocity. Depending on the circumstances, LNG carrier personnel could provide assistance in rescuing personnel in the water using a rescue craft, as well as provide medical treatment if necessary until assistance from shore is available. The design of the carrier incorporates a forward collision bulkhead and double hull, thereby preventing a breach of containment.	
Risk Evaluation:	This scenario will be assessed in the MQRA as it is part of the collision frequencies that will be provided by BMT.	

South Soko Hazard No. H3: Ship Collision – Drifting Collision

Description:	Another vessel drifting into the LNG carrier, or the LNG carrier drifting into another vessel. The LNG carrier is sharing the delineated fairways with several other vessels. Typical types of vessels are container, bulk carriers, tankers, ferries, fishing boats and recreation crafts. Based on their deadweight, smaller vessels would not require a pilot.	
Nodes:	Nodes 1-2: Approach to pilot boarding area at South Lamma DG Anchorage. Potential for several anchored vessels South of Lamma Island; LNG carrier may have to anchor to await available pilot. Node 3: Dredged channel around South Soko; few vessels in the area, mostly fishing vessels and other small craft. LNG carrier turning basin.	
Cause:	1. Dragging Anchor. 2. Propulsion Power Failure. 3. Not maintaining efficient bridge watch.	
Consequence:	Low impact energy, superficial damage to LNG carrier. Considered unlikely to cause breach of LNG cargo containment. Could cause severe damage to, or even loss of small craft. Potential personnel injuries on both struck and striking vessel. However, it is considered unlikely that any debris would lead to breach of LNG cargo containment.	
Safeguards:	1. Dragging Anchor	Automated anchor watch system (ARPA). Alarm on GPS. Bridge continuously manned and position verified while anchored.
	2. Power Failure	Redundant electrical power supply for critical instrumentation and redundant steering motors. Presence and intervention from tug boats could reduce the probability and potential impact of a collision or grounding.
	3. Not maintaining efficient bridge watch	Bridge continuously manned and position verified while anchored.
Typical Risk Assessment Potential Scenario:	LNG carrier dragging anchor or drifting following a breakdown in propulsion system causing collision with other vessel type. Other vessel type drifted into LNG carrier. At drifting speeds, there is not sufficient energy that could be generated in a collision that would lead to a breach of LNG containment. The collision bulkhead and forecastle of the carrier together with its double hull and bottom safeguard against breach of LNG containment from a drifting collision.	
Risk Evaluation:	Drifting collisions would not lead to a breach of LNG containment and hence will not be assessed in the MQRA.	

South Soko Hazard No. H4: Ship Collision - Powered Collision of another vessel into the LNG carrier

Description:	Another ship colliding into the side of the LNG carrier, i.e. typical bow to side collision. The LNG carrier is sharing the delineated fairways with several other vessels. Typical types of vessels are container, bulk carriers, tankers, ferries, fishing boats and recreation crafts. Based on their deadweight, smaller vessels would not have a pilot onboard.	
Nodes:	Nodes 1-2: Limited cross traffic of large vessels; large numbers of vessels approaching Hong Kong waters (total of 40,000 ocean going transits per year in all approaches); on main approach to Hong Kong until turning to South Lamma DG Anchorage. Must cross main channel to reach anchorage. Node 3: Limited cross traffic of any type of vessel; unlikely to encounter ocean going vessels. LNG carrier turning basin. Potential for collision with small vessel with limited risk to LNG carrier.	
Cause:	1. Failure to Follow Collision Avoidance Regulations 2. Loss of Navigational Ability / Power Failure 3. Environmental Factors	
Consequence:	Depending on the size, displacement, design speed and angle of the striking vessel, into the side of the LNG carrier, the result could be severe damage to both vessels. Worst case scenario would be penetration through the double hull and cargo tank resulting in breach of containment, leading to an accidental LNG release to sea. This could result in fire on the carrier or, without immediate ignition, a vapor cloud forming, potentially affecting populated areas.	
Safeguards:	1. Failure to Follow Collision Avoidance Regulations	The LNG carrier is equipped with advanced navigational aids such as Differential Global Positioning System (DGPS), radar with Automatic Radar Plotting Aid (ARPA) and communication systems. Monitoring of traffic by (Vessel Traffic System) (VTS) and where appropriate, providing for ship traffic control within Hong Kong waters. Forward collision bulkhead for the LNG carrier. A water spray system is installed on the front of the accommodation to protect the cargo space and tank covers on the LNG carrier to prevent any fire escalation. Fire water/foam would normally be available on other vessel involved in the collision especially if carrying dangerous cargo.
	2. Loss of Navigational Ability / Power Failure	Redundant electrical power supply for critical instrumentation and redundant steering motors.
	3. Environmenta l Factors	Based on the intended initial practice, loaded vessel transit only during day light. Two pilots onboard LNG carrier.
Typical Risk Assessment Potential Scenario:	Weather conditions/ human error resulting in another vessel colliding into the side of the LNG carrier. The collision impact could result in major damage, and fatalities/injuries on both vessels. If the impact energy is high from a combination of displacement, speed and striking angle, such a scenario could lead to penetration through the double hull and cargo tank resulting in breach of containment, and leading to an accidental LNG release to sea. This would result in a pool fire or vapor cloud, potentially affecting populated areas.	
Risk Evaluation:	Scenario will be assessed further in MQRA due to potential for breach of LNG containment.	

South Soko Hazard No. H5: Ship Collision (Striking) – Powered Collision of LNG vessel into obstructions

<table>
<tr><td>Description:</td><td colspan="2">LNG carrier colliding into objects such as South Soko jetty or other marine structures along the route. However two pilots with local knowledge will be onboard for the entire transit. This knowledge will reduce the probability of striking known obstructions.</td></tr>
<tr><td>Nodes:</td><td colspan="2">Nodes 1-2: No fixed obstruction in the area. Potential impact to the vessels anchored south of Lamma island.
Node 3: Transit around South Soko island up to turning basin. Potential for impact to new aids to navigation for dredged channel. LNG carrier turning basin. Risk of impact to jetty, with damage to LNG carrier and the jetty..</td></tr>
<tr><td>Cause:</td><td colspan="2">1. Tug Boat Equipment Failure or Human Error.
2. Loss of Navigational Ability / Power Failure
3. Environmental Factors</td></tr>
<tr><td>Consequence:</td><td colspan="2">Striking the jetty at an angle during the berthing maneuver is likely to damage the bow of the LNG carrier; however damage to cargo tank (LNG) containment is unlikely. Jetty could be rendered inoperable.
Possible fire if anchored dangerous goods vessel is struck.</td></tr>
<tr><td rowspan="3">Safeguards:</td><td>1. Tug Boat Operational Error</td><td>Tugs used are of required type and bollard pull.
Tug boat crews are trained for emergency scenarios.
Dimension and delineation of turning basin per LNG industry standards with allowance for maneuver with designated number of tugs.</td></tr>
<tr><td>2. Loss of Navigational Ability / Power Failure</td><td>Redundant electrical power supply for critical instrumentation and redundant steering motors.</td></tr>
<tr><td>3. Environmenta l Factors</td><td>Based on the intended initial practice, loaded carrier transit only during daylight.
2 pilots onboard LNG carrier.</td></tr>
<tr><td>Typical Risk Assessment Potential Scenario:</td><td colspan="2">Fishing nets and buoys could result in fouling of propeller with loss of propulsion, or loss of steering, with either possibly leading to grounding or collision. LNG carrier impacts jetty while attempting to berth. Jetty could be rendered inoperable, with commercial impact on LNG availability for the generating facility. The LNGC impact into the jetty during berthing would be at very low speeds and under tug escort; therefore, the energy of collision would not be large enough to cause a breach of LNG containment.</td></tr>
<tr><td>Risk Evaluation:</td><td colspan="2">This eventuality is included within the frequencies of grounding of the LNG Carrier, and hence will be assessed in the MQRA.</td></tr>
</table>

South Soko Hazard No. H6: Sinking / Foundering

Description:	Structural failure of laden LNG carrier, eventually leading to capsize/sinking. Typically occurring in combination with extreme weather. Due to causes other than collision, grounding, etc. Carrier will maneuver to avoid extreme weather.
Nodes:	General issue.
Cause:	Material defect, fatigue, extreme environmental loads, corrosion, exceeded permissible shear and bending moments.
Consequence:	Potentially leading to delayed breach of LNG containment with eventual release of all cargo into the surrounding water.
Safeguards:	LNG carrier design in accordance with International Gas Carrier (IGC) regulations and classification requirements. Seaworthiness inspections every 5 years. Annual certificate for handling hazardous liquids. The cargo tank is divided into five subdivisions. Forecast of extreme weather provides avoidance action.
Typical Risk Assessment Potential Scenario:	Extreme weather impacts LNG carrier. Structural failure of hull, eventually leading to foundering/capsize. Release of all LNG cargo is possible. Circumstances and availability of emergency services will dictate successful evacuation of carrier personnel. This scenario is dependent on extreme weather. An LNGC is designed according to significant wave height and period criteria. At sea the vessel encounters waves of up to 10 meters crest to trough and is able to maneuver in this significant heave amplitude without experiencing structural damage. For overall strength, a ship's hull must be capable of withstanding design values of still water and wave induced loads within specified stress criteria. Within the Hong Kong harbor transit area, waves in excess of 5m have not been achieved even in a typhoon. The capability of modern weather prediction would allow an LNGC to avoid operating in severe conditions above the design criteria. Also, in the 40 years of operation of LNGCs, a sinking event has never occurred. The LNG carrier is expected to be classified by a classification society. Classification is carried out in order to contribute to the development and implementation of technical standards for the protection of life, property and the environment according to the International Association of Classification Societies. A classification society periodically inspects the LNG carrier during the design and construction phases and in the years of operation thereafter. Classification rules are developed to contribute to the structural strength and integrity of essential parts of the carrier's hull and its appendages, and the reliability and the function of the propulsion and steering systems, power generation and those other features and auxiliary systems which have been built into the carrier in order to maintain essential services on board for the purpose of safe operation of the carrier.
Risk Evaluation:	Given the typhoon sea states in the Hong Kong transit area and the design of LNGCs, this scenario is not credible.

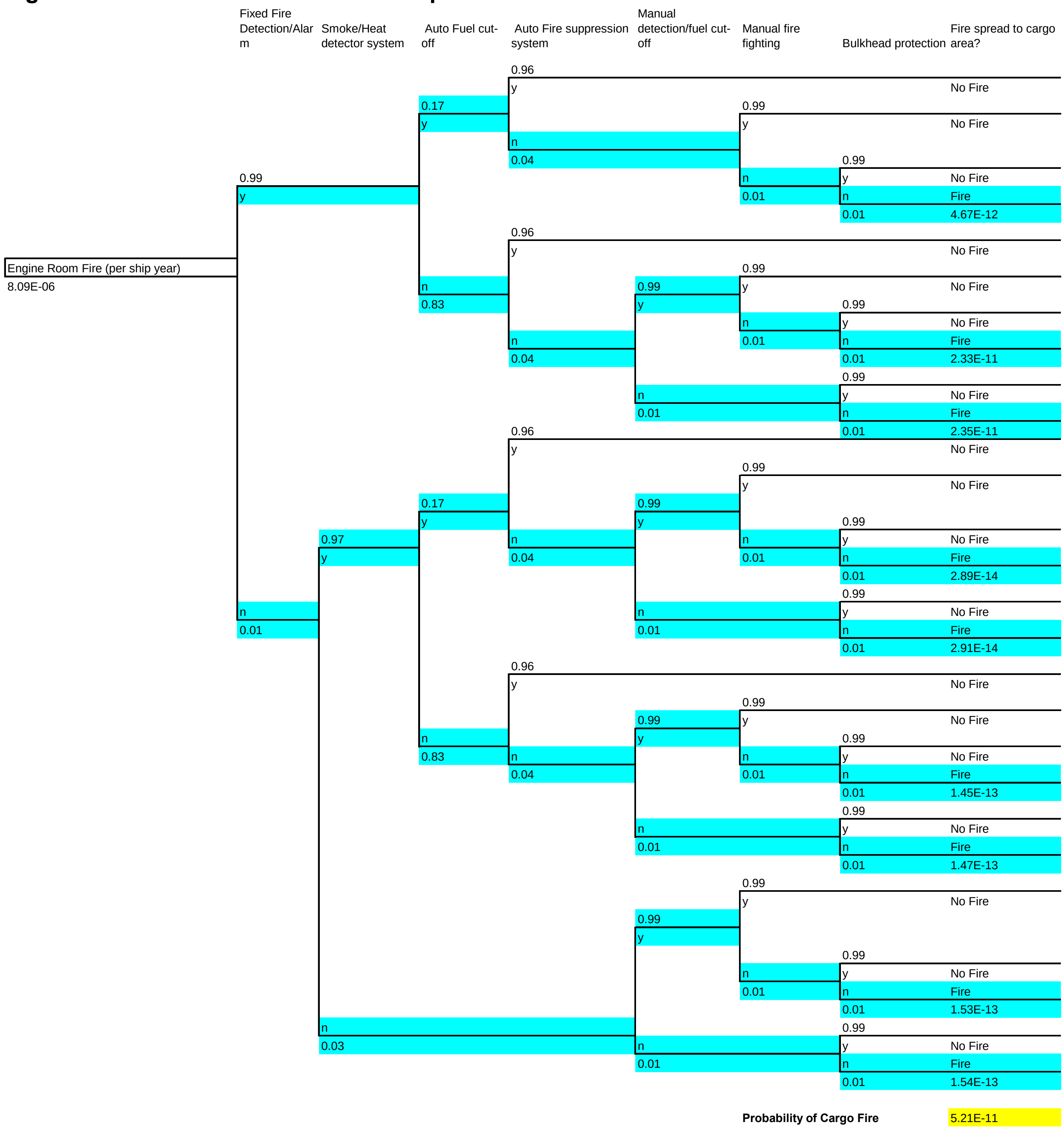
South Soko Hazard No. H7: Breach of Cargo Containment

Description:	The forces of sloshing due to environmental loads could cause damage to and/or possible loss of membrane structural integrity.
Nodes:	General issue.
Cause:	Material defect, fatigue, extreme environmental loads, corrosion, overfilling/overpressure of tanks. Non compliance with prescribed cargo tank liquid operating levels while underway.
Consequence:	Breach of LNG containment; accumulation of LNG in hold spaces resulting in embrittlement of steel. Potential release of LNG to the sea.
Safeguards:	Double containment barrier of cargo tank. Leak detection system installed between the two membrane barriers. Materials used for membrane construction have a very high corrosion resistance. Procedures exist for gradual warming and cooling of cargo containment. Carrier tanks will be full on the inbound voyage; hence there will not be a sloshing issue. If discharge is interrupted (e.g. environmental conditions) and the carrier has to leave the jetty with a partial cargo, the allowable tank liquid levels are prescribed to avoid sloshing. Design basis of LNG tanks per current practice (IGC code) which ensures that the secondary containment is able to contain the whole volume of the primary containment should it fail. In accordance with reference 05, the base failure rate of a full containment atmospheric tank (catastrophic failure of both inner and outer containers) is set at 1.0E10-08 per year. This applies to land-based atmospheric tanks. In the absence of available failure rates for LNG vessel containers (no breach of containment occurrences to date) the double containment failure rate for land-based atmospheric tanks is applied. The frequency of exposure is calculated as the number of hours LNG vessels are present in the Hong Kong transit area with a full laden cargo. The conservative estimate for transit per vessel is estimated to be between 2.5 and 3 hours for Black Point and less for South Soko. Taking the conservative longer of the two Black Point time periods and dividing by the number of hours in a year yields: 75 trips into harbor per year x 3 hours / 8760 hours per year = 2.6E10-02 The total frequency of failure of a double containment cargo tank in the Hong Kong transit area is: 1.0E10-08 x 2.6E10-02 = 2.6E10-10 per year (based on onshore failure frequency)
Typical Risk Assessment Potential Scenario:	The sloshing scenario is dependent on the LNGC loading and the sea states. The LNGC always inbound transits in a full condition, such that sloshing will not occur. Weather windows are monitored to ensure that transit and discharge can take place safely. During typhoon conditions in the Hong Kong transit areas, wave heights of greater than 5m have not been experienced. Given the unforeseen need to leave the berth before fully unloading, the LNGC can conduct an internal cargo transfer between tanks to fill/empty tanks such that sloshing would not be a potential hazard.
Risk Evaluation:	Given the typhoon sea states in the Hong Kong transit area, the passage plans for weather windows, and the ability to conduct intra-ship cargo transfers between tanks, this scenario is not viewed as credible. If there would be a potential for failure, this would have been small and occurred in the open seas given the increased load to the carrier in these conditions and not in Hong Kong Harbour. In the 10,000 tank years for LNG sea vessels this has not occurred. Failure of a double containment cargo tank is an order of magnitude below the lower bound of the Hong Kong EIAO criteria and thus is not considered credible.

South Soko Hazard No. H8: Fire and Explosion

Description:	Fire/explosion on LNG carrier during transit. Potential spreading to other areas. Leakage of fuel piping system, impinging on hot surface, e.g. diesel generator causes fire. Resulting flammable gas vapors can contact electrical equipment that is not intrinsically safe causing an explosion.
Nodes:	General issue.
Cause:	1. Leakage or rupture of fuel system in engine room 2. Accommodation fire/explosion 3. Fire in cargo handling 4. Fire in storage area 5. Boiler explosion 6. Fire on neighboring vessel
Consequence:	Loss of power, loss of steering, potential fatalities. Potential escalation to living quarters and LNG cargo tanks.
Safeguards:	Double wall piping for fuel supply lines in engine room. Engine room air exchange frequency. Redundant electrical power supply for critical instrumentation and redundant steering motors. Fire suppression in engine room; diesel driven fire pump located outside of engine room. The living quarters and engine room are separated by means of firewalls. The LNG cargo tank is located away from the engine room, hence low escalation probability. Double wall diesel oil tank. Training in compliance with boiler re-firing procedures
Typical Risk Assessment Potential Scenario:	An event tree has been developed as shown in Figure 2 to illustrate this scenario probability. The event tree considers the layers of protection that would typically exist on an LNG carrier. These include fixed fire detection, smoke/heat detection, automatic fuel cut-off, automatic fire suppression, manual detection/fuel shut off, manual fire firefighting and bulkhead protection. From the event tree, which has been derived from internationally recognized databases on accidents (Eknes M., Kvien M. H., “Historical risk levels in the maritime industry”, Report No. 99-2028, Rev 01, October 1999) and reliability of equipment (OREDA – Offshore Reliability Data Handbook), it can be seen that the probability of an engine room fire escalating to the cargo areas is seen of the order of 5E-11 per ship year. This is two orders of magnitude below the lower bound of the EIAO-FN curve; hence this scenario is not considered credible and will not be considered further. This event tree supports the experience that in 40 years of LNG history, this event has not occurred.
Risk Evaluation:	Based on the event tree and historical events, this scenario is not credible.

Figure II-2 – Event Tree for Fire and Explosion



South Soko Hazard No. H9: Aircraft Impact into LNG Carrier During Takeoff/Landing from Chep Lap Kok Airport

Description:	Impact on LNG carrier during takeoff or landing of aircraft at Chep Lap Kok Airport (relevant for Nodes 4 – 5 of Black Point route)
Nodes:	There are no nodes of concern as the carrier transit route does not cross the normal flight path of aircraft to/from Chep Lap Kok airport.
Cause:	Failure on aircraft due to significant deviation during takeoff or landing
Consequence:	Immediate fire on carrier from jet fuel with potential for breach of LNG containment.
Safeguards:	Modern airport with most recent aircraft landing assistance devices; separation of channel from end of runway is more than 5 km. Path of aircraft does not cross carrier route.
Typical Risk Assessment Potential Scenario:	The values calculated for Hazard H9 – Black Point would actually be reduced further as the flight path does not coincide with the carrier route.
Risk Evaluation:	An analysis of this event was carried out, and the frequency of occurrence was calculated to be below $1x10^{-9}$. This frequency falls below the lower bound of the EIAO criteria, and thus, this scenario is not considered credible and will not be developed further in the MQRA.

II.7 Events Excluded from the Analysis

The following section details the scenarios that have been excluded from the analysis. The scenarios have been judged to either not result in a breach of cargo containment, have a frequency of less than $1x10^{-9}$ per year, or do not increase the consequence (hazard to life). Further analysis (performed as needed) is also discussed.

II.7.1 Events without Breach of Cargo Containment

1. 750mm and 1500mm Grounding Events

For the grounding scenario, it was decided to only consider a small release (250mm inner cargo tank hole size), given that large and medium releases (750mm and 1500mm inner cargo tank hole sizes, respectively) related to grounding were considered unlikely, and are below the frequency criteria.

The Sandia report conducted an analysis for the penetration of a double-hulled tanker, and determined that the penetration would need to be approximately three meters before generating a hole in the inner hull (ref. 03). The Sandia report does not consider an accidental grounding event to result in cargo tank breach. To date there has not been a loss of containment of LNG due to grounding. The two grounding events that have occurred at 12 and 17 knots did not lead to a breach of containment. As the speed of the LNG carrier in Hong Kong waters will not exceed 12 knots, the possibility of a medium or large breach of containment is remote. To include grounding events in the analysis, the most credible scenario was determined to be a small hole in the cargo tank (250mm).

2. Drifting Collision between LNG carrier and another vessel

The drifting collision between an LNG carrier and another vessel is described in the earlier sections related to Black Point and South Soko Hazard No. H3. The speed of the current in the Hong Kong harbor is not expected to exceed 1-3 knots. A carrier will assume roughly 75% of the current strength, leading to a drifting speed of 0.75-2 knots. The safe berthing speed is not greater than 4 knots. At this speed, the design of the LNG carrier must be able to withstand collision with a fixed object or other vessel. A drifting collision would involve such low impact energy that there would not be a breach of containment.

3. Breach of Containment from Pipework/Equipment on LNG Carrier

Breach of containment from pipework or equipment on the LNG carrier would occur due to spontaneous failures (material defects, construction defects, fatigue, corrosion, etc.) and/or operation errors. Any release from the carrier equipment would be localized to the carrier and would be mitigated by the safety systems on board, such as the fire water protection systems. As detailed in the Black Point and South Soko Hazard No. H8, in the 40 year history of LNG carrier transit there has not been a fire/explosion on board that resulted in a breach of containment.

II.7.2 Events with Frequency of $< 10^{-9}$ per year

1. Breach of Cargo Containment

A cargo containment breach due to material defect, fatigue, extreme environmental conditions, overfilling, etc. is described in the earlier sections related to Black Point and South Soko Hazard No. H7. The tank construction materials are very highly corrosion resistant. Forecasts will be available to assist in making any decision for avoidance of adverse weather to limit hull stresses from sloshing and potential structural fatigue. Onboard operational procedures will describe how to avoid overfilling of tanks. If there would be a potential for failure, this would have occurred in the open seas given the increased load to the carrier in these conditions and not in Hong Kong Harbour. The frequency of a double containment cargo tank failure (2.6×10^{-10} per year based on onshore failure frequency) falls below the EIAO criteria and thus was not considered further in the MQRA analysis. The postulate of instantaneous tank failure has also been raised. The mechanisms for instantaneous tank failure do not exist for the transit of LNG in LNG carriers.

2. Potential Aircraft impact into the LNG Carrier

The hazard of an aircraft impacting the LNG carrier is described in the earlier sections related to Black Point and South Soko Hazard No. H9. The frequency of this event (estimated at 4.7×10^{-10}) showed that the likelihood of aircraft impact on an LNG carrier is below the EIAO criteria and was thus not considered further in the MQRA analysis.

II.7.3 Events without Increase to Consequence

1. Potential LNG spill / fire / explosion in the carrier void space

The potential to have an LNG spill in the carrier void space that would lead to breach of containment from a second LNG tank due to embrittlement or that would lead to a fire or explosion that may also lead to a breach of containment from a second LNG tank is addressed more fully in Appendix III, Section III.2. The Sandia Report (ref. 03) considers several incident scenarios and assesses the potential for and impacts of LNG carrier damage. Sandia draws its conclusions from "embrittlement scoping analyses (that) were conducted to assess the potential damage to an LNG carrier from small and large LNG spills based on available fracture mechanics data and models". Sandia concludes:

- While accidental incidents could lead to minor to moderate damage to a LNG carrier, they would not lead to severe structural damage and the potential for cascading damage to other tanks.

- Should there be a secondary event, "This cascading release is not expected to increase significantly the overall fire size or hazard ranges, but the expected fire duration would increase."

2. Sinking / Foundering

The sinking / foundering of an LNG carrier is described in the earlier sections related to Black Point and South Soko Hazard No. H6. Capsize or sinking of the LNG carrier would most likely result from extreme weather. In the 40 years of LNG carrier operations, a sinking event has never occurred. According to the Stolt Nielsen Transportation Group (ref. 04), the Draught Fore at Normal Ballast for Ship Stolt Aquamarine (whose length is 176.8 meters) is 7.8 meters. This is higher than the maximum wave height in Hong Kong Harbour in a typhoon, which is 5 meters. This ship is almost the same size as LNG cargo transiting through Hong Kong harbor, Thus, it is almost impossible that the LNG cargo could be submerged by water even in extreme weather like a typhoon in the Hong Kong Harbour, as the sea states that the LNG carrier is designed for are of the order of 10 meters in normal operation. Should wave conditions in the order of 10 meters arrive in Hong Kong harbor, there would be much more serious consequences for the harbor and surrounding area such that the LNG carrier events become inconsequential.

The carrier would avoid operating in severe weather conditions that exceeded its design criteria. Thus the low likelihood of such an event deemed the scenario not credible to include in the analysis.

II.8 References

01 *"World Aircraft Accident Summary 1990-2002",* CAP 479, Airclaims Ltd., London, updated annually.

02 *"A Methodology for Calculating Individual Risk due to Aircraft Accidents Near Airports",* Cowell, P.G., et. al., R&D Report 0007, National Air Traffic Services Ltd., London, 2000

03 *"Guidance on Risk Analysis and Safety Implications of a Large LNG Spill Over Water",* Sandia National Laboratory December 2004.

04 Stolt Nielsen Transportation Group, *http://sims.sntg.com/sims/sntgdotcom/specs.jsp?shipsite=sntgdotcom&logistics=7uhd0s2k5r&Class=All&Ship=109,* accessed Sept. 26, 2006

05 CPR 18E "*Guidelines for quantitative risk assessment*", Committee for the Prevention of Disasters, First Edition 1999

Appendix III – Additional Analysis

Contents:

III Additional Analysis

This appendix presents additional analyses and further investigations performed for unlikely events and sensitivities to some study assumptions.

III.1 Cryogenic Effects

The LNG carrier will be constructed in compliance with the International Maritime Organization (IMO) Code for the Construction and Equipment of Ships Carrying Liquefied Gases in Bulk. This standard requires that the inner hull forming the cargo tanks be protected against embrittlement from liquid cargo through a combination of proper material selection and insulation.

Figure III-1 illustrates the usual configuration of an example LNG membrane carrier. To protect the carrier's inner hull against embrittlement, there is a primary and secondary membrane together with primary and secondary insulation. Material on the carrier that comes into contact with LNG (typically at -162°C) is typically made of stainless steel or Invar. This alloy is designed to withstand LNG temperature and thus prevent embrittlement of these surfaces. With more than 45,000 LNG shipments worldwide over the past four decades, there have been no reports of collisions or groundings that have resulted in a breach of containment.

However, the three most likely scenarios envisioned which could potentially lead to LNG coming into contact with steel not designed for low temperatures. These are:

1. Spillage from the LNG piping at the manifold
2. Seepage from a containment system
3. Breach of LNG containment

III.1.1 Scenario 1 – Spillage from LNG Piping at the Manifold

The first scenario that could lead to the contact of LNG with non-cryogenic service steel is spillage from the LNG piping at the manifold during disconnection of the cargo transfer arms. The probability of this scenario is low given the operational procedures and the double valve arrangement. These limit the possible release volume to a small amount. As a safeguard against localized damage to deck plating, and to ensure rapid evaporation of any spill, a water curtain is provided during the cargo transfer and while disconnecting the arms. Although localized damage to deck plating may result, this would not threaten the ship's structure or the cargo containment. Operating history has shown no escalation from this type of spillage and the resulting local embrittlement of the deck plate.

III.1.2 Scenario 2 – Seepage from Containment System

Seepage through seams or small leaks in the containment system may occur. These are monitored and detected by a nitrogen purging and monitoring system provided in the space between the inner hull and containment membrane. Experience has shown that the volumes involved vaporize rapidly without any cryogenic damage occurring. When warranted, the carrier is then taken out of service to repair the leak.

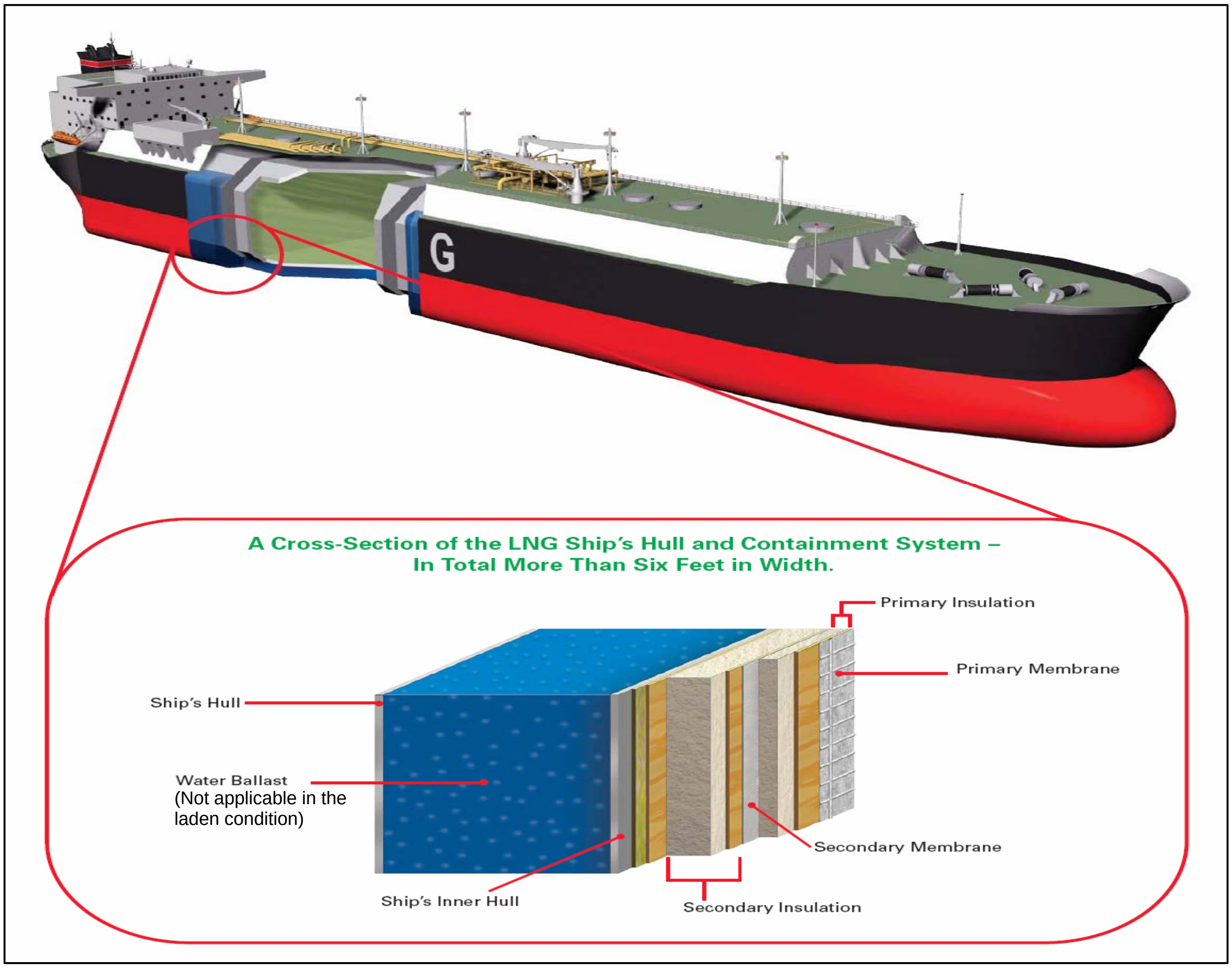


Figure III-1 Typical Membrane Design LNG Carrier

III.1.3 Scenario 3 – Breach of LNG Containment

Various low probability scenarios resulting in a large leak of LNG have been postulated (most notably following a high energy collision or grounding). These scenarios have been included in the MQRA study, with their hazard zones being determined by the extent of the vapor cloud or pool fire that would result from the primary breach. In the context of this discussion regarding the risks associated with cryogenic effects of an LNG release, the critical question is; can the cascade events, caused by embrittlement due to the cryogenic effect of the spilled LNG, be worse than the consequences of the initiating breach event?

This issue is addressed in the following section.

III.2 Cascading Failures

The question to be answered is – can the cascade events, caused by embrittlement due to the cryogenic effect of the spilled LNG, be worse than the consequences of the initiating breach event?

There are two hypothetical scenarios under which this would be the case:

- Direct impact, leading to worse damage to the leaking cargo tank or new damage to an adjacent cargo tank
- Break up of the LNG Carrier structure leading to collapse of the cargo tanks

The MQRA study has concluded that the answer to the critical question expressed above is; no.

The impact of LNG on the carrier's structure or adjacent containment following such a release is a complex sequence of events that to assess involves analysis of the following:

- Likely interaction between potential water ingress and LNG egress
- Location of structural damage with respect to the water line
- Susceptibility of the materials to embrittlement
- Identification of structural members/bulkheads contacting the LNG

Given the impracticality of replicating the events, no full scale tests have simulated such scenarios. Hence, analytical methods of the above factors and professional judgment must be employed to assess and understand the impact of such an event as part of MQRA.

The Sandia Report (ref. 01) considers several incident scenarios and assesses the potential for and impacts of LNG carrier damage. Sandia draws its conclusions from "embrittlement scoping analyses (that) were conducted to assess the potential damage to an LNG carrier from small and large LNG spills based on available fracture mechanics data and models". Sandia concludes:

- While accidental incidents could lead to minor to moderate damage to a LNG carrier, they would not lead to severe structural damage and the potential for cascading damage to other tanks.

- Should there be a secondary event, "This cascading release is not expected to increase significantly the overall fire size or hazard ranges, but the expected fire duration would increase."

As part of the MQRA, further consideration has been given to the underlying basis in order to substantiate the conclusions.

III.2.1 Direct Impact of Cargo Tanks

The following factors combine to ensure that the likelihood of worse damage (than the primary containment breach) is sufficiently small to be discounted in the context of the MQRA:

- Mitigated where there is also a significant inflow of seawater

- Cargo tank construction materials designed to contain LNG
- Damage to adjacent tanks has the pre-requisite of bulkhead failure
- Cascade damage will not be instantaneous
- Embrittlement damage mechanism (cracking) results in much smaller leak sizes than from massive physical trauma

Where there is also a significant influx of seawater, the LNG would be rapidly vaporized (thus reducing the embrittlement that prolonged contact with the cryogenic liquid could cause). This therefore reduces the potential for such damage with grounding events or below the waterline breaches of containment following high energy collisions.

For a secondary loss of containment due to embrittlement, the expected size of a secondary release is likely to be much smaller than that of the initial event. Having considered the smaller size/volume of the secondary leak along with the time elapsed following the initial event, an embrittlement failure is not anticipated to increase the size of the hazard zone that was created by the initial release assessed.

Therefore, the potential for embrittlement related secondary leaks is not expected to increase the transit risk levels assessed in the MQRA. The potential for secondary leaks should, of course, still be considered when developing prevention and mitigation strategies.

III.2.2 Impact to Carrier Structure

The following factors combine to ensure that the likelihood of significant damage to the carrier structure is sufficiently small to be discounted in the context of the MQRA:

- Mitigated where there is also a significant inflow of seawater
- As in any ocean going vessel, the primary strength consideration for an LNG Carrier is the longitudinal strength that runs along the longitudinal axis of the vessel (ref. 02)
- Due to their further distances away from the neutral axis, bottom, inner tank top and deck plates with associated stiffeners contribute more to longitudinal strength than vertical members like sideshell, longitudinal bulkheads with associated stiffeners
- Vessel is designed for damaged stability with certain flooded conditions.
- Bending moment and shear forces are usually greatest amidships, so collisions towards the bow and stern will be less critical

Again, where there is also a significant influx of seawater, the LNG would be rapidly vaporized (thus avoiding the embrittlement that prolonged contact with the cryogenic liquid could cause). This therefore eliminates the potential for such damage with grounding events or below the waterline breaches of containment following high energy collisions.

LNG spilled from an above waterline breach of containment will only come into contact with structural members that are not critical to overall structure of the carrier. Thus only localized damage will result.

There is considerable residual strength available in the carrier, unless it is flooded. This can be assumed to exist since flooding would mitigate the cryogenic damage.

III.2.3 Event Tree Approach

An event tree approach was initially used to determine the possible frequency related to cascade event failures. However, to populate the event tree probabilities, a majority of the entries were decided by expert judgment or assumptions as there has never been such an event in the historical record. Thus the above approach to logically evaluate the mechanisms of such a release event and how these relate to the scenarios that have been included in the current MQRA study has been adopted.

III.3 Tsing Ma Bridge Impact

III.3.1 Tsing Ma Bridge Description

The Tsing Ma Bridge links Tsing Yi Island on the east to Ma Wan Island on the west over Ma Wan Channel. It is a suspension bridge with two deck levels and carries both road and railway traffic. It has a main span of 1,377 meters and a height of 206 meters. There are two towers with one located on Wok Tai Wan on the Tsing Yi side and the other on a man-made island 120 meters from the coast of Ma Wan Island. Since both towers are located on land, it is not possible for the LNG carrier to collide with the bridge towers. Both towers extend 206m above the sea level and are comprised of two legs constructed with high strength concrete. The decks are constructed of steel. The scenario that may impact the bridge is an LNG pool fire due to grounding of an LNG carrier or LNG carrier collisions. The Tsing Ma Bridge detailed technical information is presented in the following table.

Table III-1 Details of the Tsing Ma Bridge

Construction materials	
Construction materials of cables	Steel
Construction materials of towers	Reinforced concrete
Construction materials of deck	49 000 tonnes structural steel
Dimensions	
Main span	1377 m
Total lengths	2160 m
Shipping clearance	62 m
Tower height	206 m

III.3.2 Failure Case Definition for Pool Fire

The grounding and collision scenarios modeled for pool fire are defined in Appendix I (Table I-33). Sensitivity analysis has shown that the small carrier and large carrier result in almost the same pool size for the same scenario. Therefore, the fire dimension and radiation to the bridge will be almost the same. In this study, the pool fire caused by collision was modeled based on small carrier, and the pool fire caused by grounding was modeled based on large carrier.

III.3.3 Calculation of Pool Fire Impact

III.3.3.1 Flame Height

The pool fire is analyzed through fire consequence modeling described as follows. The pool fire flame is modeled as a cylinder that is tilted by the wind with a diameter D, height H, and tilt angle θ (measured from the vertical), as shown in Figure III-2. The wind can also cause the flame to extend downwind from the pool in addition to the tilting effect.

Various correlations are available to model the flame height. SAFETI uses the Thomas (ref. 03) correlation.

$$\frac{H}{D} = 42 \times \left(\frac{m_B}{\rho_a \sqrt{gD}} \right)^{0.61}$$

Where:

- H : visible flame height (m)
- D : equivalent pool diameter (m)
- m_B : mass burning rate (kg/m^{2}s) (0.35 kg/m^{2}s)
- ρ_a : air density (1.2 kg/m3 at 20 ^{O}C and 1 atm)
- g : acceleration of gravity (9.81 m/s^2)

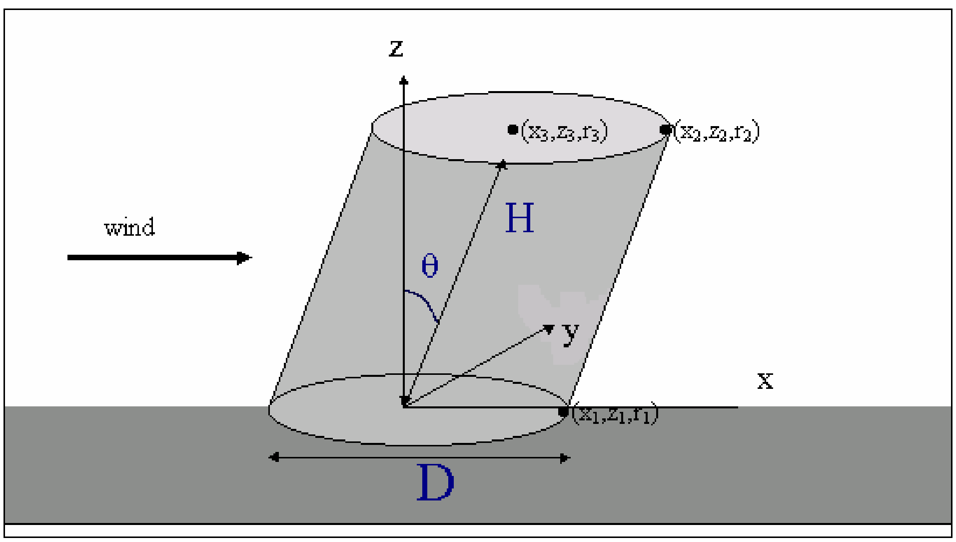


Figure III-2 Illustration of the Shape of Pool Fire Flame

Moorhouse (ref. 04) proposed another flame height correlation based on large LNG tests and it includes the effect of wind on the flame length:

$$\frac{H}{D} = 6.2 \times \left(\frac{m_B}{\rho_a \sqrt{gD}} \right)^{0.254} \times u_{10}^{*\ -0.044} \qquad u_{10}^{*\ -0.044} = \frac{u_w}{\left[{(g m_B D)}/{\rho_v} \right]^{1/3}}$$

Where,

u_{10}^{*}: nondimensional wind speed

u_w: measured wind speed at 10m height (m/s)

ρ_v: vapor density at the boiling point of liquid (kg/m3) 1.80 kg/m^3

LNGFIRE3 software was also employed to assess the flame height. For circular pools, LNGFIRE3 also uses the Thomas (ref. 03) correlation.

The flame height results from SAFETI, Moorhouse, and LNGFIRE3 are summarized in Table III-2 for the four weather cases modeled at the bridge location.

Both SAFETI and LNGFIRE3 use the Thomas correlation, but different flame heights resulted from the two models for the same scenario. The difference could result from different values used in the two models for the same parameters, especially the mass burning rate. SAFETI uses 0.35 kg/m^{2}s as the burning rate over water. The value used in LNGFIRE3 was not found in the available documentation. It could use a lower value, which would result in a lower flame height.

Table III-2 Pool Fire Flame Height for Different Scenarios

Scenario	Weather Condition	Weather Frequency	Pool Diameter D (m)	SAFETI		Moorhouse		LNGFIRE3	
				Flame Length H (m)	Flame Height Z (m)	Flame Length H (m)	Flame Height Z (m)	Flame Length H (m)	Flame Height Z (m)
Grounding	B 3.1 m/s	28.25%	24	90	73	54	44	45	39
	F 2.2 m/s	8.78%	24	90	78	55	48	45	45
	D 3.3 m/s	30.30%	24	90	71	54	43	45	38
	D 7 m/s	32.67%	24	90	55	52	32	45	26
Collision-Small	B 3.1 m/s	28.25%	28	99	80	61	49	49	40
	F 2.2 m/s	8.78%	28	99	86	62	54	49	43
	D 3.3 m/s	30.30%	28	99	79	61	49	49	39
	D 7 m/s	32.67%	28	99	62	59	37	49	31
Collision-Medium	B 3.1 m/s	28.25%	83	217	189	164	143	106	93
	F 2.2 m/s	8.78%	83	217	200	166	153	106	98
	D 3.3 m/s	30.30%	83	217	187	163	141	106	92
	D 7 m/s	32.67%	83	217	154	158	112	106	75
Collision-Large	B 3.1 m/s	28.25%	167	352	319	303	275	172	156
	F 2.2 m/s	8.78%	167	352	332	308	291	172	163
	D 3.3 m/s	30.30%	167	352	316	303	272	172	155
	D 7 m/s	32.67%	167	352	268	293	223	172	131

III.3.3.2 Thermal Radiation

LNGFIRE3 was employed to calculate the thermal radiation to the bridge structure. LNGFIRE3 has been validated against the results of large scale experiments. It is recommended by NFPA 59A to calculate LNG thermal radiation in LNG handling.

Most of the models/software can only calculate the thermal radiation for target not higher than the flame height. To model the radiation to the bridge above the flame, one assumption was made in the calculation: the radiation to the above bridge deck A is the same as the radiation to the vertical deck B beside the flame. As shown in Figure III-3, A and B are at the same distance h to the flame. For example, if the pool fire flame height is 45 m, the distance of the target to the flame is h=62 m – 45 m =17 m (where 62m is the clearance height of the bridge).

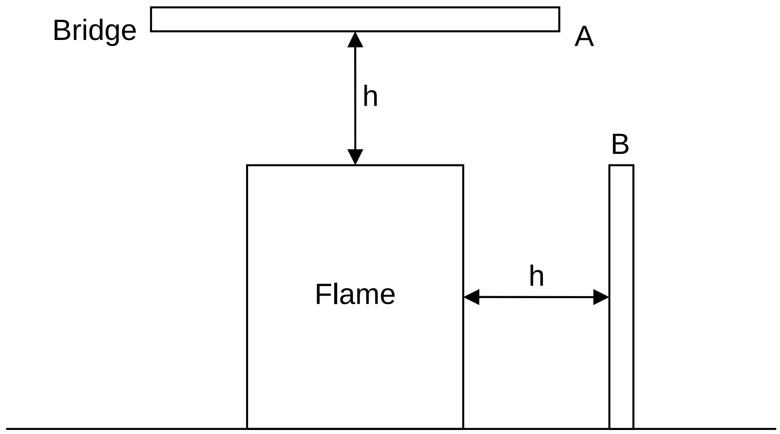


Figure III-3 Thermal Radiation to Bridge

In LNGFIRE3, the target exposed to a cylindrical fire will receive radiation at a rate determined by the following equation:

$$q = \tau \times F \times E_f$$

Where:

q :	Radiant flux at receiver
τ :	Atmospheric transmissivity
F :	Solid plume view factor
E_f :	Average surface emissive power at the flame centre

Some assumptions were made in calculating the radiation using LNGFIRE3:

- No tilt in the pool fire flame, i.e., the flame height is equal to the length.
- Thermal radiation is different if the target point is at different height levels, even the horizontal distance of the target from the flame is the same. According to LNGFIRE3, the largest radiation occurs when the height is at about the same level as the center of the flame. In this study, the bridge is assumed to be exposed to the largest radiation that could occur at its distance to the flame.
- If the flame height is higher than bridge height, the bridge is engulfed by flame, and the radiation is equal to the emissive radiation of the flame.

The thermal radiation to the bridge is shown in Table III-3.

Table III-3 Thermal Radiation to Bridge

Scenario	Vertical/Horizontal Distance to Flame from Bridge (m)	Modeled Radiation Target Height (m)	Thermal Radiation Exposed to Bridge (kW/m^2)
Grounding	17	23	81.58
Collision-Small	27	25	116.91
Collision-Medium	Engulfed	-	190
Collision-Large	Engulfed	-	190

III.3.3.3 Structure Failure due to Fire

As stated, the Tsing Ma bridge has two deck levels. The lower deck level will serve to protect the structure of the upper deck level as well as the suspension cables. The deck is made of steel. For the damage evaluation of structure steel elements, usually two levels are considered (ref. 05):

- Damage level-1: Ignition of surfaces exposed to heat radiation and then breakages or other types of failures of structural elements
- Damage level-2: Damages such as serious discoloration of the exposed material.

For level 1 damage, the failure of structural steel is decided by the failure temperature of the structure. For a conventionally dimensioned steel element, the failure temperature value lies between 673 K and 873 K. For a global average value a figure of 773 K can be retained (ref. 05).

With the help of a heat balance it is possible to establish a relationship between the radiation intensity acting on the deck surface and the temperature which will be reached on this surface. Since both the surface exposed to radiation and the surface from which heat is discharged need to be considered in the heat balance, the geometry of the structure is important in the calculation. No detailed geometry information is available for the Tsing Ma bridge, so a global average value for a steel profile is assumed, and then the corresponding critical radiation intensity can be calculated.

For level 1 damage, which requires the target temperature to be 773 K, the critical thermal radiation is 100 kW/m^2 (ref. 05); that is, if the radiation is less than 100 kW/m^2, the discharge rate from the "cold" side of the steel will maintain the temperature at a steady state at a temperature lower than 773 K.

In this study, the pool fire caused by grounding results in a thermal radiation of 81.58 kW/m^2, which is lower than the critical thermal radiation, so the bridge can not reach the failure temperature and structure damage will not occur due to the pool fire.

For the medium and large collision scenarios, the bridge is engulfed by flame. The flame temperature is usually 1325 K. The engulfed bridge will reach its failure temperature 773 K very quickly, and the structure could potentially fail very quickly, within minutes. The probability is very low that a collision event would occur directly under the bridge and also remain stationary under the bridge. The hazard to life of these scenarios has been included in the risk analysis. Implementation of collision mitigation measures would further reduce the probability.

For the small collision scenario, the radiation caused by the pool fire is 116.91 kW/m^2. The time to reach the failure temperature is calculated according to the following equation (ref. 05):

$$\Delta T = \frac{s_i}{\rho c A}\left[a q_i - \frac{s_u}{s_i}\left\{ \varepsilon \sigma T^4 + \alpha\left(T - T_0\right)\right\}\right] \times \Delta t$$

Where,

- ΔT: Increase of the temperature of the steel during Δt, K
- Δt: Time interval, s
- s_i: Surface of the steel profile per unit-length on which heat is supplied, m^2
- ρ: Specific mass of steel (7850 kg/m^3)
- c: Specific heat of steel (510 J/kg*k)
- A: Contents of steel per unit-length (m^3)
- a: Absorption coefficient (0.85)
- q_i: Acting radiation intensity (116,910 W/m^2)
- s_u: Surface of the steel profile per unit-length on which heat is discharged, m^2
- ε: Emission coefficient (0.84)
- σ: Constant of Stephan-Boltzmann (5.67E-08 $Wm^{-2}K^{-4}$)
- T: Temperature of the steel at the beginning of the time interval, K
- T_0: Ambient temperature, K
- α: Coefficient for convective heat transfer, $Wm^{-2}K^{-1}$

For this case, the following assumptions were made:

- the bridge is assumed to be at the ambient temperature at the beginning of the pool fire,
- the thickness of the lower deck of the bridge is assumed to be 0.33 m,
- $\frac{s_u}{s_i}$ is assumed to be the global average value, 0.25

Based on the calculation and assumptions, the time for the bridge to reach 773 K is calculated to be 1.6 hr for the small collision scenario pool fire.

III.3.4 Conservatism of Pool Fire Impact Calculation

III.3.4.1 Direct Impingement Impact

Different correlations result in different assessments on flame height. SAFETI resulted in the most conservative assessment among the three models/software used and only the SAFETI calculation resulted in a flame height higher than the clearance height of the bridge. However, the flame height in reality will be lower than the SAFETI modeled result due to the following uncertainties:

1. Release scenario assumption

This study assumes that the LNG released underwater will remain in liquid phase as it rises to the water surface. In reality, some of the LNG released under water will be vaporized due to the heat input from the water, therefore, in reality, smaller pools will be formed, and lower flame height will be resulted.

2. Nature of the pool fire

A pool fire on the sea tends to burn down and to break up into small patches of fire. Zukoski (ref. 06) and the Sandia Report (Section 5.5.1, page 51, last paragraph) (ref. 01) discussed that large pool fires are expected to break up into smaller pool fires because the center of the pool will not have enough oxygen to sustain combustion. The pool fire will then break up into "flamelets" which will have shorter flame heights and diameters, and thus smaller radiation ellipses. This phenomenon is not included in the modeling; rather the conservative, large, single pool is modeled.

3. Flame tilt effect

The flame tilt will reduce the flame height. The dominant weather condition during the day is a "D" stability condition with a 7 m/s wind speed. Under that condition, the flame height modeled by SAFETI for the small collision and grounding scenarios is less than the clearance height of the bridge.

SAFETI is very conservative in modeling the flame height. Due to those uncertainties mentioned above, the flame height would be even lower than the height calculated by using the various models. The calculations from the other two models/software, Moorhouse correlation and LNGFIRE3, result in values lower than the clearance height of the bridge. So the real flame height should be lower than SAFETI modeled results. According to the calculation on flame height, the bridge is not expected to be exposed to direct flame impingement for a release caused by grounding or small collision. Direct impingement could occur for medium and large collision accidents.

III.3.4.2 Thermal Radiation Impact

The thermal radiation exposure on the bridge is calculated by LNGFIRE3. However, the radiation should be lower due to the following uncertainties and conservatisms used in the radiation calculation:

1. Nature of large LNG pool fire flames

The flame will be smoky to some extent, which will reduce the radiation flux, and the real flame is not a homogeneous cylinder as modeled, so the radiation will be less than the modeled result.

2. Steel bridge insulation

The bridge insulation will reduce the radiant flux received.

3. Conservative assumptions in modeling radiation flux using LNGFIRE3

The following outline the conservative assumptions mentioned in item 3 above.

Humidity attenuation

The presence of water vapor in the atmosphere will attenuate the thermal radiation. For a conservative answer, a relative humidity of 0% is used in calculating the thermal radiation. For example, in the grounding case, a humidity of 79% will reduce the maximum radiation level to 61.36 kW/m^2, which is lower than 81.58 kW/m^2, the radiation level when the relative humidity is 0%.

Maximum radiation flux

The maximum radiation flux is calculated as the vector sum of the fluxes to the vertical and horizontal targets assuming both the horizontal and vertical targets are in full view of the flame. Most of the time the element can only see a fraction of the flame, and the maximum flux can not be reached.

The vertical and horizontal radiation

This calculation assumes the radiation to the side and above the flame will cause the same radiation. However, in the grounding scenario, since the flame height is 45 m, and the diameter is 24 m, the radiation area from the top is much less than the radiation area to the side. So it is a conservative assumption that the target at the top of flame will have the same radiation flux as the target on the side of the flame if they are at the same distance from the flame.

Therefore, the calculated maximum thermal radiation that could be exposed to the bridge is a very conservative assessment.

III.3.5 Conclusions Regarding Effects of Pool Fires on the Tsing Ma Bridge

The largest possible thermal radiation to the bridge from pool fire caused by grounding is 81.58 kW/m^2, which is lower than the critical radiation (100 kW/m^2), so the bridge will not be damaged due to the pool fire. For the pool fire caused by small collision, the bridge can reach the failure temperature after 1.6 hr exposure to the pool fire. The pool fire caused by medium or large collision will cause the bridge to reach its failure temperature in a very short time. However, these radiation and flame heights must be viewed as conservative due to the unknown nature of the large LNG pool fire flame. In addition, the probability that a collision event would occur directly under the bridge and also remain stationary under the bridge is very low.

III.3.6 Impact on Individuals

The risk calculation has included the people present on the bridge given the assumed traffic levels on the bridge. SAFETI does not place populations at height; thus the risk result is conservative in that the populations are considered at the same height level of the pool fire. The impact of the thermal radiation on the populations follows the impact criteria presented in Appendix I (Table I-57).

III.4 Sensitivity Analysis of Immediate Ignition Probability

The immediate ignition probability for the collision scenarios is assumed to be 0.8. The initiating event of the collision and the energy involved in penetrating the cargo tank will be a strong potential ignition source. The immediate ignition probability for the grounding scenarios is assumed to be 0.2. Since the grounding events occur underwater, there is a much less probability for immediate ignition of the event.

A sensitivity study was performed regarding the collision immediate ignition probability for the Black Point 2021E Small Carrier case. The FN curve generated based on the study immediate ignition probability (0.8 for collision events) is shown in Figure III-4.

For a sensitivity case, an immediate ignition of 0.5 for collision events was applied to the Black Point small LNG carrier 2021E scenario. The resulting FN curve for the sensitivity case is presented in Figure III-5.

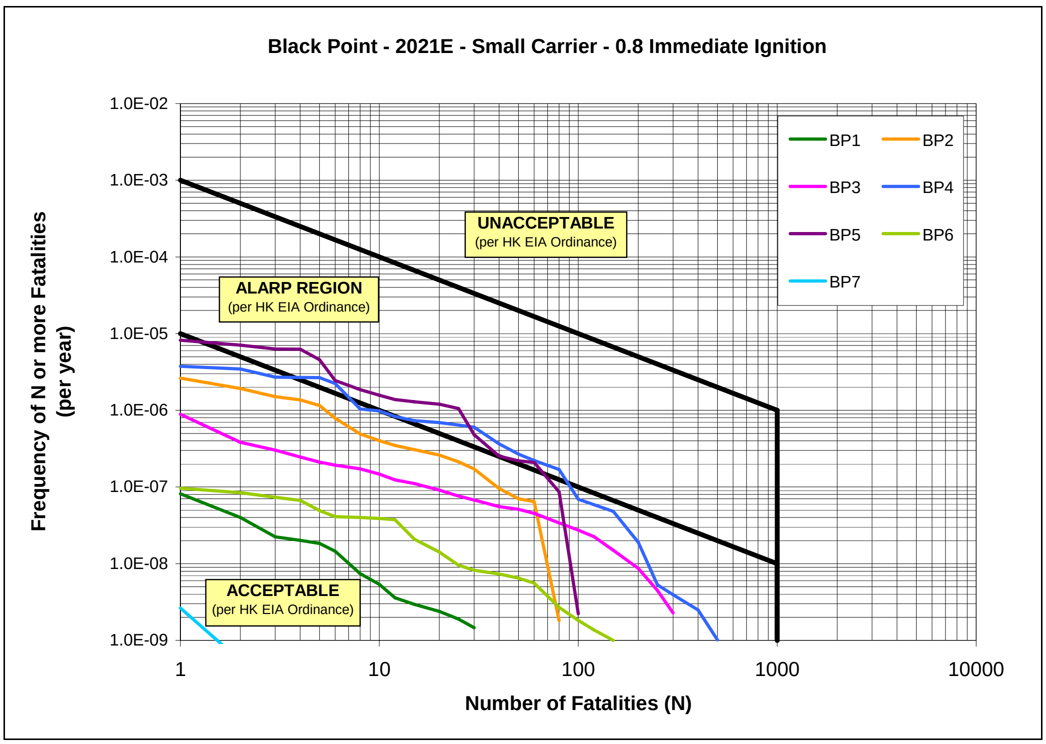


Figure III-4 Base Case Result, 0.8 Immediate Ignition for Collision Events

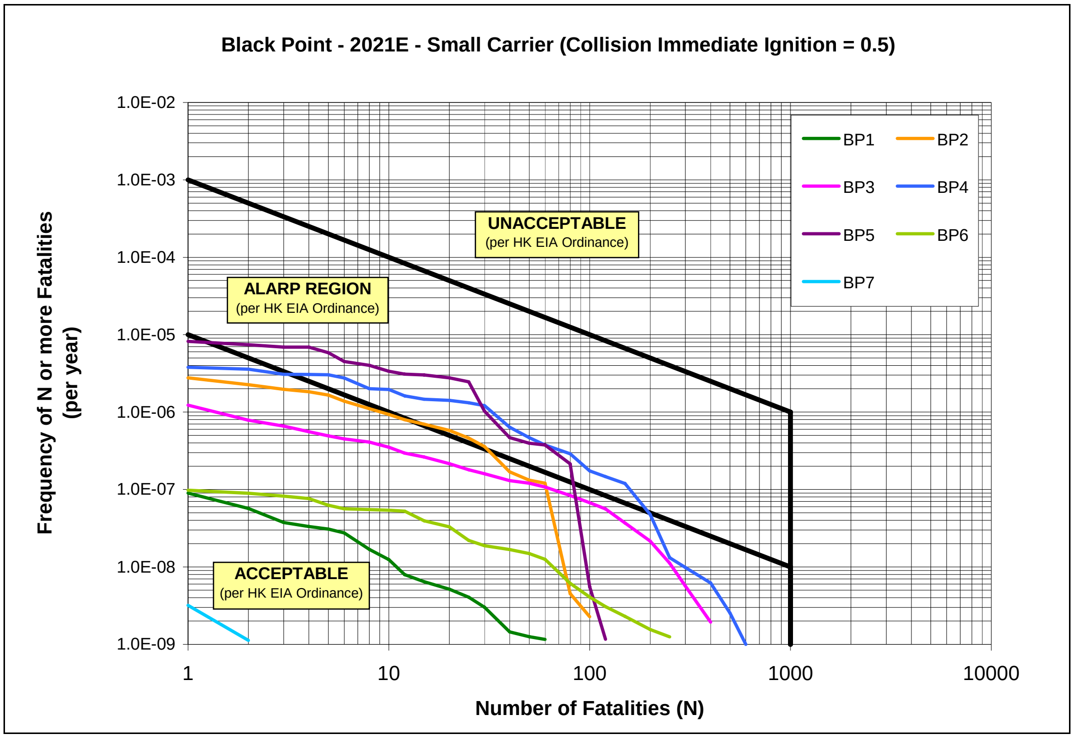


Figure III-5 Sensitivity Case Result, 0.5 Immediate Ignition for Collision Events

The decrease in immediate ignition probability results in the segments BP4 and BP5 remaining in the ALARP region but shifting to the higher frequency level, and the BP2 segment moving into the ALARP region between N = 12 and N = 30. Segment BP3 approaches closer to the ALARP region but does not exceed the criteria. Decreasing the immediate ignition probability increases the frequency of events resulting in flash fire, which has a larger hazard zone than a pool fire.

The justification for the 0.8 immediate ignition is that for an event to breach the inner tank, the collision event will have strong ignition characteristics associated with it.

III.5 Sensitivity Analysis of Population Analysis

III.5.1 High-rise and Mid-rise Buildings

High-rise and mid-rise buildings compose a large portion of the buildings within the Hong Kong area. It was assumed that a potential vapor cloud resulting from an LNG release will not affect the entire population of high-rise and mid-rise buildings. The dense cloud is likely to stay close to the ground and thus affect only the populations on the bottom floors. Thus for the high-rise and mid-rise buildings, a factor was applied to the indoor populations to allow only the affected populations on the bottom floors be included in the model.

The development of appropriate factors depends upon the characteristics of the resulting gas clouds and the dimensions of the subject buildings. The development of relevant factors is presented in the next section. The buildings categories to which this factor was applied and the assumed numbers of floors if the actual numbers of floors are not available are the following:

Residential (H): 35
Residential (M): 25
Industrial (H): 25
Industrial (M): 15
Administrative/Commercial (H):10
Hospital (H): 10

Another consideration that would potentially reduce the number of affected populations is building shielding. In some areas, the buildings are positioned close together and are situated such that one building shields the buildings behind it from the potential consequences. As the flammable cloud disperses further away from the source, the flammable concentration within the cloud will not be homogeneous, may develop pockets (of no gas) and will not envelop all buildings or building faces equally. Taking a conservative approach, the shielding effect of buildings has not been credited and all building populations are considered equally impacted.

III.5.2 Cloud Height and Associated Building Impact

The cloud height analysis was applied based on the large release cases. The small and medium release cases have lesser cloud height and only partially impact the land-based populations. Thus only considering the large release case was judged to be a conservative assumption.

The average cloud height of a large spill was calculated by factoring the mean cloud height for each of the four different daytime weather conditions modeled for Black Point by the probability of such a weather condition occurring. The four weather conditions used in the consequence modeling are:

Stability Class B, 2.5 m/s wind
Stability Class D, 3.0 m/s wind
Stability Class D, 7.0 m/s wind
Stability Class F, 2.0 m/s wind

Using DNV's SAFETI software, cloud heights were then modeled as a function of downwind distance from the release point. These results are presented on the graph illustrated as Figure III-6 and are shown separately for each of the four weather conditions at Black Point. Therefore, in order to find the average cloud height on any given day, the probabilities of each weather condition occurring on that day must be factored.

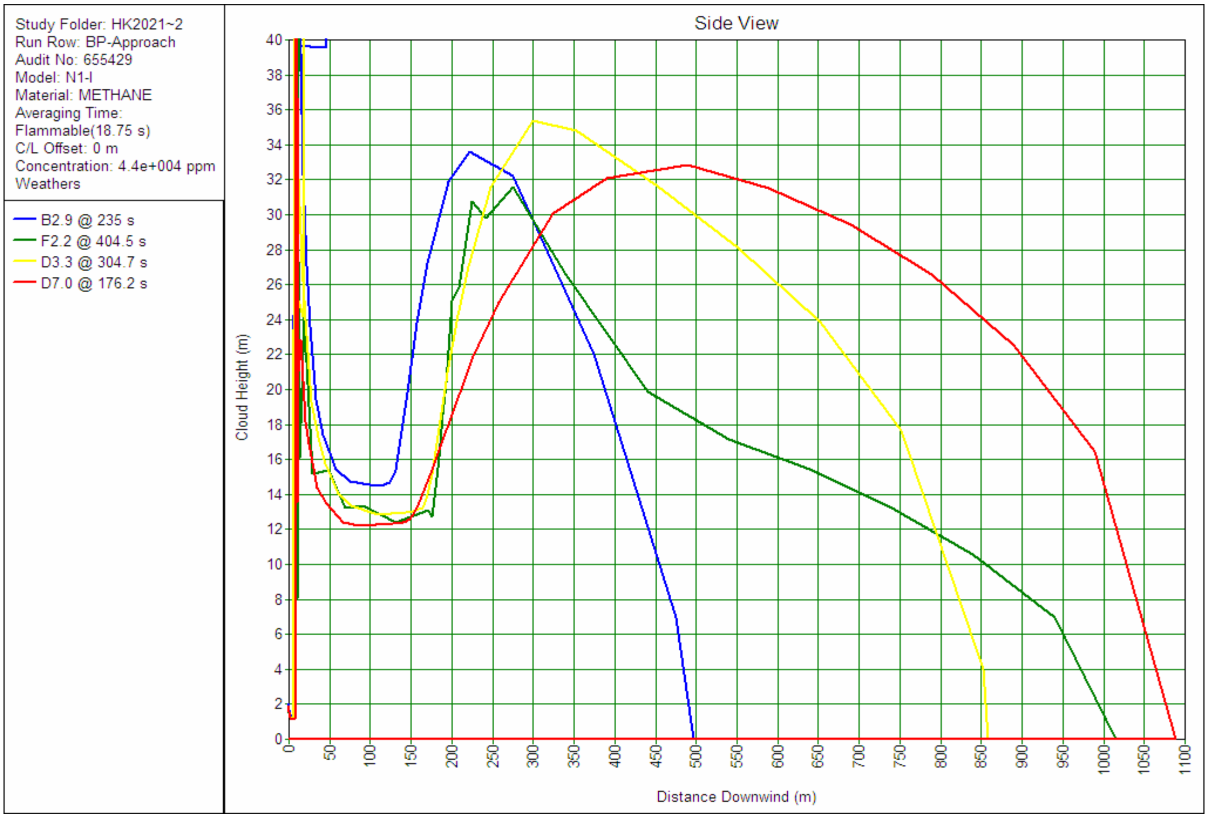


Figure III-6 Cloud Height as a Function of Downwind Distance (for the Large Release Case)

The detailed meteorological data, upon which this study was based, is provided in Appendix I.

The probabilities of each weather condition occurring were arrived at by analyzing meteorological data acquired from the Hong Kong observatory for the six stations located along the Black Point and South Soko routes. These stations are:

Shau Chau (SC) – BP1 and part of BP2
Tai Mo To (TMT) – BP2 and part of BP3
Ching Pak House (CPH) – BP3 and BP4
Green Island (GI) – BP5 and BP6
Waglan Island (WGL) – BP7 and SK4
Cheung Chau (CCH) – SK1, SK2, SK3

Table III-4 presents the probabilities of each weather condition at the 6 different stations as well as the overall probability of each weather condition. This overall probability was calculated as an average of the 6 probabilities (one per station) associated to each weather type:

Table III-4 Probabilities of Weather Conditions

	Probabilities of Weather Conditions			
Station/Weather	**B2.9**	**F2.2**	**D3.3**	**D7.0**
WGL	0.202	0.039	0.144	0.615
GI	0.208	0.051	0.156	0.584
CPH	0.283	0.088	0.303	0.327
TMT	0.284	0.077	0.254	0.384
SC	0.198	0.081	0.102	0.619
CCH	0.163	0.067	0.097	0.673
Average	**0.223**	**0.067**	**0.176**	**0.534**

Knowing the overall probabilities of these weathers, the average cloud height for all weather conditions can then be calculated.

First the mean cloud height for each weather type is arrived at by averaging those heights over the distance of the cloud. Then these average cloud heights are factored by the weather probabilities presented above.

The details behind this calculation are presented in Table III-5 to establish a weighted average cloud height of 22.5m. This was assumed equivalent to 8 floors of a typical high-rise Hong Kong building.

Table III-5 Calculation of Cloud Height Weighted Average (m)

Distance Downwind (m):	Cloud Height (m)				Weighted Average (m)
	B 2.9	F 2.2	D 3.3	D 7.0	
50	16	15	15	13	14.2
100	15	13	13	12	12.9
150	22	13	13	13	15.0
200	32	24	22	19	22.8
250	33	30	32	24	27.8
300	30	30	35	28	29.8
350	24	26	35	31	29.8
400	18	23	33	32	28.4
450	11	20	32	33	27.0
500	0	18	30	33	24.1
550	0	17	28	32	23.1
600	0	16	26	31	22.2
650	0	15	24	30	21.2
700	0	14	21	29	20.1
750	0	13	18	28	19.0
800	0	12	12	26	16.8
850	0	10	4	24	14.2
900	0	0	8	22	13.1

Distance Downwind (m):	Cloud Height (m)				Weighted Average (m)
	B 2.9	F 2.2	D 3.3	D 7.0	
950	0	0	6	19	11.2
1000	0	0	1	14	7.6
1050	0	0	0	7	7.0
1100	0	0	0	0	0.0
Average cloud height (m)	**22.3**	**18.2**	**20.4**	**23.8**	**22.5**

Thus the populations on 8 floors (assumed equivalent to 22.5m) of the high-rise and mid-rise building categories in Section III.5.1 were used in the population analysis of the MQRA study.

The maximum cloud height presented in Table III-5 is 35m for the weather category D 3.3m/s. This height would be equivalent to 12 floors of a high-rise building. Using the Black Point 2021E Small Carrier case, a sensitivity was performed using 12 floors instead of the 8 floors determined from the average.

By using 12 floors for the above building categories (if the buildings exceeded 12 floors), the total indoor land population (for 2021) increased from 211,656 to 246,799 (increase of 35,143). The following figures present the FN curves from the base case results using the weighted average cloud height, Figure III-7, and the results for the sensitivity case using the maximum cloud height Figure III-8.

The differences are imperceptible and not significant on the FN curve graphs. Increasing the indoor population has a dual and contrary effect. It increases the strength of the indoor population ignition factor; since the ignition presence is stronger, the vapor cloud tends to ignite more often without traveling as far and encompassing populations further away. However, increasing the indoor population places more people in the hazard zones; but hazards that impact a large fraction of the populations only occur at frequencies well below the EIAO criteria and thus are not represented in the FN result.

As a result, the method using the average cloud height was utilized in the study.

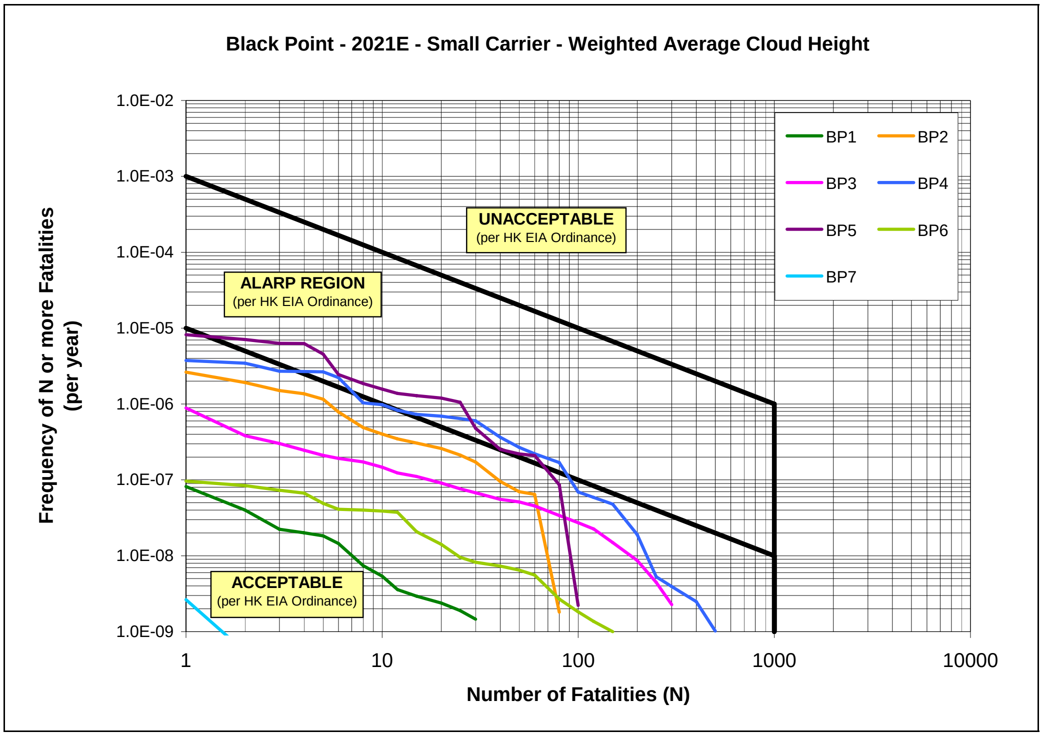


Figure III-7 Base Case Result, Weighted Average Cloud Height

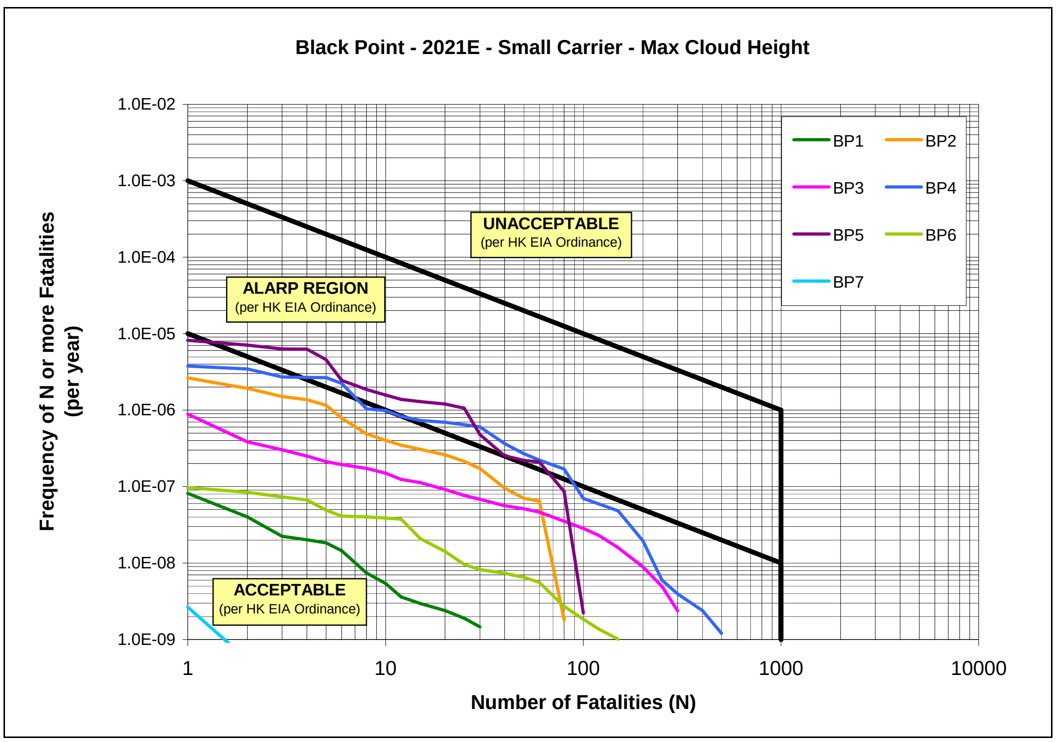


Figure III-8 Sensitivity Case Result, Maximum Cloud Height

III.6 Sensitivity Analysis of Length Factor

Distribution of vessel arrivals LOA and recorded collision incidents in fairways has been analyzed based on local and worldwide collision data. BMT believes the presence of corroborative data provides a basis for adoption of a Factor of Safety of 2 for collision against LNG carriers. This can be attributed to the fact that vessels over 200m LOA are staffed with two pilots, generally have trained crews, and due to their size generally command greater care. The data analysis suggested a potential range of factors between 1.0 and 2.9. A sensitivity analysis was performed on the 2021E Small Carrier case using a Length Factor of 1. The relative heading angle standard deviation remained at 17 degrees. The remaining variables were unchanged from the base case. Figure III-9 presents the sensitivity unmitigated case.

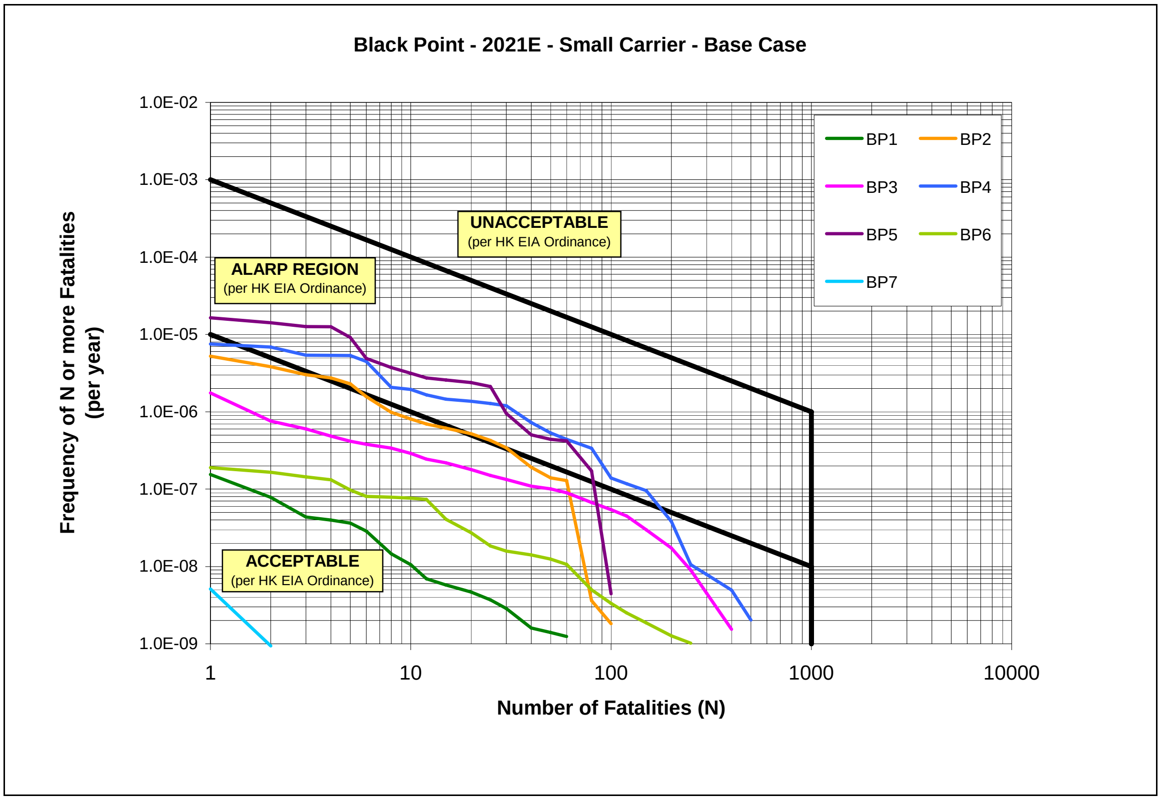


Figure III-9 Unmitigated, 2021E Small Carrier, Length Factor 1

The sensitivity analysis regarding the length factor was also performed for the South Soko route. The results are displayed in Figure III-10; as shown the results remain within the HK EIAO acceptable criteria.

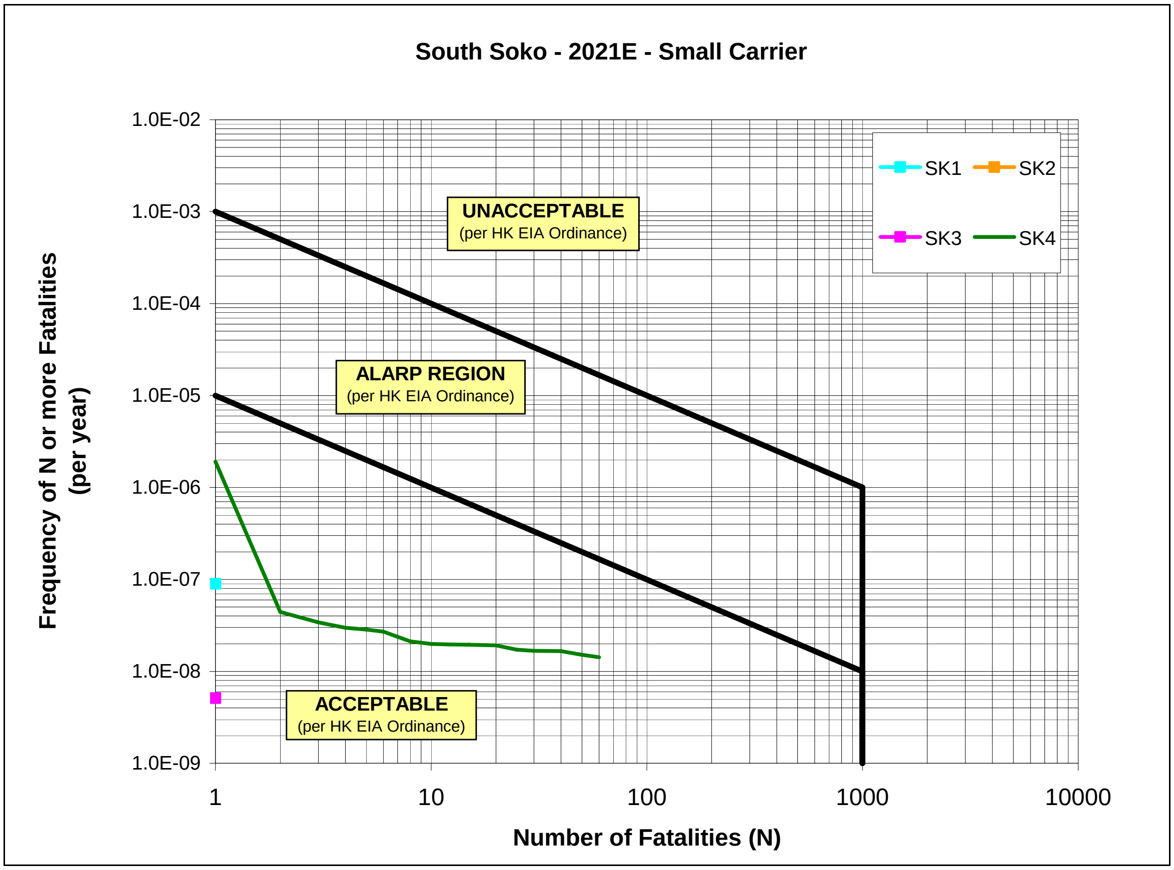


Figure III-10 South Soko 2021E Small Carrier, Length Factor 1

III.7 Sensitivity Analysis of Collision Angle

The relative heading angle with a standard deviation of 17 degrees has been analyzed and is supported with work performed by BMT. Changing the relative heading angle standard deviation from 17 to 30 degrees increases the collision frequency (adding conservatism into the model and tests the sensitivity to this parameter), and thus the unmitigated case presented displays higher risk results than the study current base case results. A sensitivity analysis was performed on the 2021E Small Carrier case using a relative heading angle standard deviation of 30 degrees. The remaining variables were unchanged from the base case, including a Length Factor of 2. Figure III-11 presents the sensitivity unmitigated case.

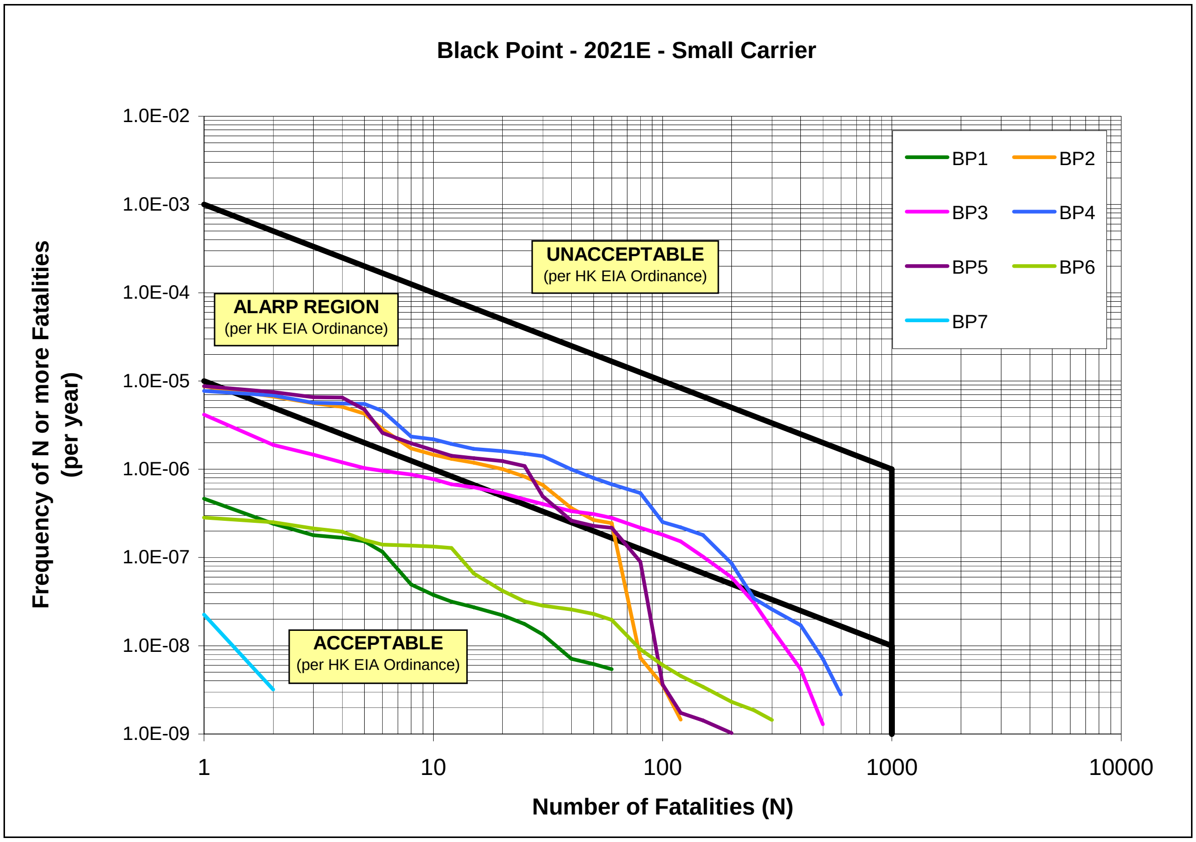


Figure III-11 Unmitigated, 2021E Small Carrier, Angle SD=30

III.8 Sensitivity Analysis of Proposed Mitigation Method

BMT evaluated the proposed moving safety zone in the Working Paper #8 "LNG Specific Risk Issues & Safety Zones" (ref. 07). The proposed mitigation excluded various collision events from the dynamic model, in the form of head-on, crossing, and overtaking encounters, thus reducing the collision risk by a factor of 10 – 16. In the current study a reduction factor of 10 was applied to the collision risk for all segments to reflect the impact of the mitigation measure on the LNG Carrier transit.

BMT also evaluated another implementation of the safety zone.

The revised mitigation method is presented in the BMT LNG Safety Zone paper (ref. 08). The revised mitigation proposes different safety zones for the different segments along the LNG carrier transit to Black Point. The following table presents the safety zone implementation differences along the Black Point transit route.

Table III-6 Proposed Revised Mitigation Safety Zone

Segment	Safety Zone Proposal
Approach	No safety zone
Ap Lei Chau – Green Island & Western Fairway (Ma Wan 1)	Head-on passing ONLY, all crossings & overtakings restricted
Ma Wan (2 –5) & Tuen Mun 1	Head-on passing for non piloted vessels ONLY. Head-on, Crossing & Overtaking for piloted vessels restricted
Tuen Mun 2 & Black Point	Head-on passing ONLY, all crossings & overtakings restricted

The revised safety zone effectively moves vessel encounters away from the Ma Wan area as well as restricting crossing traffic encounters to designated segments along the LNG carrier route. Two chase boats would be required and deployed port and starboard of the flotilla to ward off wayward excursions of small craft near the LNG carrier.

Although this mitigation measure has been implemented at other ports around the world that receive LNG carriers, it would involve restrictions on other marine traffic in the Ma Wan Channel. Implementation of these measures are beyond CAPCO's control. On the advice of the relevant authority, due to uncertainties regarding the level of safety improvement, the estimated impact to other port users, and the practicality of implementing these measures in the busy marine environment of Hong Kong, these measures are not considered implementable at this time.

III.9 References

01 *"Guidance on Risk Analysis and Safety Implications of a Large LNG Spill Over Water", Sandia National Laboratory December 2004.* Sandia Report (SAND2004-6258)

02 DNV Rules for Classification of Ships Pt 3, Ch 1 Sec 5 - Longitudinal Strength

03 *Lees' Loss Prevention in the Process Industries*, Vol 1, 3rd Edition, 2005

04 *Guidelines for Chemical Process Quantitative Risk Analysis*, 2nd Edition, CCPS, 2000

05 *Methods for the Determination of Possible Damage*, CPR 16 E, Green Book

06 "Fluid Dynamic Aspects of Room Fires", E. E. Zukoski, 1985

07 *"Marine Impact Assessment for Black Point & Sokos Islands LNG Receiving Terminal and Associated Facilities: LNG Specific Risk Issues & Safety Zones – Working Paper #8,*" Issue 1, October 2006.

08 *"Marine Impact Assessment for Black Point & Sokos Islands LNG Receiving Terminal and Associated Facilities: LNG Safety Zone (Further Notes #2)*, October 2006.

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Annex 13A

Quantitative Risk Assessment: Terminal

Annex 13A1

Terminal Design and Operating Details

CONTENTS

1 TERMINAL DESIGN AND OPERATING DETAILS

This section describes briefly the facilities at the LNG terminal.

1.1 MARINE FACILITIES

Jetty Structure

A jetty trestle structure, with a berth to moor the carriers, will be of steel construction with a concrete deck, abutted to a footing of rock. A typical steel trestle jetty is shown in *Figure 1.1.*

The pier, jetty head and 'dolphins' at the berth, will have steel piles founded in the seabed approximately 50m apart. On the jetty head, articulated piping (unloading arms) will be installed to connect the carrier to the piping of the onshore Terminal. The unloading arms are designed with an operating envelope that allows for prescribed carrier movement due to environmental factors while the arms are connected.

Figure 1.1 Typical Steel Trestle Jetty with Berthed Vessel

1.2 LNG STORAGE TANKS

Three LNG storage tanks, each of capacity up to 180,000 m^3 will be built.

The tank design will be full containment, with all tank connections made through the roof to maximize mechanical strength and integrity. The double wall construction will comprise an inner wall of low temperature steel and an outer wall of pre-stressed concrete. Full containment tanks provide higher safety standards compared to single containment tanks in view of the intrinsic robustness of the concrete outer structure.

The inner steel container will hold the LNG at -162°C. Cryogenic steels will be used (such as 9% Ni), which can withstand these very low temperatures. The outer concrete wall will include a reinforced concrete bottom slab and roof. The wall will be designed to withstand the cryogenic temperatures involved, ie it will contain any leak from the inner tank. Insulation materials will be applied to the space between the steel inner container and the outer concrete tank to minimise the transfer of heat from the environment to the bulk LNG. Boil-off gas from the LNG tank will be compressed and fed into the sendout system (see *Section 1.4*).

Internal tank piping will be designed to enable bottom or top filling without the need to install any connections through the tank wall below the liquid level. Special attention will be given to the instrumentation on the storage tanks. Alarm and shutdown devices will be incorporated in the design to ensure safe tank operation. These alarms and shutdown devices will be sequenced to conform to the requirements of the operating philosophy and the safety failure mode analysis. Tanks will also be provided with pressure relief safety valves with a set of pressure and vacuum breaker relief valves.

Temperature and density measuring devices along the height of the tank will be provided as a mean to help detect stratification (formation of layers of LNG with different densities) and avoid tank rollover. Automatic, continuous level measurement will be provided for the storage tanks. A typical LNG storage tank is shown in *Figure 1.2.*

The tank design pressure will be 290 millibars (mbar), with all tanks intended to simultaneously send out and receive LNG discharged by the LNG carrier. The LNG storage tanks will be fitted with pressure-control valves (PCVs), which will prevent excess vapour from accumulating in the tanks.

Figure 1.2 Typical LNG Storage Tank

1.3 BOIL-OFF GAS (BOG) HANDLING SYSTEM

Gas Compressors

Boil-off gases (BOGs) produced during normal Terminal operations as a result of inevitable heat transfer from the atmosphere to the storage tanks and piping as well as those arising from ship unloading operations, will be sent to the BOG compressor and re-condenser for condensing (liquefying) and re-inclusion into the LNG bulk product stream.

Vent System

The vent system is designed for emergency venting. The vent will not be used under normal operations.

1.4 SENDOUT PUMPS

Because of the high pressures involved, two stages of sendout pumps are required.

First Stage LNG Sendout Pumps

Electrically driven high-capacity (first stage) LNG sendout pumps will be installed in each LNG storage tank. These pumps operate fully submerged in LNG and are located within pump wells, allowing for easy pump removal, maintenance and installation. The pump wells also serve as the discharge piping from the pumps and are connected to the tank-top piping.

LNG from the in-tank pumps is routed directly to the re-condenser. All boil-off vapours during normal sendout or during carrier unloading are routed to this drum, mixed with the LNG, and re-condensed into the bulk LNG fluid. The re-condenser houses a packed bed of stainless-steel pall rings (or equivalent), which creates additional surface area for vapour-liquid contact.

Second Stage LNG Sendout Pumps

LNG from the re-condenser on level control is directed to the second stage sendout pumps. The second stage sendout pumps are high-pressure pumps, delivering LNG to the LNG Vaporisers (see *Section 1.5*) at a pressure of 75 to 80 bar (which could be increased to 100 bar).

1.5 LNG VAPORISERS

Stored LNG will need to be re-gasified in order for it to be conveyed along the gas transportation pipework. This will be accomplished via LNG Vaporisers, which will either utilise piped seawater (in open-rack vaporisers) or hot combustion gases (in submerged combustion vaporisers) to raise the temperature of the LNG to ambient temperature, thereby causing it to re-gasify.

- *Open Rack Vaporisers*. In open-rack vaporisers (ORVs) seawater flows over aluminium heat exchange panels that contain tubes through which the LNG flows. The seawater falls over the panels to a trough below and is then discharged back to the sea. A typical vaporiser used for LNG Terminals is shown in *Figure 1.3.*

- *Submerged Combustion Vaporisers*. Submerged Combustion Vaporisers (SCVs) involve burning off a small amount of gas and using the heat of combustion to maintain the temperature of a water bath. The cold LNG passes through coils within the bath and gets vaporised.

Figure 1.3 Typical Open Rack Vaporiser

1.6 GAS TRANSPORTATION

The gas leaving the LNG Vaporiser will be routed to the sendout gas pipework.

1.7 PROTECTIVE SYSTEMS

Fire water

A closed-loop fire water system will be provided to protect the LNG Terminal equipment, utilities, storage and unloading areas. The system will include main pumps and a standby mobile pump, along with hydrants and monitors. Fire water will also be provided to protect the berth.

Security

Security will be designed to prevent unauthorised access and to ensure the safety and integrity of the facilities. The site will be provided with a perimeter fence.

1.8 UTILITIES AND ANCILLARY FACILITIES

Nitrogen

Nitrogen in the gaseous form will be required at the LNG Terminal for purging of equipment during maintenance as well as during start-up. A facility for onsite nitrogen generation through PSA process or air separation unit will be provided. Details will be finalised during detailed design.

Power

For the Soko site, onsite power generation by gas turbines will be provided in addition to subsea power cables.

Water

Service and drinking water tanks will be required. Maximum $80m^3/hr$ service water will be required for startup or shutdown operation. Seawater will be used for general washdown purposes.

Sewerage

Sewage will be treated onsite in a packaged plant compliant with relevant local regulations.

Communications

Arrangements will be made for provision of telephone and emergency communications.

Fuel and Materials Storage

Diesel will be stored on-site in a permanent fuel tank. Diesel will serve as fuel for the emergency generator. Diesel will be transported to site by barges.

Plant and Instrument Air

Atmospheric air will be compressed by centrifugal compressors (each driven by electric motors) and dried for use as both plant and instrument air.

Plant Buildings

The following permanent buildings will be provided on site for the operational phase:

- administration building;
- control room;
- workshop and store room; and
- gatehouse.

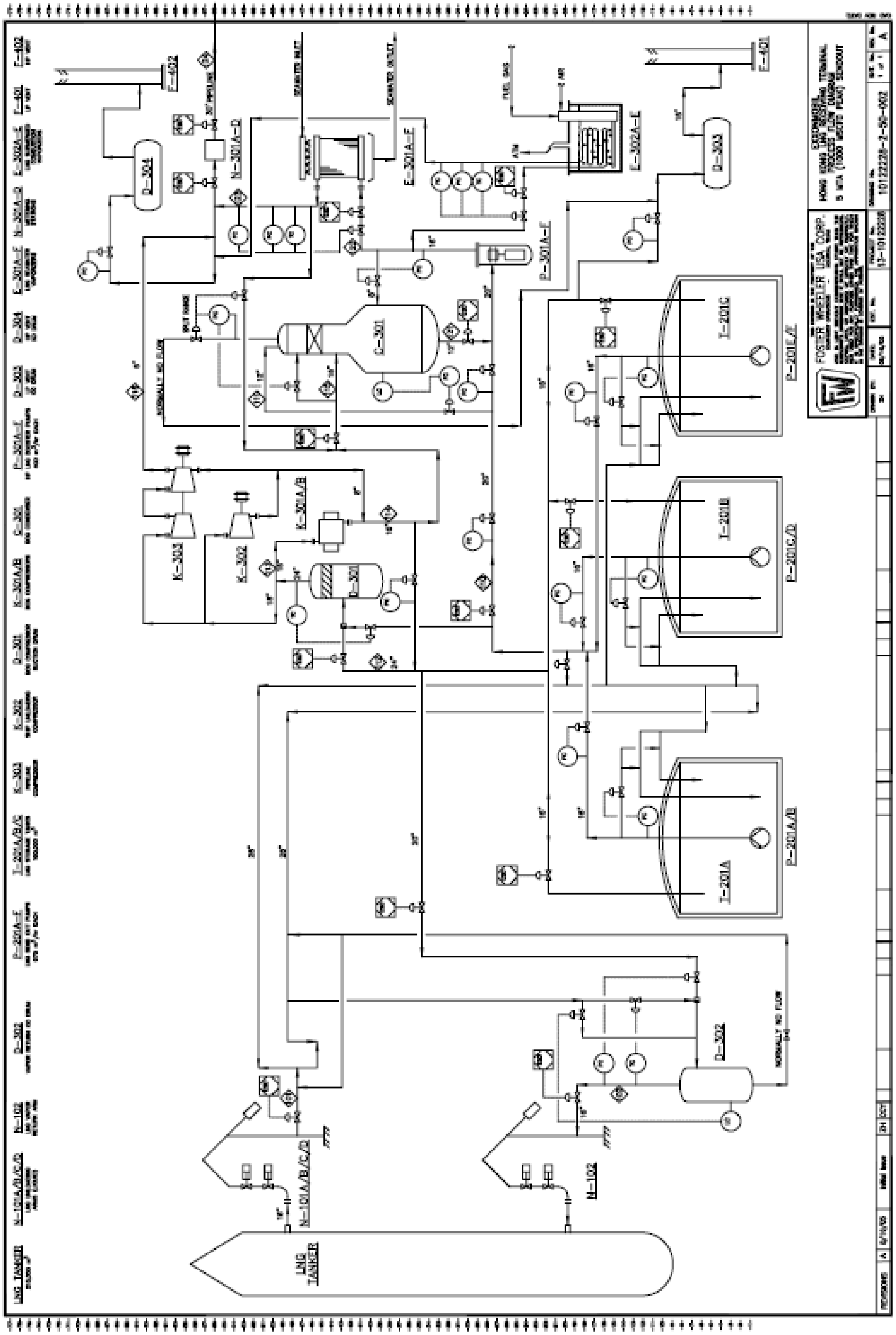
1.9 *SITE ACCESS*

Site access will be provided by boat. Emergency access by helicopters will also be provided.

1.10 *PROCESS FLOW DIAGRAM*

Detailed process flow diagram of the LNG terminal is shown in *Figure 1.4*, with details of the process streams indicated.

Figure 1.4 Detailed Process Flow Diagram for Soko LNG Terminal



2 OPERATION AND MAINTENANCE OF THE LNG TERMINAL FACILITIES

2.1 COMMISSIONING

Upon completion of all control systems testing, the units will be purged of oxygen using nitrogen as the displacement gas. Various Terminal units will then be checked for pressure leaks by pressurising and depressurising over an approximate three-day period. The Terminal will then begin cooldown operations using LNG. In this process, a small continuous flow of LNG will accumulate in the tanks displacing the inert nitrogen to the atmosphere via a vent. The cooldown will continue with LNG being introduced gradually to the piping and other equipment.

2.2 OPERATIONAL SUMMARY

2.2.1 *Overview*

The facilities that comprise the LNG Terminal are described above. Operation of the Terminal facilities will include the following significant process operations:

- LNG carrier approach, berthing and departure;
- LNG unloading from carriers at the marine facility and transfer to shore;
- LNG storage in onshore storage tanks;
- Re-gasification of the LNG to natural gas in LNG vaporisers; and
- Final sendout of natural gas via a pipework.

2.2.2 *LNG Carrier Approach*

In the final segment of the approach fairway, tugboats will assist in controlling the heading and speed of the carrier while entering into and manoeuvring within the turning circle as well as for the final approach towards the jetty. The tugboats will continue to assist until the mooring operation has been completed. The number and bollard pull of tugboats for such operations will be based on the findings of a simulation study for the safe manoeuvring of the LNG carrier.

LNG will be pumped from the storage tanks of the LNG carriers, through unloading arms on the jetty, to the storage tanks onshore via insulated unloading lines.

2.2.3 *Unloading Operations*

It will take approximately 18 hrs to unload an LNG carrier. During cargo discharge the vapour pressure in the LNGC cargo tanks will be maintained by returning vapour from the shore. With this balanced system, under normal circumstances, no hydrocarbons will be released to the atmosphere from ship or shore. Unloading rates vary between 12,000 and 14,000 m^3 per hour depending on the size of the carrier.

Before disconnecting the unloading arms, remaining liquid will be drained and the arms purged with nitrogen. The onshore liquid pipework will be left full and a minor circulation maintained to hold the temperature at approximately -162°C. This is required to avoid thermal cycling of the piping.

Ballasting operations (i.e. taking on seawater to compensate for the unloaded mass of LNG) will be concurrent with the LNG unloading. Under normal circumstances, the LNG carrier will leave the berth approximately 24 hours after arrival. This includes allowances for the pre-cooling operations, arrival cargo measurements, unloading operations, cargo measurements on completion of discharge and nitrogen displacement of unloading arms prior to disconnection.

To reduce the potential for LNG spillage, the carrier and shore Emergency Shut Down (ESD) systems will be interlinked such that an unusual event on either will automatically activate a transfer system shutdown (ESD I) and in a severe case will also disconnect the unloading arms (ESD II). An ESD I test will be completed before the start of unloading operations. In the event of an ESD II unloading arm disconnection, LNG spillage would be very small due to the activation of isolation valves on either side of the Emergency Release coupler.

Before and during LNG transfer operations, a safety zone of approximately 250m around the LNG carrier will be maintained.

2.2.4 *Onshore Modes of Operation*

The LNG Terminal will operate in two main modes of operation:

- **Unloading Mode –** The unloading mode is the period when an LNG carrier is moored to the jetty and is connected via the unloading arms and the jetty piping to the onshore storage tank. The pumps on the LNG carrier will transfer the LNG in both the unloading and the re-circulation lines to the onshore storage tanks. At the end of unloading, pressurised nitrogen gas will be used to purge the arms of LNG before disconnecting;

- **Holding Mode –** The holding mode is the period when no unloading takes place. During the holding mode, cryogenic conditions will be maintained in the unloading line by circulating LNG to the jetty head and back to the onshore storage tanks or the sendout system via a dedicated re-circulation line.

During both of these modes of operation, sendout of LNG to the vaporisers and gas pipeline will continue.

2.3 UTILITIES

Utilities required during the operation of the Terminal facilities are summarised in *Table 2.1*.

Table 2.1 Utilities

Material	Use	Handling and Transport	Storage quantity
Diesel	Operation (for emergency generator)	Barge	20 m^3
Liquified nitrogen	Maintenance (purging)	Drum to be filled via barge every 2 weeks	25 m^3
Hydrochloric acid 30% HCl	Maintenance; neutralise using caustic and flush to ocean	Aboveground storage on a skid	200 L
Caustic soda 10% NaOH	To neutralize the acid from maintenance of the electro-chlorination units	Drum	2 m^3
Raw water	Fire fighting and for service	Pump	1,500 m^3
Seawater	Vaporisers	Pump	
Electricity		132 kV or 111 kV	

Annex 13A2

Topography, Land Use and Population

CONTENTS

1 TOPOGRAPHY, LAND USE AND POPULATION

This section describes the methodology employed to determine the population in the vicinity of the proposed site at South Soko as well as the population to be adopted in the Quantitative Risk Assessment (QRA) study. The QRA considers the years 2011 and 2021 in the analysis and so the population was estimated for these years.

1.1 LOCATION AND TOPOGRAPHY

The proposed site for the LNG Terminal on South Soko Island is located at the south of Lantau Island, in the south-western waters of Hong Kong. South Soko Island is currently an uninhabited island which has historically housed villages and more recently a detention centre operated by the Hong Kong Government. The majority of the habitat is hillside and rocky shore typical of offshore islands in Hong Kong (*Figures 1.1* and *1.2* depict South Soko Island and the area under consideration for population study respectively).

1.2 CURRENT LAND USE

A number of Private Lots and derelict buildings are present on the Island as well as the recently refurbished Tin Hau Temple, but there is no permanent development or resident population at either South Soko or North Soko at present. A radioactive storage facility is located on North Soko Island but there are no permanent residents and waste is delivered just twice a year.

1.3 LAND POPULATION ESTIMATION

The following information sources were referred to for population estimation:

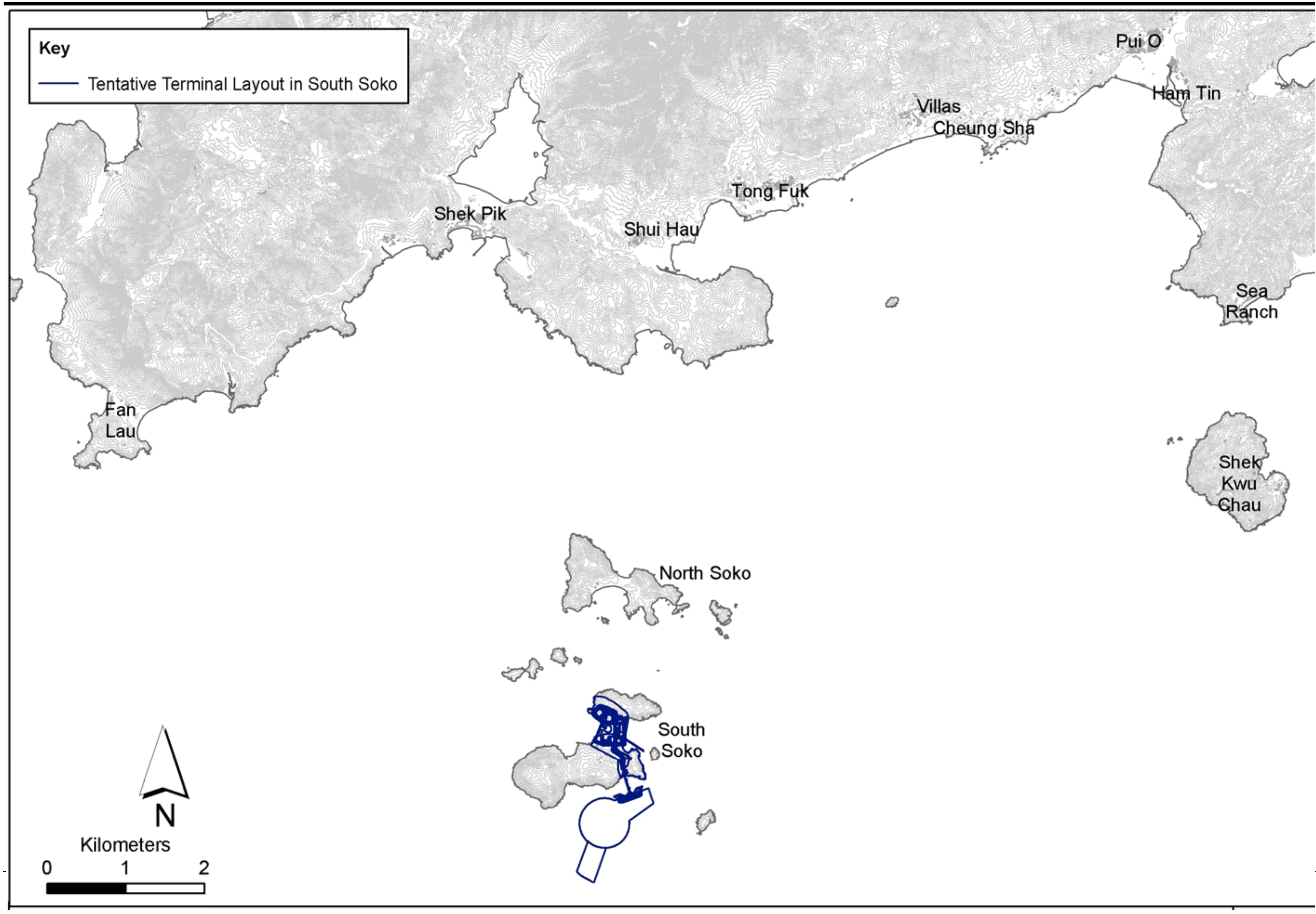
- Site Survey Data
- Census Data [1]
- Land Records from Lands Department
- Road Traffic Data [2]
- Data on Key Individual Developments
- Marine Traffic Data [3-5]

1.3.1 Residential Population

South Soko is uninhabited. North Soko also has no residential population and none is planned (TPU 934) [6]. This was confirmed by a site survey, which found no population currently on either island.

Figure 1.1 Aerial Photo of the South Soko Site

Figure 1.2 Population in Vicinity of South Soko


Key
Tentative Terminal Layout in South Soko
Pui O
Ham Tin
Villas
Cheung Sha
Tong Fuk
Shek Pik
Shui Hau
Sea
Ranch
Fan
Lau
Shek
Kwu
Chau
North Soko
South
Soko
N
Kilometers
0
1
2

ERM

The population in villages along the southern coast of Lantau was estimated based on a buildings count and the assumption of 3 persons per unit. The population of major buildings such as the prison and hospital was researched directly to obtain reliable numbers. Finally, population figures were scaled to obtain predictions for 2011 and 2021 based on the Planning Vision Strategy (PVS) [7]. However, the PVS predicts no change in population up to 2021. The residential population used in the assessment of South Soko Terminal are summarised in *Table 1.1*.

Table 1.1 Estimated Residential Population Data

Location	Approx. Distance from Terminal Site	2011 Population	2021 Population
Fan Lau	7km	52	52
Tai Long Wan Tseun	7km	293	293
Shek Pik Prison	7km	824	824
Tung Wan School	6km	152	152
Shui Hau	6km	375	375
Ma Po Ping Prison	6km	1,728	1,728
Tong Fuk	7km	1,133	1,133
Cheung Sha Villas	9km	665	665
Cheung Sha	9km	597	597
San Shek Wan	10km	156	156
Pui Wo	11km	2,628	2,628
Ham Tin	11km	859	859
Mong Tung Wan	11km	43	43
Sea Ranch	10km	313	313
Tai Long	11km	34	34
Shek Kwu Chau	8km	43	43
South Lantau Hospital	9km	90	90

1.3.2 *Industrial Population*

A low level radioactive waste storage facility is located on North Soko Island. The facility is about than 1.5km from the South Soko site. Waste is delivered at most twice a year. No permanent working population is present. No other industrial facilities are located within the vicinity of South Soko.

1.3.3 *Road Traffic Population*

There is only one road running along the southern edge of Lantau Island, namely South Lantau Road. The population estimation is based on the 2005 Annual Traffic Census [2]. The AADT value is 2170 vehicles per day for station number 5859 from Tung Chung Road to Sham Wat Road. Assuming an average speed of 50km/hr and an average of 3 persons per vehicle, the number of persons on the road is:

No. of persons = (AADT x Vehicle Occupancy / 24 / Speed)
= 2,170 x 3 / 24 / 50 = 5 persons/km

The traffic along this section of road has decreased in recent year as more convenient modes of access to Lantau Island have become available. The population for 2011 and 2021 is therefore assumed to be the same at 5 persons/km.

1.3.4 *Occupancy and Indoor/Outdoor Fractions*

The land population is categorised further into 4 time periods: night time, weekday, peak hours and weekend day. These are defined in *Table 1.2*.

Table 1.2 Population Time Periods

Time Period	Description
Night time	7:00pm to 7:00am
Weekday	9:00am to 5:00pm Monday through Friday, and 9:00am to 1:00pm Saturday
Peak hours	7:00am to 9:00am and 5:00pm to 7:00pm, Monday to Friday
	7:00am to 9:00am and 1:00pm to 3:00pm, Saturdays
Weekend day	3:00pm to 7:00pm Saturdays, and 7:00am to 7:00pm Sundays

The occupancy assumed [8] during these time periods is given in *Table 1.3*. Different occupancy figures are assumed for each category of land population. The proportion of the population outdoors is also assumed to vary according to type of population and time period (*Table 1.3*).

The hazards that can potentially affect offsite population are flash fires and thermal radiation from pool fires. Buildings are assumed to offer protection to its occupants for these events. The protection factor used is 90%, or equivalently the exposure factor is 10%. Scenarios are therefore assumed to affect 100% of the outdoor population and 10% of the indoor population.

Road vehicles are also assumed to offer some protection, although less than a building. An exposure factor of 50% is used for vehicles.

Table 1.3 Land Population Occupancy and Indoor/Outdoor Fractions

Population Type	Occupancy				% Outdoors			
	Night	Peak	Weekday	Weekend day	Night	Peak	Weekday	Weekend day
Residential	100 %	50 %	20 %	80 %	0 %	30 %	10 %	20 %
Prison	100 %	110 %	100 %	110 %	5 %	100 %	50 %	50 %
Hospital	100 %	120 %	110 %	120 %	0 %	30 %	10 %	30 %
School	0 %	10 %	100 %	10 %	0 %	100 %	20 %	20 %
Road	10 %	100 %	50 %	20 %	0 %	0 %	0 %	0 %

1.4 MARINE POPULATION ESTIMATION

South Soko Island lies within 4km of the Adamasta Channel. The marine traffic in this fairway consists of mainly fast ferries serving Macau.

1.4.1 *Vessel Population*

The vessel population used in this study are as given in *Table 1.4*. The figures are based on BMT's Marine Impact Assessment report [4] 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 Adamasta Channel. However, the average load factors for fast ferries to Macau and Pearl River ports are 52% and 37% respectively while the overall average load factor considering all ferries is about 50% [5]. Hence, a distribution in ferry population was assumed as indicated in *Table 1.4*. This distribution gives an overall load factor of about 58% which is conservative and covers any future increase in vessel population.

Table 1.4 Vessel Population

Type of 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)	22.5
	175 (typical ferry at 50% capacity)	52.5
	105 (typical ferry at 30% capacity)	12.5
	35 (typical ferry at 10% capacity)	5.00
Tug and Tow	5	
Others	5	

1.4.2 *Marine Vessel Protection Factors*

The population on marine vessels is assumed to be offered some protection by the vessel structure, in a similar way that buildings offer protection to their occupants. 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
- The ability of gas to penetrate into the interior of the vessel and achieve a flammable mixture.

Small vessels such as fishing boats will provide little protection but larger vessels such as ocean-going vessels will 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 vessel are as given in *Table 1.5*.

Table 1.5 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
	35	0.3	11
Tug and Tow	5	0.9	5
Others	5	0.9	5

1.4.3 *Methodology*

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

The marine area around South Soko was divided into 12.67km^2 grid cells, each grid being approximately 3.6km x 3.6km. The transit time for a vessel to traverse a grid is calculated based on the travel distance divided by the vessel's average speed. The average speed [3] and transit time for different vessel types are presented in *Table 1.6.*

Table 1.6 Average Speed and Transit Time of Different Vessel Type [5]

Type of Vessel	Assumed Speed (m/s)	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 vessels traversing each grid daily was provided by the marine consultant [3]. These are provided in *Table 1.7*, where the grid cell reference numbers are defined according to *Figure 1.3*. The number of marine vessels present within each grid cell at any instant in time is then calculated from:

$$\textit{Number of vessels} = \textit{No. of vessels per day} \times \textit{grid length} / 86400 / \textit{Speed} \qquad (1)$$

This was calculated for each type of vessel, for each grid and for years 2011 and 2021. The values obtained represent the number of 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.

Figure 1.3 Grid Cell Numbering Scheme

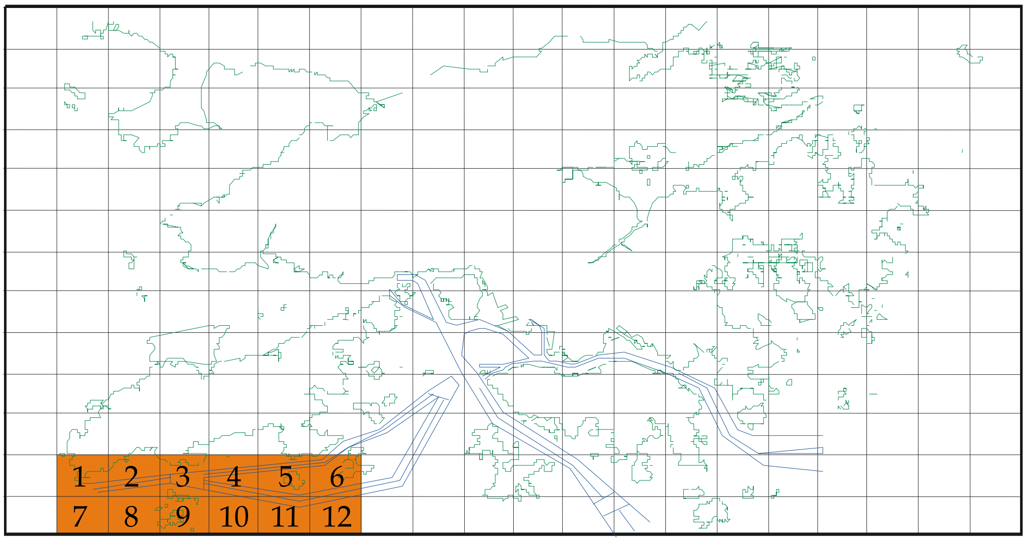


Table 1.7 Number of Marine Vessels Per Day

Grid No.	Average Number of Vessels Per Day									
	2011					2021				
	OG	RT	TT	FF	OTH	OG	RT	TT	FF	OTH
1	0	21	0	99	284	0	23	0	117	311
2	0	0	0	121	168	0	0	0	143	184
3	0	0	0	143	210	0	0	0	169	230
4	0	0	0	121	210	0	0	0	143	230
5	0	0	0	121	210	0	0	0	143	230
6	0	21	21	99	210	0	23	23	117	230
7	0	84	53	0	95	0	92	58	0	104
8	0	63	21	0	63	0	69	23	0	69
9	0	0	0	0	11	0	0	0	0	12
10	0	0	0	0	11	0	0	0	0	12
11	0	0	0	0	11	0	0	0	0	12
12	0	0	11	0	168	0	0	12	0	184

OG = Ocean-going vessels
RT = Rivertrade coastal vessels
TT = Tug & tow vessels
FF = Fast ferries
OTH = others

Average Density Approach

The average marine population for each grid is calculated by combining the number of vessels in each grid (from *Equation 1*) with the population at risk for each vessel (*Table 1.6*). The results are shown in *Figures 1.4* and *1.5*. This grid population is assumed to apply to all time periods. Note 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 fatalities = *grid population* x *impact area* / *grid area* (2)

Figure 1.4 Marine Population at Risk by Grid, Year 2011

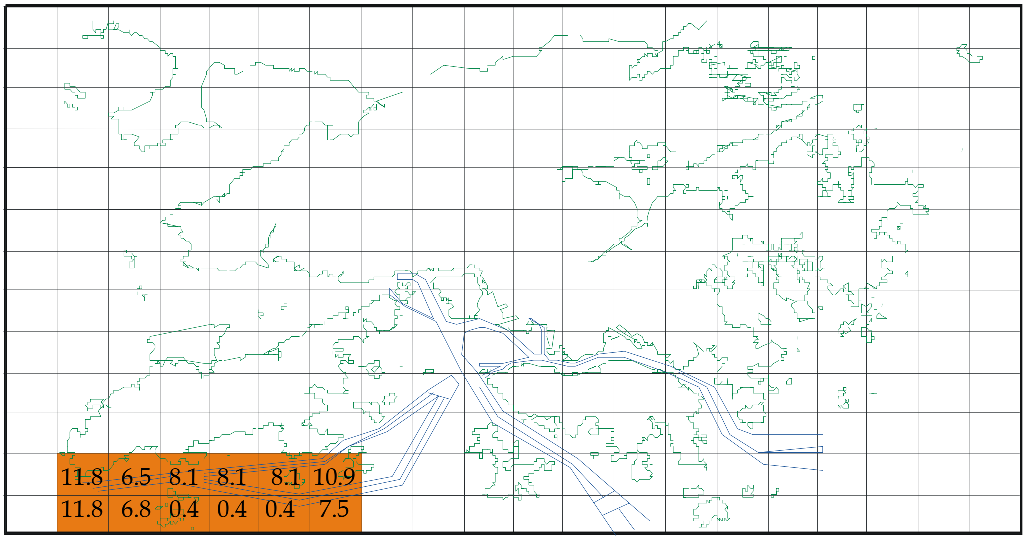
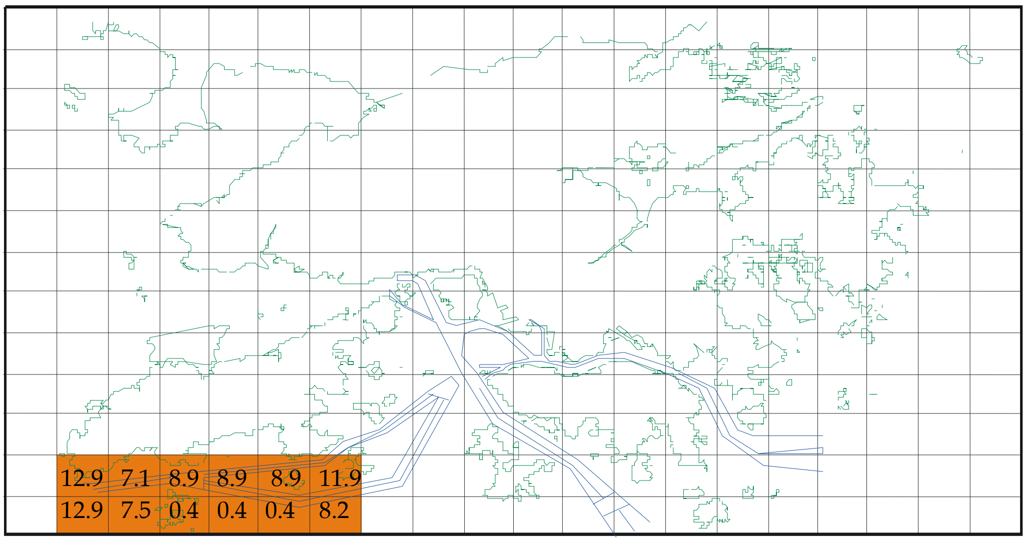


Figure 1.5 Marine Population at Risk by Grid, Year 2021



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 a little differently in the analysis.

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 number 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 equivalently 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:

$$\textit{Prob. that ferry is affected} = \textit{presence factor} \times \textit{impact area} / \textit{grid area} \qquad (3)$$

The fast ferry population distribution adopted was described in *Table 1.5*. Information from the main ferry operators suggests that 25% of ferry trips take place at night time, while 75% occur during daytime. Day and night ferries are therefore assessed separately in the analysis. The distribution assumed is given in *Table 1.8*.

Table 1.8 ***Fast Ferry Population Distribution for Day and Night Time Periods***

Population	Population at Risk	% of Day Trips	% of Night Trips	% of All Trips (= 0.75 x day + 0.25 x night)
450	135	5	-	3.75
350	105	5	-	3.75
280	84	30	-	22.5
175	53	60	30	52.5
105	32	-	50	12.5
35	11	-	20	5.0

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.

1.5 AIRBORNE POPULATION

Helicopters shuttling to and from Macau pass fairly close to the South Soko site. Flights travelling westward towards Macau pass to the north of South

Soko, while the return flights pass to the south of the island. The impact of accidental releases of LNG from the terminal on these helicopters was included in the analysis by including the helicopter passengers in the population.

Helicopters were analysed the same way as fast ferries, namely as mobile receptors with a presence factor, or probability of being within a grid cell when an accident occurs. The cruising speed of the Macau helicopters is 254 km/h. It therefore takes just 51s for a helicopter to traverse one of the grid cells shown in *Figure 1.3*. There are 27 return flights per day; one flight every 30 minutes during the daytime and early evening. Applying *Equation 1*, the helicopter presence factor becomes:

$$\text{Presence factor} = \text{No. of flights per hour} \times \text{grid length} / 3600 / \text{Speed} = 0.028 \qquad (4)$$

This presence factor is applied to all grid cells in *Figure 1.3*. Westbound flights are assumed to pass through the upper row of grids (cells 1-6) while the return eastbound flights pass through the lower row of grid cells (7-12). This presence factor is applied to the daytime period while night time is assumed to have no flights. Each helicopter is assumed to be full with 12 passengers and crew.

The presence factor is further modified by the size of the impact area for each scenario by applying *Equation 3*.

It should be noted that this treatment of helicopters is very conservative. Effectively, the population are treated as being at ground level. In reality, these helicopters fly at 500 feet and so few release scenarios will be able to impact on them. However, helicopters are not expected to make a significant contribution in the results and hence this simplistic approach is regarded as sufficient.

Marine vessels and road vehicles were assumed to offer some protection to their occupants. The same assumption was not applied to helicopters since they will likely crash if they are impacted by an LNG release. 100% fatality is assumed.

REFERENCES

[1] www.censtatd.gov.hk

[2] The Annual Traffic Census 2005, Transport Department, Hong Kong SAR, Jun 2006.

[3] BMT Asia Pacific Ltd., personal communication, 2006

[4] BMT Asia Pacific Ltd, Marine Impact Assessment for Black Point & Sokos Islands LNG Receiving Terminal & Associated facilities, Pipeline Issues, Working Paper #3, Issue 8, Sep 2006

[5] Passenger Arrivals/Departures and Passenger Load Factors at Cross-Boundary Ferry Terminals, January to December 2005, Marine Department, Hong Kong SAR.

[6] Projected Hong Kong Resident Population by TPU, Planning Department, Hong Kong SAR, 2004

[7] Hong Kong 2030, Planning Vision and Strategy, Planning Department, Hong Kong SAR.

[8] ERM, Liquefied Natural Gas (LNG) Terminal and Associated Facilities – Marine Quantitative Risk Assessment, Population Survey Report, Jun 2006.

Annex 13A3

Meteorological Data

CONTENTS

1 METEOROLOGICAL DATA

Data on local meteorology such as wind speed, wind direction, weather stability, ambient temperature and humidity was obtained from the Hong Kong Observatory.

The location of weather stations in the vicinity of the LNG Terminal at South Soko is shown in *Figure 1.1*.

Data from Cheung Chau weather station was adopted for the site, as it is closest to the proposed terminal and also the most relevant based on the topography.

The meteorological data used in this study is based on data recorded by the stations over a five year period.

The raw data from the Observatory is a series of readings taken every hour for a period of one year. This data has been rationalized into different combinations of wind direction, speed and atmospheric stability class, as per the following:

- Each data record is rated with a stability class A through F. For simplicity, this study has used 3 stability classes, B, D and F. Accordingly, the data records have been assigned to these 3 classes;
- Each data record has an associated wind speed. For simplicity, this study has used 4 wind speed classes. Accordingly, the data records have been assigned to these 4 classes;
- Each data record has an associated wind direction. For simplicity, this study has used 12 wind directions. Accordingly, the data records have been assigned to these 12 classes;
- The data has been split into night and day times encompassing day time from 7am to 7pm and night time from 7pm to 7am.

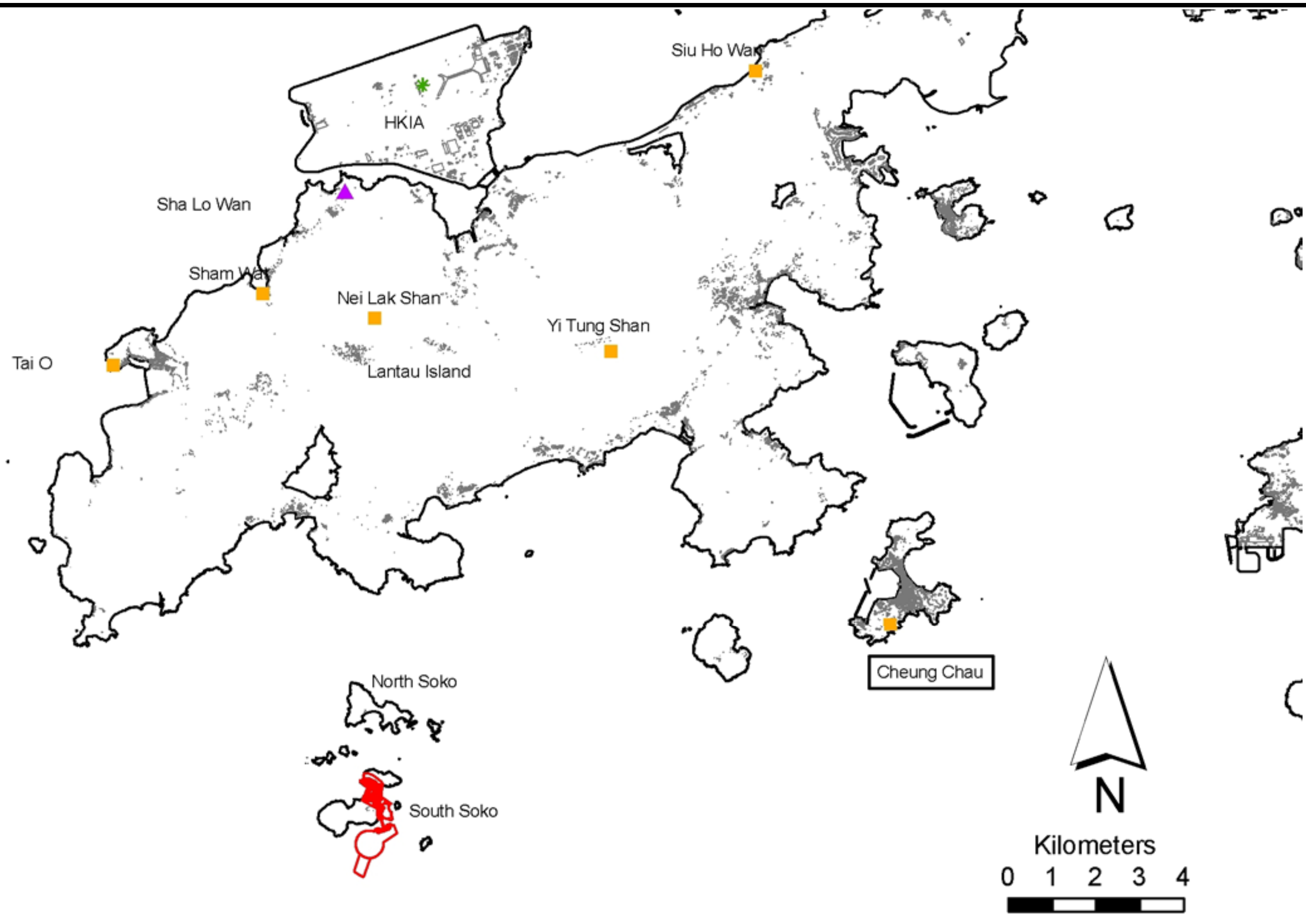
The annual average temperature for the Soko site is 22.4°C. The relative humidity is 78%. *Table 1.1* below tabulates the temperature statistics.

Table 1.1 Temperature Statistics for Soko

		Min.	Max.	Average
Ambient air (T°C)[1]	*Soko*	6.2	33.1	22.4
Surface (T°C)[1]		20.9	25.7	23
Seawater (T°C)[2]	*Soko*	18.0	27.6	23.5
Humidity (%)[1]		65	82	77

Source: 1. Hong Kong Observatory, "The Year's Weather – 2003"
2. HK EPD, "Summary water quality statistics of the Junk Bay and Deep Bay WCZs in 2002"

Figure 1.1 Weather Stations near South Soko

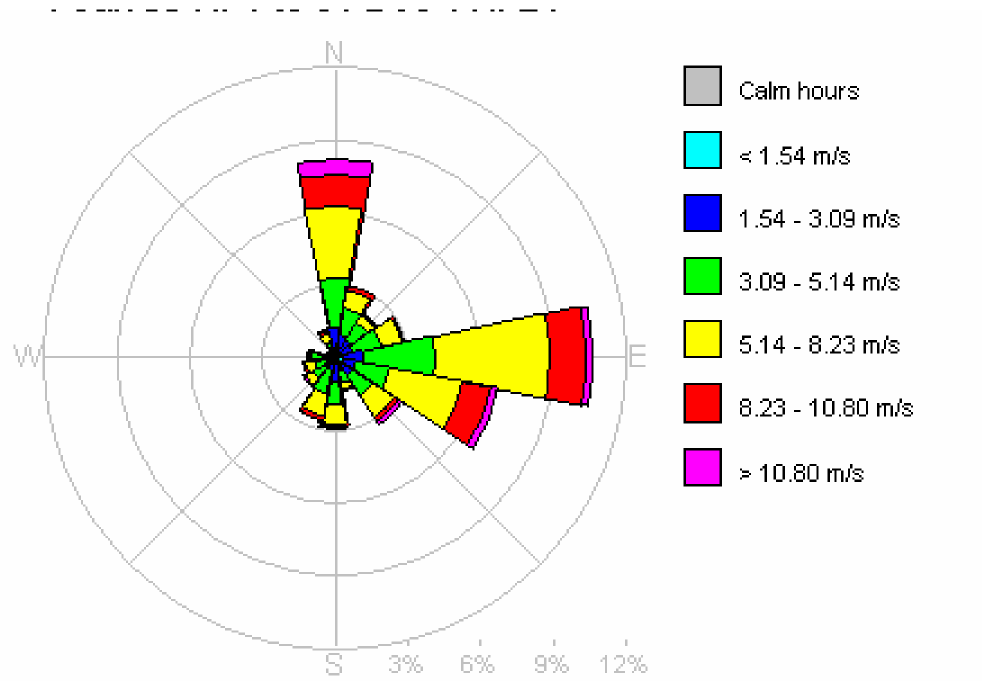


The percentage of occurrence for each combination of wind direction, speed and atmospheric stability during day and night are presented in *Table 1.2*. In addition, the percentage frequencies are plotted in the form of a wind rose in *Figure 1.2*.

Table 1.2 Data for Cheung Chau Weather Station

	Day				Night			
Wind Speed (m/s)	2.5	2	3	7	2.5	2	3	7
Atmospheric Stability	B	F	D	D	B	F	D	D
Wind Direction	Percentage of Occurrence							
0°	1.57	1.92	1.31	11.42	0.00	6.05	1.31	13.14
30°	1.60	0.94	1.34	4.21	0.00	3.02	1.20	4.36
60°	0.81	0.68	0.92	3.05	0.00	3.26	1.56	5.02
90°	0.87	0.65	1.39	14.86	0.00	3.57	2.19	19.48
120°	3.18	0.62	1.38	18.32	0.00	2.02	0.75	9.32
150°	2.10	0.44	0.93	2.92	0.00	1.21	0.36	2.29
180°	2.41	0.35	0.72	2.77	0.00	1.35	0.53	3.47
210°	1.78	0.27	0.67	4.97	0.00	1.40	0.58	4.13
240°	0.89	0.23	0.44	2.10	0.00	1.20	0.54	1.80
270°	0.40	0.27	0.28	0.79	0.00	1.27	0.41	0.83
300°	0.22	0.17	0.09	0.30	0.00	0.61	0.10	0.25
330°	0.47	0.22	0.21	1.57	0.00	0.65	0.18	0.59

Figure 1.2 Wind Rose for Cheung Chau Weather Station (1999-2004)



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

Note on Atmospheric Stability

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 moderately stable conditions, which typically arise on clear nights with little wind.

Annex 13A4

HAZID Session Report

CONTENTS

1 HAZID SESSION REPORT

This document describes the findings of the Hazard Identification (HAZID) study conducted in support of the Quantitative Risk Assessment for the LNG Terminal.

A HAZID workshop was conducted on the design of the LNG Terminal between 26th and 28th October 2004.

As part of the current EIA process and in cognisance of further developments in the design of the LNG Terminal, an additional HAZID workshop was held on 19th and 20th October 2005, to update the earlier study.

A layout review workshop was held on 21st October 2005. The recommendations made during the workshop are reflected in the layout drawings used for the EIA studies.

1.1 OBJECTIVES & SCOPE

The objective of the HAZID study was to identify hazards posed by the siting of the LNG Terminal in Hong Kong SAR, with the main aim of identifying major hazards.

The HAZID study was based on the preliminary layout drawings, design basis and design/construction philosophies for the facilities. The HAZID study covered mainly the operational phase of the project.

The study assessed potential hazards associated with, amongst others, the following areas:

- LNG Terminal
  - Natural Hazards
  - External Hazards
  - Material Hazards
  - Loss of Utilities
  - Layout Hazards

- Plant Systems
  - Unloading Operation
  - Transfer Pipeline from Jetty to Tank
  - LNG Storage Tanks
  - LP LNG System – Tank Pumpout
  - Compressors – BOG, Ship, Pipeline
  - HP LNG System
  - ORV/SCR Vaporisers
  - Fuel Gas, Gas Heating, Gas Metering

  - Vent & Drain System
  - Utilities & Auxiliary Systems

- Construction Phase
  - Blasting Operations During Initial Construction
  - Third LNG Tank Construction – Expansion
  - Process System Construction - Expansion

1.2 METHODOLOGY

1.2.1 *Documents Reviewed*

The following documentation was available for the HAZID studies:

- PFDs, Process description;
- Location and layout of facilities, plot plans.

1.2.2 *HAZID Methodology*

The hazards posed by the facility were identified based on team's experience, past accidents, lessons learnt and checklists. The hazard identification was carried out at a high level, i.e. at the plant and unit level.

In order to ensure that a systematic approach is adopted, the facility was divided into a number of 'subsystems' based on the layout and the process; the guidewords from the checklist (*Table 1.1*) was then applied to each subsystem as relevant. Some of the guidewords such as natural hazards and external hazards however, were applied at the plant level only.

A "brainstorming" session was held involving a team of specialists from various disciplines. The objective of this brainstorming session was to identify all the hazards, particularly those specific to the plant/project under consideration.

The study team considered each area in turn and any hazards that apply to it. The hazards discussed included hazardous materials stored in these areas.

The study included the assessment of:

- Hazards;
- Potential Consequences;
- Safeguards; and
- Proposed Prevention, Control and Mitigation Factors.

The Study Team discussed recommendations for risk reduction and/or further study as appropriate.

HAZID worksheets were used to record the hazards, the consequences, safeguards and additional mitigation measures.

The study output will also serve as a basis for identification of scenarios for the QRA study.

Table 1.1 Checklist for Hazard Identification

General

Material hazards
Toxic, flammable, explosion, oxidising, spontaneously flammable, carcinogenic

Plant Level

Natural hazards
Earthquake
Tidal waves
Storm/flooding
High wind
Subsidence/movement
Extreme weather
Sand storm

External hazards
Aircraft crash
Arson/sabotage
Neighbouring plants/facilities
HV cables
3rd party interference

Layout hazards
Separation
Approach
Escape

Unit Level

Process hazards
(process areas, storage areas, utility areas & unloading areas)
Loss of containment
Inventory
Fire
Explosion
Missiles
Toxicity
Reaction exotherm
Interface with other plants : isolation, control
Loss of utility/communications

Transport hazards
Road vehicles on site
Helicopter

Shipping Hazards
Collision
Grounding
Striking
Fire/explosion
Foundering

1.3 *HAZID SESSIONS AND LAYOUT REVIEW WORKSHOP*

1.3.1 *Study Period*

The HAZID study was conducted from 19th to 20th October 2005. A layout review workshop was held on 21st October 2005. The HAZID sessions and layout review workshop were held in Foster Wheeler's office in Houston, USA.

1.3.2 *HAZID Study Team*

The HAZID team comprised a multidisciplinary team of personnel involved with the project and having adequate experience of design, operations, and safety and loss prevention.

Representatives from CLP Power, ExxonMobil, ARUP and Foster Wheeler participated in the HAZID sessions. Venkatesh S of ERM chaired the HAZID sessions.

The details (names, discipline and company) of the HAZID team members who attended each HAZID session are presented in *Table 1.2*.

Table 1.2 *List of Participants for the HAZID Study during the EIA Studies*

Name	*Company*	*Discipline*	*19th Oct 2005*	*20th Oct 2005*
Jim Power	CLP	Technical Advisor	√	√
Siu Fung Wong	CLP	Technical Associate	√	√
Francis Chau	CLP	Technical Services	√	√
Peter Thompson	Arup	Civil Design	√	√
Cathy Duke	EM	Gas Engineering	√	√
Cheryl Grounds	EMDC	Safety and Risk	√	√
Charles Hughes	EMDC	Marine and Civil	√	√
Winston Shu	EMDC	Senior Technical Advisor, Gas Engineering	√	√
Steven Wu	EMDC	Civil and Structure	√	√
Gary Spargo	EMDC	Construction Advisor	√	√
William Duncan	EMDC	Captain	√	√

Patrick Wong	EMDC	Geotechnical	√	√
Efren P Rocha	EMPC	Operations Advisor	√	√
Sam Hwong	Foster Wheeler	Project Manager	√	√
Zupeng Huang	Foster Wheeler	LNG Process	√	√
C C Yang	Foster Wheeler	Director, LNG Technology	√	√
David Labay	Foster Wheeler	Piping Engineer	√	√
Risk Speicher	Foster Wheeler	Construction	√	√
Justo Benitez	Foster Wheeler	Electrical Engineering	√	√
K B Tammana	Foster Wheeler	Instrumentation	√	√
Ted Ban	Foster Wheeler	Civil	√	√
Larry Watrous	Mustang	Fire Protection	√	√
Robin Kennish	ERM	EIA Permitting	√	√
Venkatesh S	ERM	HAZID Facilitator/ QRA	√	√

1.3.3 *HAZID Study Worksheets*

The session proceedings were recorded using *PHA-Pro 6* software. The records were projected on a screen for comments and agreement by the team members during the sessions.

The completed HAZID worksheets are attached in the *Appendix*.

1.4 RECOMMENDATIONS

Table 1.3 lists the actions identified during the HAZID sessions. These actions will be incorporated in the detailed design.

Table 1.3 Actions for Each Area Considered

Action No.	Hazards	Action
1	Natural Hazards - Typhoon - high wind & storm waves	Design criteria for jetty design at Castle Peak station may be referred in relation to design against wave height
2	Natural Hazards - Lightning	Consider the impact of power dips due to lightening in equipment specification for motor drives
3	Natural Hazards - Hill fire	Liaise with AFCD and FSD to provide a fire barrier at the boundary fence to prevent fire propagation
4	Natural Hazards - Subsidence	Consider past experience in Hong Kong reclamation areas on subsidence and incorporate applicable action in to the design of this facility
5	Natural Hazards - Sea water - seasonal variation in salinity	Consider seawater salinity variation in the design of loading arm and jetty design as well as the dredging requirement at the berth to accommodate the carrier
6	External Hazards - Aircraft crash	Include in the QRA study for Soko, the likelihood of aircraft crash
7	External Hazards - Helicopter crash	Consider establishing no fly zone over the terminal area or impact of helicopter flight path on the facility to be considered

Action No.	Hazards	Action
8	Loss of Utilities - Loss of Power supply	Reliability of power supply to the LNG terminal to be studied during pre-FEED. Options may include direct supply from station, redundant supply sources
9	Loss of Utilities - Loss of sea water supply	Design of sea water intake to consider potential for blockage due to debris including fishing nets etc to ensure reliability of sea water supply
10	Loss of Utilities - Loss of fresh water supply	Fresh water supply to Soko to be reviewed during pre-FEED
11	ORV/SCV Vaporisers - Heavy metals in sea water	Potential impact on ORV due to mercury content in sea water to be (re)confirmed during design based on vendor data
12	External Hazards - Radio-isotopes	Review the regulatory requirements for storage and handling of radio-isotopes for welding/ inspection and make suitable provisions at the site
13	Transfer Pipeline from Jetty to Tank - Collision of drifting vessels or fishing vessels with trestle structure	Review the requirements for a safety zone around jetty.
14	LNG Storage Tanks - Loss of containment	Develop a write up documenting this scenario, i.e. the impact of overpressure inside the tank on the outer containment/ roof
15	LNG Storage Tanks - Hydrotesting of tanks	Consider the impact of seawater for hydrotesting on tank metallurgy
16	LP LNG System – Tank pumpout - inspection of pressure vessel	Investigate whether on-line inspection is feasible and meets regulatory requirements
17	ORV/SCV Vaporisers - Overpressure in vaporizer outlet piping	Review, during detailed design, overpressure safeguards for piping downstream of vaporiser
18	Vent & Drain System - Discharge of gas from vent stack	Analyze the pros and cons of a vent versus flare option to determine the appropriate path forward
19	Natural Hazards - Landslip - landslides	Detailed layout will consider pipe rack routing from/to tanks to not be at the base of the rock cut
20	Natural Hazards - Tsunami - associated with subsea earthquake	Consider developing procedures for LNG carrier departure following Tsunami warning

Appendix

HAZID Worksheets

HAZID Worksheet

System: 1. LNG Terminal Overview

Subsystem: 1. Natural hazards

Hazards/ Keywords	Description/ Causes	Consequences	Safeguards	Recommendations
1. Typhoon - high wind & storm waves	1. High wind	1. Possible impact on structures due to high wind	1. Design basis for the facility - HK Code of Practice for Wind Effects 2004 by BD (3 sec gust for 50 yr return period) for land buildings/ structures. Port Work Design Manual will be followed for marine structures (3 sec gust for 50 yr return period). Based on the design factors specific to the HK Code, this may be considered equivalent to 1 in 100 year return period of other international codes	1. Design criteria for jetty design at Castle Peak station may be referred in relation to design against wave height
	2. Storm waves	2. Impact on berthing and unloading operation	2. Operating practice with regard to berthing & unloading in adverse conditions	
		3. Possible damage to structures/ facilities due to storm wave and associated flooding	3. Site elevation to be based on wave height for 1 in 100 year return period. Sea wall will be constructed along the shoreline. Elevation at South Soko locations exposed to storm waves (east side) will be +10m PD.	
2. Lightning	1. Lightning	1. Possible ignition of discharges from vent stack/ PSVs on tank roof	1. Fire snuffing system for PSVs on tank top and vent stack	2. Consider the impact of power dips due to lightening in equipment specification for motor drives
		2. Possible ignition of discharges to vent at ship end	2. Radiation effects from ignited vent stack considered in vent stack design (i.e. height and proximity to other features)	

Hazards/ Keywords	Description/ Causes	Consequences	Safeguards	Recommendations
		3. Possible impact on instrumentation and control due to power surge	3. Plant instrumentation system designed for fail safe condition	
		4. Power dips leading to possible interruption in plant	4. Procedure to shut down cargo transfer operations	
3. Earthquake	1. Earthquake	1. Possible damage to facility; potential leaks due to loss of containment	1. Tank designed as per code EN1473 requirement	
			2. Other process structures - piping & jetty designed as per EN1473	
			3. Occupied buildings designed to Hong Kong building codes (1in 2475 return period for MCE (Maximum Credible Earthquake) which is similar to IBC 2003	
4. Heavy rainfall - flooding	1. Heavy rainfall	1. Possible damage to facilities due to flooding	1. Stormwater drainage system designed to DSD Manual for 1 in 50 year storm on the basis that this is a urban branch drainage system with diameters not exceeding 1.8m.	
5. Fog - poor visibility	1. Fog	1. No significant impact during unloading or facility operation	1. Collision hazards while the vessel is berthed considered in marine traffic impact study	
		2. Possible collision of other craft with the LNG vessel while berthed		
6. Landslip - landslides	1. Landslides from man-made slopes or natural terrain due to slope instability or earthquake	1. Possible damage to tanks, piping, and facility including control room/ admin buildings	1. Geotechnical studies during design phase and slope design and maintenance	19. Detailed layout will consider pipe rack routing from/to tanks to not be at the base of the rock cut.
			2. Geotechnical studies during design phase and slope stability measures to consider impact of earthquakes of 1 in 10,000 year return period	

Hazards/ Keywords	Description/ Causes	Consequences	Safeguards	Recommendations
7. Landslip - boulderfall	1. Boulderfall	1. Possible damage to tanks, piping, and facility including control room/ admin buildings	1. Geotechnical studies during design phase and boulder removal/ stabilisation measures. See recommendation 19	
8. Hill fire	1. Hill fire within the boundary fence	1. Potential source of ignition	1. Vegetation management inside the fence	3. Liaise with AFCD and FSD to provide a fire barrier at the boundary fence to prevent fire propagation
	2. Hill fire outside the boundary fence - in the vicinity of the fence	2. Potential fire spread to vegetation inside the fence & possible impact on facility		
9. Subsidence	1. Subsidence in reclamation	1. Misalignment and damage to tank/ piping structures (at Soko site, part of the process areas and two tanks could be on rock while future 3rd tank and part of the process areas could be on reclaimed land)	1. 3rd tank will be built some years after reclamation, providing time for monitoring	4. Consider past experience in Hong Kong reclamation areas on subsidence and incorporate applicable action in to the design of this facility
			2. Geotechnical studies to determine performance of sub-soil and incorporation in design	
			3. If required, 3rd future tank can be supported on piles	
10. Tsunami - associated with subsea earthquake	1. Tidal waves higher than predicted	1. Possible damage to structures/ facilities due to high wave and associated flooding	1. LNG ship cargo transfer operations would be ceased following Tsunami warning.	20. Consider developing procedures for LNG carrier departure following Tsunami warning
			2. Stormwater drainage system	
			3. Black Point site does not face the open seas & hence less susceptible, as compared to Sokos	

Hazards/ Keywords	Description/ Causes	Consequences	Safeguards	Recommendations
			4. Analysis has shown that expected Tsunami height at terminal locations would be approximately equal to the historical extreme sea level (5.5m PD) (based on 8.5 Richter scale earthquake in the Philippines). S. Soko Terminal elevation exposed to Tsunami proposed at +10m PD.	
11. Sea water - seasonal variation in salinity	1. Salinity varies from 2000 to 45,000ppm depending on Pearl River water discharge	1. Sea water density will vary which could affect the LNG carrier draft and accordingly the loading arm movement envelope		5. Consider seawater salinity variation in the design of loading arm and jetty design as well as the dredging requirement at the berth to accommodate the carrier
		2. Impact on electrochlorination plant as hypochlorite will not be generated at low salinity levels. This could impact hypo injection in sea water intake. No significant consequence		
12. Sea water - seasonal variation in suspended solids	1. Suspended solids may vary from 40 to 800 mg/l	1. Increased siltation leading to increased seawater intake filter maintenance	1. ORV and intake filter system design specification will reflect suspended solids content	
		2. Impact on ORV operation		
13. Tidal currents	1. Tidal currents may impact the ability to safely berth	1. Possible impact on berthing of LNG carrier	1. Maximum current condition to be considered in design basis	
			2. Berthing operations will not be undertaken in high current conditions (based on evaluation of tug capacity to handle berthing operations).	

System: 1. LNG Terminal Overview

Subsystem: 2. External hazards

Hazards/ Keywords	Description/ Causes	Consequences	Safeguards	Recommendations
1. Aircraft crash	1. During take-off / landing	1. Damage to the facility and fire	1. Black Point site not in the flight path; site about 20km away from airport	6. Include in the QRA study for Sokos, the likelihood of aircraft crash
2. Helicopter crash	1. Helipad at BPPS and at the radar station	1. Damage to the facility and fire	1. Helipad at the radar station near BPPS used for specific purpose and not frequent (about once per week)	7. Consider establishing no fly zone over the terminal area or impact of helicopter flight path on the facility to be considered
	2. Helipad at Sokos (provided for site access by air- usage infrequent)	2. Same as 1		
3. Fishing vessels in the vicinity		1. Fishing vessels may be present within the safety zone while the carrier is berthed; possible ignition source as well as collision hazards	1. Enforce safety zone	
4. Drifting/ Passing vessels	1. Loss of power or collision between passing vessels	1. Possible damage to the jetty/ trestle and the carrier while berthed; loss of containment due to damage to piping	1. Tugboats in attendance while the carrier is berthed	
			2. Isolation valves at the jetty and shore end	
			3. Jetty and trestle designed for certain impact load as per standard practice	
			4. Trestle sheltered by mooring dolphins and connecting structures	

Hazards/ Keywords	Description/ Causes	Consequences	Safeguards	Recommendations
			5. Marine traffic impact study to consider collision of passing and drifting vessels with the jetty structure as well as carrier while berthed	
			6. Navigation aids, lights, buoys and guard boats	
5. Radar station	1. No issue other than helicopter activity considered above			
6. Oil or chemical spills on the sea	1. Due to collision or sinking of passing vessels or due to incidents associated with oil barges serving BPPS	1. Contamination of seawater intake leading to shutdown of ORV operation	1. Intake at about 10m depth	
		2. Possible ignition of spill affecting the jetty and trestle structure	2. Emergency response measures	
7. Hikers in the vicinity		1. Impact on hikers in the event of any incident at the terminal	1. Impact considered in the risk study	
			2. Property/security fence with some setback distance from the facility	
8. Pleasure fishing in the vicinity	1. Same as fishing boats, considered above			

Hazards/ Keywords	Description/ Causes	Consequences	Safeguards	Recommendations
9. Illegal immigrants or smugglers approaching the facility by fast boats or other means		1. Security concern/ trespass	1. Security plan for the facility	
10. Fuel oil tank on fire or fuel oil tank rupture at BPPS	1. Fuel oil stored as emergency back up fuel for gas turbine	1. Facility is about 500m away and hence impact due to fire not likely		
11. H2 fire/ explosion at BPPS	1. H2 stored at BPPS for generator cooling	1. Potential for projectiles causing damage to the facility	1. Trailer bay located in a concrete compound with ventilation, leak/fire detection	
			2. No. of cylinders in a trailer limited to 12 or 26 and max 2 trailers	
			3. Trailer house about 1km from LNG terminal	
12. 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. Periodic inspection of the turbine	
			2. Turbine located in a housing and turbine housing is within a structure	
			3. Full containment tank designed to withstand projectile impact	
			4. Natural terrain acts as a barrier between the tanks and the BPPS site and the turbines are located greater than 500 m from the terminal	

Hazards/ Keywords	Description/ Causes	Consequences	Safeguards	Recommendations
13. Gas leaks at BPPS	1. Leak in the open or in the gas turbine enclosure	1. Fire or explosion in the BPPS; impact on LNG terminal considered less likely due to the separation distance of more than 200m	1. Gas leak detection and shutdown system at BPPS	
14. Boiler explosion	1. High pressure (100 bar) steam boiler	1. Potential for projectiles causing damage to the facility	1. Full containment tank designed to withstand projectile impact 2. Natural terrain acts as a barrier between the tanks and the BPPS site 3. Boiler controls/ inspection and maintenance	
15. Pipeline leak from BPPS to CPPS	1. Pipe at about 38barg, 6km long and 600mm diameter	1. Possible impact on the access road to BPPS and LNG terminal site; impact on the LNG terminal is considered less likely due to the separation distance and the natural terrain barrier	1. Pipeline is buried with shutdown valve at either end 2. Pipeline inspection and maintenance	
16. Temporary ammonium nitrate emulsion storage near BPPS	1. Facility operated by 3rd party	1. Potential fire and explosion	1. Separation distance is at least 1 km and there is a hill located between the emulsion storage and the LNG terminal. 2. Impact considered in QRA	

System: 1. LNG Terminal Overview

Subsystem: 3. Material hazards

Hazards/ Keywords	Description/ Causes	Consequences	Safeguards	Recommendations
1. LNG	1. LNG handled as liquid at -162 deg C (at 0.1 to 6barg) and as gas at max of 101 barg (at about 5 to 15 deg C for South Soko and about 50 to 60 deg C for Black Point)	1. Potential for fire; potential overpressure upon ignition of vapour cloud in confined and congested environment	1. Design as per Codes with appropriate safety systems including detection, shutdown, area classification	
		2. Potential for brittle failure where non-cryogenic material is exposed	2. Operating and safety procedures	
		3. Personnel hazards on contact with cold liquid; asphyxiation hazards		
2. Hypochlorite	1. Onsite generation likely using electrochlorination process. Used for disinfection of seawater intake	1. Concentration very low; personnel hazards; small amounts of hydrogen generated	1. Design provision to vent off H2 safely	
3. Caustic solution	1. Caustic required for neutralising SCV water discharge	1. Personnel hazards	1. Operating and safety procedures	
4. Nitrogen	1. Nitrogen may be generated onsite or purchased - used for loading arm operations, maintenance purging	1. Asphyxiation hazards, particularly in confined spaces	1. Operating and safety procedures	

Hazards/ Keywords	Description/ Causes	Consequences	Safeguards	Recommendations
	2. N2 bottles for purging of vent stacks/ fire extinguishment			
5. Pressurised air	1. Generated onsite for process and instrument requirements	1. Pressure system hazards	1. Design procedures 2. Operating and safety procedures	
6. Dry chemical powders	1. Used for fire fighting	1. Personnel hazards (inhalation) while handling	1. Operating and safety procedures	
7. Diesel oil	1. For emergency power generation, fire water pumps and other maintenance equipment (cranes)	1. Potential fire hazards	1. Design safety and operating procedures	
8. Glycol solution (about 35%)	1. Used as heating fluid for the fuel gas heater	1. Not a combustible fluid as it is a solution in water and concentration is low. Personnel handling hazards	1. Operating and safety procedures	
9. Lubricants/ greases	1. For general machinery maintenance	1. Spill/ contamination	1. Curb area around user equipment including drip pans	
10. Hydraulic oil	1. Hydraulic oil for loading arm movement - pressures of about 300psi	1. No significant safety issue. Spill hazard on the jetty platform and possibly on the sea (from connections)	1. Curb area in the jetty platform. Volume in connection piping insignificant	
11. Methanol	1. Methanol for de-icing of flanges and valves (external application) - handled in containers	1. Flammable hazards. Personnel hazards in the event of spillage/ contact	1. Operating and safety procedures 2. Storage in approved DG stores	

Hazards/ Keywords	Description/ Causes	Consequences	Safeguards	Recommendations
12. Paints and Solvents	1. For painting use at site	1. Flammable hazards	1. Operating and safety procedures	
			2. Storage in approved DG stores	
13. Radio-isotopes	1. For maintenance operation - welding/ inspection	1. Radiation hazards to personnel but low level radiation	1. Procedures for handling and storage	12. Review the regulatory requirements for storage and handling of radio-isotopes for welding/ inspection and make suitable provisions at the site
14. Gas cylinders	1. Helium or other gas for GC calibration, lab analysis	1. Physical explosion hazards	1. Storage in approved DG stores	
	2. CO2 cylinders for fire extinguishment			
15. Laboratory Chemicals	1. For any lab analysis of samples	1. Flammable, toxic hazards to personnel handling chemicals	1. Operating and safety procedures	
16. Chemicals for sewage treatment at Soko	1. Alums	1. Personnel hazards during handling	1. Operating and safety procedures	

System: 1. LNG Terminal Overview

Subsystem: 4. Loss of Utilities

Hazards/ Keywords	Description/ Causes	Consequences	Safeguards	Recommendations
1. Loss of Power supply	1. For Black Point site, power will be supplied externally	1. Terminal will shutdown in safe mode; gas export will stop leading to loss of supply to BPPS; boil-off gas may be vented to stack; unloading operation will likely stop; heat leak in piping and equipment leading to overpressure under blocked condition	1. Insulation and thermal/pressure relief	8. Reliability of power supply to the LNG terminal to be studied during pre-FEED. Options may include direct supply from station, redundant supply sources
	2. For Soko site, onsite generation may be required in addition to external supply		2. Emergency generator & UPS for critical users/systems including lighting, controls and other safety critical systems	
2. Loss of Instrument air supply		1. System designed to go to safe shutdown mode	1. Redundant air compressors; air receiver; emergency power supply	
3. Loss of Nitrogen supply	1. N2 required for unloading arm swivel joint operation when in use (and for draining and purging after unloading); continuous purging requirements for electrical junction boxes and potentially for vent stack purging	1. Potential impact on swivel joint operation. Delay in completion of unloading	1. Redundant N2 source (generation and small liquid storage/vaporizer)	
		2. Potential moisture ingress or gas ingress into junction boxes	2. Operating procedures	
4. Loss of sea water supply	1. Sea water used for ORV operation; power supply failure	1. Impact on ORV operation leading to partial loss of sendout	1. SCVs may be operating or on standby for partial supply of gas	9. Design of sea water intake to consider potential for

Hazards/ Keywords	Description/ Causes	Consequences	Safeguards	Recommendations
	or debris in sea water intake or flooding of pump house may cause loss of sea water supply	gas	2. Multiple sea water supply pumps & power source	blockage due to debris including fishing nets etc to ensure reliability of sea water supply
5. Loss of fuel gas supply	1. Fuel gas supplied from LNG	1. For the Black Point site, it will affect SCV operation and reduce sendout gas supply (under peak supply condition)	1. Redundancy in fuel gas supply considered in design	
		2. For Sokos site, it will affect onsite power generation and hence the sendout of the gas	2. External power supply for Soko	
6. Loss of diesel supply	1. Diesel used for fire water pumps and emergency power generator	1. Impact on emergency response	1. On-site diesel storage	
			2. Day tank storage associated with each user equipment	
7. Loss of fresh water supply	1. Fresh water used for initial fill of SCVs; fire water jockey pump operation; personnel use; washing/ hose station etc	1. No significant consequence to the plant operations; potential personnel issue	1. On-site fresh water storage	10. Fresh water supply to Sokos to be reviewed during pre-FEED
			2. Water will be provided via pipeline. Either the existing line will be used or a new line will be installed. (South Sokos)	

System: 1. LNG Terminal Overview

Subsystem: 5. Layout hazards

Hazards/ Keywords	Description/ Causes	Consequences	Safeguards	Recommendations
1. Layout Hazards	1. A layout review was carried out separately and actions from the review will be incorporated in the new layout	1. The layout will be reviewed based on QRA results & during pre-FEED phase		

System: 2. Plant Systems

Subsystem: 1. Unloading operation

Hazards/ Keywords	Description/ Causes	Consequences	Safeguards	Recommendations
1. Loss of containment	1. Unloading arms - leakage from swivel joints	1. Leakage from swivel joints would be minor leakages	1. N2 purge and leak detection system	
	2. Unloading arms - leakage from mechanical flange joints	2. Liquid spill or vapour release; potential fire; impact on structure due to cold liquid spill	2. Operator monitoring	
	3. Unloading arms - disconnection under extreme weather condition	3. Impact of cold liquid spill leaking from the connection flange on the ship manifold area	3. Emergency shutdown of unloading operation	
	4. Leak from piping and equipment at the jetty - drain vessel and/or knock-out drum		4. One of the liquid unloading arms can be used as vapour return arm during maintenance of vapour arm; periodic maintenance of arms/ swivel joints	
			5. Gas detection and low temp. detection; fire detection; fire water monitors at the jetty at different elevation (remote operated)	
			6. Loading arm platform designed to withstand cold liquid spill	
			7. Arm position limit detection and activation of shutdown valves at jetty end	

Hazards/ Keywords	Description/ Causes	Consequences	Safeguards	Recommendations
			8. Powered Emergency Release Coupler with valves at either end of coupling results in isolation of both ship end and jetty end	
			9. Spill containment system at the jetty platform with high expansion foam	
			10. Continuous water curtain during unloading localised at the ship manifold area	
2. Spill/ Fire on the carrier while berthed	1. Spill from connections on the ship deck	1. Radiation effects on the jetty structure and facilities and personnel	1. Spill containment system & emergency shutdown system on the ship	
			2. Fire protection system on the ship	
			3. Fire protection system at the jetty	
			4. Tugs with fire fighting capability	
3. Manual Operations	1. Arm movement and coupling connection between the arm and ship manifold (done on the ship) thru hydraulic controls operated manually.	1. Impact of arm on the ship manifold due to operator error or due to ship movement. Possible damage to the arm connection coupler	1. Operator training	
	2. Gangway positioning from the platform to the ship	2. Impact with the ship causing damage to the gangway	2. Hydraulic control is slow and controlled	
			3. Weather condition check	

Hazards/ Keywords	Description/ Causes	Consequences	Safeguards	Recommendations
			4. Cabling assisted connection to enable loading arm operation under adverse conditions if required	
4. Personnel Hazard	1. Fall from gangway, jetty platform	1. Possible injury	1. Guard rails on platform and gangway	
	2. Contact with cold surfaces - coupling connection on the ship (platform piping is insulated)		2. PPE (flotation devices)	
			3. Controlled access to the platform/ gangway	
	3. Ice falling off from the arm after disconnection		4. Controlled access to the arm coupling connection	
			5. PPE (hard hats) and controlled access	
			6. Operating Procedures	
5. Impact while berthing	1. Impact of LNG carrier on the jetty while berthing due to higher than operational approach speed limit	1. Damage to jetty structure; possible damage to piping	1. Tug assisted berthing with approach speed limits and indicators	
			2. Fenders designed for specified impact load	
			3. Mooring masters on the shore side to supervise the berthing	
			4. Local HK Pilots onboard LNG carriers during berthing	

Hazards/ Keywords	Description/ Causes	Consequences	Safeguards	Recommendations
6. Maintenance	1. Maintenance of arm - replacement of seals (about once every 5 years) - undertaken between unloading operations and will require scaffolding	1. General personnel hazards associated with maintenance activities, such as fall	1. Operating and safety procedures	
	2. Replacement of arm (expected about once every 20 years) - this will require barge/ crane operation. Operation undertaken between unloading operations			
7. Emergency Egress	1. Emergency on the ship or the jetty	1. Potential injury if unable to escape	1. Normal access to the jetty and secondary egress to the mooring dolphin	
8. Others - jetty operator shelter	1. Weather shelter for operator presence during unloading operations	1. No significant issue		

System: 2. Plant Systems

Subsystem: 2. Transfer Pipeline from Jetty to Tank

Hazards/ Keywords	Description/ Causes	Consequences	Safeguards	Recommendations
1. Leak in liquid transfer piping	1. Sudden closure of shutdown valve at shore end while unloading leading to surge or weld defect	1. LNG spill and potential fire, and potential exposure of marine traffic to liquid spill	1. Transfer piping on the trestle is welded with no flange connections	
			2. Pressure and flow sensors on the transfer piping	
			3. Surge analysis during design	
			4. Provision of shore isolation valve with spill containment system	
			5. Any thermal reliefs required will discharge to a closed system	
			6. Activation of Emergency Shutdown System stops LNG carrier unloading pumps before closing isolation valves	
2. Collision of drifting vessels or fishing vessels with trestle structure		1. Possible damage to the structure leading to potential damage to transfer piping	1. Buoys and navigation aids, lights	13. Review the requirements for a safety zone around jetty.
			2. Emergency shutdown valve in piping at jetty end and shore end	
			3. Safety zone around jetty would be documented on navigational charts	

Hazards/ Keywords	Description/ Causes	Consequences	Safeguards	Recommendations
3. Vehicle accidents on the roadway	1. Road access on the trestle for maintenance vehicle & personnel movement	1. Possible damage to transfer piping	1. Segregation of roadway and piping	
		2. Potential for vehicles and passengers to fall off trestle into the sea	2. Speed limit and other controls on vehicle movement	
			3. Access lighting will be provided	
4. Loss of circulation while not unloading	1. In-tank pumps used for circulation; multiple pumps provided	1. Heat leak and potential pressure build-up over a period of time	1. Insulation on transfer piping	
			2. Thermal relief valves on piping	
			3. Transfer piping floating with the tank and hence pressure build-up not expected	
5. Jetty security	1. 3rd party access from water	1. Access to jetty/ trestle equipment handling LNG	1. Cameras at jetty with surveillance in control room	
			2. Routine security guard check	
			3. Controlled access at shore end of trestle	

System: 2. Plant Systems

Subsystem: 3. LNG Storage Tanks

Hazards/ Keywords	Description/ Causes	Consequences	Safeguards	Recommendations
1. Overfilling	1. Level indication failure	1. Overflow to the annular space leading to overpressure in tank	1. Multiple level indication and trip (2 oo3 voting)	
2. Overpressure	1. LNG received from ship is at higher saturation pressure; loading rate higher than design; compressor trip	1. Potential damage to the tank	1. High pressure indication and trip of liquid inflow (2oo3 voting) isolates tank from fill lines and initiates ESD and shuts down ship's pumps	
			2. Relief from tanks to vent stacks (thru PCV and relief valves); relief valves on tank to atmosphere, as per code requirement	
3. Underpressure	1. Pressure control malfunction; barometric change of pressure; inflow of sub-cooled liquid	1. Potential damage to the tank	1. Low pressure trip of compressor & transfer pumps	
			2. Make-up gas or N2	
			3. Vacuum relief valves on tank as per code requirements	
4. Rollover	1. De-stratification of different density liquid	1. Potential overpressure due to high vapour evolution rates	1. Operating procedures	
			2. Instrumentation to detect stratification	
			3. Top and bottom tank loading provisions	
			4. Tank circulation	

Hazards/ Keywords	Description/ Causes	Consequences	Safeguards	Recommendations
			5. Relief system sized for rollover condition	
5. Failure of tank bottom heating	1. Loss of power; heating coil malfunction	1. Potential frost heave at the tank bottom leading to tank damage; impact over a period of time	1. Temp. measurement	
			2. Replacement of heating element while in operation considered in design	
			3. Turbine generators on site as back up power supply to the main supply from the grid (South Soko)	
6. Dropped object	1. Dropped object inside tank (primarily in-tank pump during maintenance)	1. Possible damage to the tank bottom plate leading to leakage of inner tank into the outer tank	1. Fail safe lifting cables	
			2. Maintenance procedures	
			3. Low temp. detector in annular space to detect inner tank leak	
7. Leaks on roof top	1. Flange joints on roof top	1. Cold liquid spill and potential ignition	1. Spill containment with gas and fire detection and fire protection system	
8. Ignition of relief discharge	1. Due to lightning occurring while relief valve is in operation (less likely)	1. Radiation effects on tank and valves/piping on roof	1. Snuffing provision at the relief discharge	
			2. Discharge piping elevation design will provide protection to piping on the roof	
9. Accidental relief discharge	1. Damage due to maintenance in the vicinity	1. Potential vapour release to atmosphere	1. Relief valves are sized/provided as n+1.	

Hazards/ Keywords	Description/ Causes	Consequences	Safeguards	Recommendations
10. Inner tank leak (9% Ni)	1. Material defect or thermal cycle stress	1. Possible overpressure	1. Liner provided on outside of inner shell 9% Ni plate at the bottom to contain design spill	
			2. Low temp. detection at the annular space	
			3. Overpressure protection thru relief valves	
11. Loss of containment	1. Overpressure inside tank	1. Potential leak at roof to wall seam with vapour release from tank surface. No loss of either tank wall integrity envisioned.	1. Relief valves provided.	14. Develop a write up documenting this scenario, ie the impact of overpressure inside the tank on the outer containment/ roof.
		2. No feasible scenario envisioned for concurrent failure of both inner and outer walls	2. Tank designed to meet EN 1473	
			3. Operating procedures and indications such as pressure	
12. External fire	1. Fire in process area	1. Possible thermal radiation effects on tank	1. Concrete outer shell can withstand radiation effects	
			2. Fire detection and emergency shutdown system	
13. Maintenance issues	1. Normal maintenance involves only external visual inspection, settlement monitoring, and foundation heating system monitoring	1. No hazards envisioned	1. No corrosion issues envisioned due to cryogenic and non corrosive service	
14. Tank start-up	1. Cool down operation	1. Localized stresses due to rapid cool down which could lead to potential inner tank failure	1. Controlled cooling rate, monitoring temperature drop across shell	

Hazards/ Keywords	Description/ Causes	Consequences	Safeguards	Recommendations
	2. Purging of inner tank and annular space with nitrogen purge to remove air and moisture	2. Venting of nitrogen- LNG vapor mix to atmosphere to achieve required cool down	2. Start up plans and procedures	
		3. Possible air pockets if purging operations not adequate	3. Monitoring of oxygen content leaving tank	
			4. Procedure for purging annular space	
15. Access and egress to/from rooftop	1. Emergency incident	1. Need to egress to a safe location	1. Two stairways provided from tank top	
16. Hydrotesting of tanks	1. Disposal of test water	1. Potential environmental impact	1. Environmental impact studies will include consideration of tank commissioning issues	15. Consider the impact of seawater for hydrotesting on tank metallurgy
	2. Use of seawater for hydrotesting	2. Potential chloride induced stress corrosion of tank metallurgy (welds and heat effected zone)		

System: 2. Plant Systems

Subsystem: 4. LP LNG System - Tank pumpout

Hazards/ Keywords	Description/ Causes	Consequences	Safeguards	Recommendations
1. Loss of containment	1. Leak from piping at recondenser and at HP pump suction	1. Potential leak and fires	1. Gas and fire detection; emergency shutdown; fire protection systems; localized containment area	
2. Inspection of pressure vessel	1. Inspection and testing of recondenser as per code requirement	1. Loss of ability to recondense BOG	1. Provision to compress part of the BOG directly to send out system which will meet a fraction of the BOG volume. The remaining BOG vapour will be vented to stack. 2. Recondenser provided with a bypass	16. Investigate whether on-line inspection is feasible and meets regulatory requirements

System: 2. Plant Systems

Subsystem: 5. BOG Compressors - BOG, Ship, Pipeline

Hazards/ Keywords	Description/ Causes	Consequences	Safeguards	Recommendations
1. Leaks	1. Three compressors – boil-off gas, high pressure pipeline send out and vapors during unloading	1. Potential gas leak and fires	1. Gas and fire detection; emergency shutdown; fire protection system	
2. Dropped object during maintenance	1. Drop compressor parts on adjacent, operating compressor	1. Potential damage and loss of containment	1. Gas and fire detection; emergency shutdown; fire protection system	

Hazards/ Keywords	Description/ Causes	Consequences	Safeguards	Recommendations
			2. Lifting and maintenance procedures	

System: 2. Plant Systems

Subsystem: 6. HP LNG System

Hazards/ Keywords	Description/ Causes	Consequences	Safeguards	Recommendations
1. Loss of containment	1. Leak from piping downstream of the HP pump (pressure approx. 100 bar); ; HP pump in canister	1. Potential leak and fires	1. Gas and fire detection; emergency shutdown; fire protection systems; localized containment area, provision of splash plates on mechanical connections	
2. Dropped object during maintenance	1. Dropped object on adjacent, operating pump	1. Potential damage and leak	1. Gas and fire detection; emergency shutdown; fire protection systems; localized containment area.	
			2. Lifting and maintenance procedures	

System: 2. Plant Systems

Subsystem: 7. ORV/SCV Vaporisers

Hazards/ Keywords	Description/ Causes	Consequences	Safeguards	Recommendations
1. Leaks	1. Leaks from flange connections & small bore piping	1. Potential liquid spill; potential gas leaks; ignition and fire	1. Gas and fire detection; emergency shutdown; fire protection system	
	2. Ingress of LNG vapor into SCV in the event of leak in surrounding environment	2. Potential non-uniform combustion in SCV	2. Spill containment system with provision for high expansion foam	
			3. SCV air intake provided with gas detection and shutdown of SCV	
2. ORV tube failure	1. ORV tubes of Aluminium at about 80 to 100bar; seawater corrosion	1. Gas leak and potential ignition	1. ORV tubes provided with external coating to minimise corrosion effect	
			2. Periodic inspection and maintenance; spare ORVs provided	
			3. Gas and fire detection; emergency shutdown; fire protection system	
3. Heavy metals in sea water	1. Mercury content in sea water	1. Potential impacts if mercury content exceeds equipment vendor's specification for ORV	1. Since initial HAZID, Project has verified with vendors that the current mercury level in seawater does not exceed the equipment vendor's specification	11. Potential impact on ORV due to mercury content in sea water to be (re)confirmed during design based on vendor data

Hazards/ Keywords	Description/ Causes	Consequences	Safeguards	Recommendations
4. SCV tube failure	1. Tubes in water bath heater; possible damage due to corrosion	1. Gas leak and potential ignition	1. Hydrocarbon monitoring in flue gas stack from SCV	
5. Low temp. hazard in vaporiser outlet piping	1. Heating failure in ORV/ SCV likely to result in low temp. liquid or gas in sendout	1. Possible damage to sendout piping (CS material); impact on gas turbine operation	1. Low temp. trip at vaporiser outlet	
6. Overpressure in vaporiser outlet piping	1. Blocked condition	1. Potential loss of containment due to overpressure caused by heat of vaporisation under blocked condition	1. High pressure trip of HP pumps and vaporizers	17. Review, during detailed design, overpressure safeguards for piping downstream of vaporizer
			2. Relief valve to HP vent stack from each vaporiser outlet (vent stack designed for only 1 relief valve load)	

System: 2. Plant Systems

Subsystem: 8. Miscellaneous - Fuel gas, Gas heating, Gas Metering

Hazards/ Keywords	Description/ Causes	Consequences	Safeguards	Recommendations
1. Leaks	1. Leak from flanges, piping connections; rupture of piping or equipment	1. Potential gas leak and fires	1. Gas and fire detection; emergency shutdown; fire protection system	

System: 2. Plant Systems

Subsystem: 9. Vent & Drain system

Hazards/ Keywords	Description/ Causes	Consequences	Safeguards	Recommendations
1. Ignition of gases from vent stack	1. Due to lightning	1. Potential thermal radiation effects on adjoining equipment	1. Stack height will be determined based on thermal radiation threshold on adjoining equipment	
			2. Snuffing system	
2. Discharge of gas from vent stack	1. Venting from HP and LP vent stack	1. Potential slumping of cold vapour leading to accumulation in plant area or in vicinity	1. Stack height will be determined based on dispersion distance, taking into consideration receivers at ground and elevation. Gas expected to become warmer as it reaches vent stack	18. Analyze the pros and cons of a vent versus flare option to determine the appropriate path forward.
			2. Knock out drum will be provided for both vent stacks to knock out any liquid although not expected	
3. Air ingress into vent header	1. Air ingress from vent stack	1. Potential for flame flashback upon ignition of vent vapours	1. Nitrogen purge	
			2. Detailed design will address ignition sequence and purging requirements	

System: 2. Plant Systems

Subsystem: 10. Utility & auxiliary systems

Hazards/ Keywords	Description/ Causes	Consequences	Safeguards	Recommendations
1. Gas turbine hazards (at Soko)	1. Potential gas leak inside turbine enclosure	1. Potential fire and explosion	1. Turbine enclosure will be protected with detection and suppression systems per the manufacturers recommendation.	
2. Transformer and switchgear at substation	1. Equipment failure	1. Potential fire and explosion	1. Protection of transformers will be provided per HK codes and applicable electrical codes and standards for process plants	

System: 3. Construction Phase

Subsystem: 1. Blasting Operations during Initial Construction

Hazards/ Keywords	Description/ Causes	Consequences	Safeguards	Recommendations
1. Explosives storage	1. Inadvertent ignition of material	1. Potential explosion; exposure of construction personnel	1. Explosives store will be specifically designed, located, and controlled as per HK regulations.	
2. Explosives handling	1. Inadvertent ignition	1. Potential explosion; exposure of construction personnel	1. Handling only by Shotfirer	
			2. Explosives handling will be specifically designed, located, and controlled as per HK regulations.	

Hazards/ Keywords	Description/ Causes	Consequences	Safeguards	Recommendations
3. Blasting operations	1. Airborne fly rock	1. Potential personnel injury	1. Blasting will be controlled as per HK regulations.	

System: 3. Construction Phase

Subsystem: 2. Third LNG Tank Construction - Expansion

Hazards/ Keywords	Description/ Causes	Consequences	Safeguards	Recommendations
1. Construction activity for 3rd tank	1. Additional construction staff at the site during construction	1. Potential exposure to hazards from the operating facility	1. Separate risk assessment for the construction phase (for 3rd tank expansion)	
			2. Simultaneous Operations procedures will be developed/implemented	
			3. 3rd tank location will be such that blasting will not be required (or blasting would be accomplished during initial construction phase)	

System: 3. Construction Phase

Subsystem: 3. Process System Construction - Expansion

Hazards/ Keywords	Description/ Causes	Consequences	Safeguards	Recommendations
1. Diesel storage during construction phase	1. Potential loss of containment	1. Potential environmental impact, potential fire	1. Containment and manual fire protection will be provided	
2. Storage of construction materials including caustic, chemicals, compressed gas, paints/solvents	1. Potential toxic exposure, fire	1. Potential exposure of personnel	1. Construction operating and safety procedures	
			2. Chemical and materials handling and storage per HK codes and MSDS	
3. Construction and installation of new pumps, vaporiser as part of expansion	1. Potential equipment damage of adjoining equipment	1. Potential fire	1. Simultaneous operations controls will be developed.	
			2. Tie-ins will be provided such that new equipment can be brought on line without requiring a plant shutdown.	

Annex 13A5

Detailed Consideration of all Hazards

CONTENTS

1 DETAILED CONSIDERATION OF ALL HAZARDS

The hazard identification process is a formal review to identify all hazards for the LNG facility. The hazards identified with potential to cause loss of containment can be broadly categorised as:

- Internal and process related hazards;
- Natural hazards;
- External hazards; and
- Intentional acts

Further elaboration of the hazards under each category is included in the following paragraphs.

For all hazards assessed as having a frequency of less than 10^{-9} per year, the frequency assessment will be documented but no quantification of consequences will be performed.

All scenarios with a frequency greater than 10^{-9} per year and potential to cause fatalities have the consequences of the event quantified.

Hazard scenarios are excluded from the consequence assessment if one of the following conditions is satisfied:

- The frequency is below 1×10^{-9} per year.
- The frequency of a particular event is significantly smaller than other causes of failure considered in the generic frequency.
- If the generic failure frequency is judged to include events of such kind, then such events are not assessed separately.
- If there are no consequences. If an event can be shown not to cause a loss of containment then the event is not considered further.

1.1 INTERNAL AND PROCESS RELATED HAZARDS

1.1.1 Internal Hazards of LNG Storage Tanks

Overfilling

The nominal capacity (i.e. usable capacity) of the tank is 180,000 m^3. The design unloading rate is 14,000 m^3/hr and the unloading time is about 18 hours.

Overfilling of the inner tank may lead to overflow into the annular space between the inner tank and the outer tank. The bottom of the annular space is provided with 9% Ni steel up to 5m height. Furthermore leak detectors are provided to detect any LNG leak in the annular space bottom. Therefore, any overfilling event, if it ever occurs, can be detected and shutdown initiated. Also, the secondary containment provided by the outer concrete wall lined with steel will be able to contain this liquid.

There are several layers of safeguards to prevent overfilling:

a) The tank to which the cargo is to be unloaded is identified before the arrival of the carrier, its level measured and the volume of cargo to be unloaded is pre-determined and this information is provided to the carrier. The total volume of cargo unloaded is also continuously monitored during unloading (typically, the volume of available space within the shore tanks is at least equal to the cargo volume to be discharged from the carrier, i.e. ships would not normally be required to unload cargo at multiple destinations);

b) Continuous level measurement on tank using four separate detection systems with at least two different types of level measuring device; pre-alarm at normal maximum level in tank, corresponding to the usable capacity;

c) Level high alarm; this is set typically with 3 to 5 minutes holding volume (between normal maximum level and high level) at design unloading rate;

d) High high level initiates trip of shutdown valves in liquid inlet including transfer piping from jetty and re-circulation lines (the trip is initiated by a 2 out of 3 voting of separate level measuring devices of different type). This will stop further inflow of liquid into the tank. High high level trip is typically set with about 3 to 5 minutes holding volume (between high level alarm and high high level trip). The safety integrity level (SIL) of the high high level trip of liquid inlet will be determined during detailed design, however, SIL 2 classification is typical for this instrumented protective system which means that the probability of failure on demand will be less than less than 0.01;

e) There is further holding volume of about 10 to 15 minutes at design unloading rate between the high high trip level and the inner suspended deck level before liquid can overflow through the suspended deck to the annular space (it may be noted that the actual height/volume between normal maximum level and the overflow level is determined based on sloshing height for the safe shutdown earthquake event; typical values are indicated above).

Based on the above, it can be seen that there is sufficient time (more than 10 minutes) for operator intervention in addition to the provision of high integrity instrumented protective system (i.e. high high level trip).

Rollover

Stratification, i.e. formation of two distinct layers of different density may occur in an LNG tank due to filling of cargo of different density than the liquid already in the tank or due to preferential boil-off in the tank resulting in a layer of more dense liquid at the top (due to evaporation of lighter components) as compared to the lower layers (where the boil-off is suppressed by the hydrostatic head but the liquid superheats due to heat ingress and becomes warmer and less dense) [1]. Stratification may also occur due to presence of sufficient nitrogen in LNG, typically more than 1%. Preferential boil-off of N_2 results in a layer of less dense liquid at the surface.

The phenomenon of rollover occurs when the interface between the layers becomes unstable, leading to rapid mixing of contents of the two layers. As the superheated liquid from the lower layer rises to the surface, it gives off large amounts of vapour leading to potential overpressure of the tank.

There are a number of safeguards to detect and prevent stratification. These include:

a) Temperature and density gradient measurement along the tank liquid column;

b) Provision for circulation of tank contents through the operation of in-tank pump. Content from tank bottom is recirculated to the top, thus releasing any superheat and promote mixing;

c) Provision for filling of tank from the top or from the bottom depending on the relative density of cargo and the tank contents;

d) Regular sampling and analysis of boil-off gas including monitoring of boil-off gas quantity.

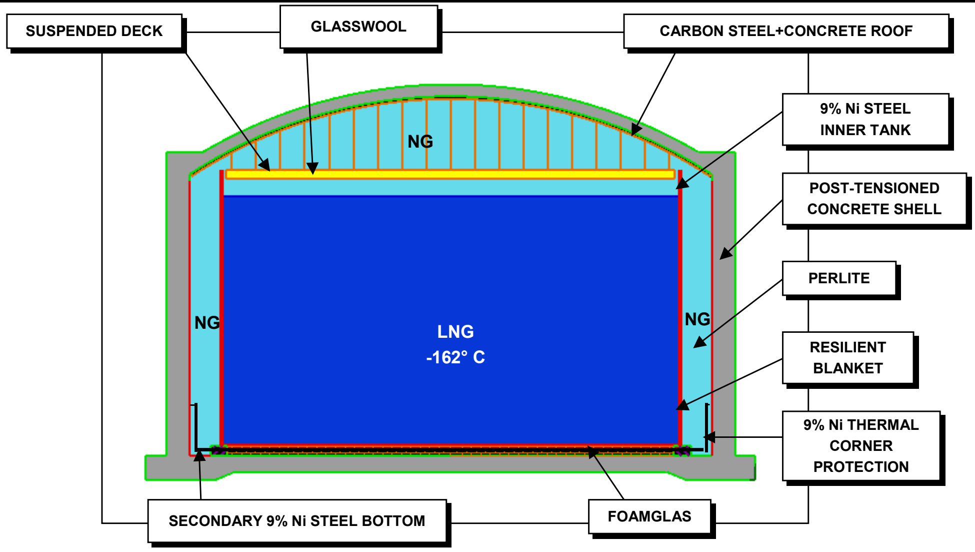
The tank is also protected by relief valves in the event of de-stratification leading to vapour generation. Relief valves are sized for rollover case as per EN 1473 requirements.

Inner Tank Leak

A sketch of a typical full containment tank is shown in *Figure 1.1*.

The main features of a full containment tank are that the liquid LNG is fully contained within a self-supporting inner 9% Nickel steel, surrounded by loose perlite insulation while the vapour is contained within a surrounding concrete outer tank (which includes the slab, the wall and the dome, all constructed of pre-stressed concrete). The concrete outer tank serves as secondary containment and is also capable of containing the liquid and of controlled venting of the vapour resulting from leakage of the inner tank, should one occur.

Figure 1.1 *Typical Structure of an LNG Storage Tank*



A 9% Ni steel plate is provided as liner along the inner surface of the outer shell at the bottom up to a height of typically 5m from the base. This protects the lower wall section of the outer tank, mainly the wall to base slab connection in the event of leakage.

A carbon steel plate lining is provided along the inner surface of the outer shell and roof (above the bottom Ni plate liner) to act as vapour barrier (i.e. to prevent vapour leakage through the concrete as well as to prevent moisture ingress from the outside).

The suspended deck is constructed of aluminium plates and is supported by suspension rods of stainless steel from the outer tank. Openings are provided on the suspended deck for vapour communication between the inner tank and the outer tank so as to ensure equilibrium of gas pressure on both sides. Insulation is provided over the deck to minimise heat leak from the outer shell to the liquid surface.

There are no penetrations through the outer wall or the inner tank shell. All piping to the inner tank is routed through the tank roof.

The tank will be constructed in accordance with BS 7777 [2].

For the capacity of tanks considered for this project, the concrete outer shell is typically about 0.8m thick and can withstand impact loading from projectiles.

In the case of a slab on the ground, installing an electrical heating system in the concrete base slab prevents the freezing of the base slab and the frost heave propagation in the ground beneath the foundation. Heating system control and monitoring is provided.

There are a number of design features to virtually eliminate any leakage from the full containment tank to the atmosphere:

a) Because all piping is routed through the tank roof, there are no through penetrations in the outer shell or the inner tank. Therefore the potential for any connection failure leading to complete loss of tank inventory is eliminated;

b) Outer tank (of pre-stressed concrete) is designed to hold the cold LNG liquid;

c) Inner tank is constructed of low carbon 9% Nickel alloy steel which is heat treated. The plate thickness varies from about 10mm at the top to about 30mm to 40mm thick at the bottom. The material remains ductile and crack resistant at cryogenic temperatures and is also of high strength and toughness. This material is not subject to brittle failure when exposed to cold temperature.

d) Tests performed on 9% Ni steel plates and welded assemblies show good performance against fatigue [3];

e) In the event of any leakage from the inner tank due to crack in the weld or other defect, the leakage rate will remain small. The liquid will be contained in the annular space. Leak detectors in the form of thermocouples are provided along the annular space to detect leakage. Operator intervention is possible to empty the tank contents and isolate the tank for inspection and repair. Liquid leakage into the annular space is likely to result in additional vapour generation due to contact with warmer surfaces including the perlite insulation. The relief valves sized for the rollover case will be able to handle vapours resulting from liquid leakage into the annular space in the event of a crack on the inner tank;

f) A 5m high 9% Ni plate at the lower wall section of the outer tank prevents any damage to the base slab to wall connection due to liquid leakage.

The engineering, construction, commissioning, and operation procedures for the inner tank have been developed to ensure the highest level of safety and reliability of the tank systems. For example, there are stringent QA/QC procedures specified for material qualification and welding qualification, material tracing and stamping, staggered vertical welds in construction, commissioning check, etc. Such measures and procedures when executed by highly experienced and competent contractors would virtually eliminate the occurrence of gross human errors in material specification and qualifications.

The long term LNG operation experience has demonstrated that there has been no reported loss of containment incidents involving full containment tanks.

It is also noted here that the full containment tank design offers significant improvements over single containment and double containment tank designs which have been prevalent earlier. More than 70 to 80% of the aboveground tanks currently in service are either single containment or double containment tanks.

Overpressure

The LNG tank is normally operated between 50 to 250mbarg. The tank is designed for a maximum pressure of 290mbarg.

Overpressure in tank may be caused by several factors:

a) Normal boil-off due to heat leak from ambient;

b) Vapour displacement during filling operation;

c) Variation in atmospheric pressure (i.e. drop in atmospheric pressure);

d) Flashing of incoming liquid if it is at a higher temperature than the bubble point of liquid at tank pressure.

Overpressure can result in failure of the tank secondary containment. However, there are a number of safeguards provided against overpressure:

a) Normal boil-off vapours from the tank is routed to a boil-off compressor where the vapour is compressed and sent for re-liquefaction in the recondenser using the cold liquid pump-out from the tank;

b) Vapour generated due to displacement during tank filling is returned to the ship through a blower (to provide the required head for transfer) or compressed by a separate high pressure compressor and routed to the sendout gas header;

c) The tank pressure is continuously monitored by two sets of pressure measurements;

d) A pressure control valve is provided on the tank to route all the excess tank vapours to a vent stack. The vent stack height and tip will be determined such that vapours discharged will disperse safely or if ignited, the radiation on the equipment and buildings adjoining the stack are within permissible limits as per EN 1473. The pressure control valve relieving to stack is typically designed for all overpressure cases under normal operations (the maximum case is typically the ship unloading case);

e) An independent high high pressure trip is provided which will initiate shutdown of unloading operations (to stop liquid inflow);

f) Relief valves are provided on the tanks which are sized for all the cases of overpressure. The maximum case is typically the ship unloading case for normal operations. The governing case for relief valve is however, the rollover case, which is an emergency case. The relief valve discharge is routed to the stack.

Underpressure

The LNG tank is normally operated between 50 to 250mbarg. The tank is designed for a minimum pressure of typically -5mbarg.

Underpressure may be caused by several factors:

a) Pump-out of liquid;

b) Increased compressor suction due to control malfunction;

c) Variation in atmospheric pressure (i.e. rise in atmospheric pressure).

Under normal operating conditions, the boil-off generated due to heat leak is sufficient to prevent under pressure condition. Underpressure or vacuum conditions below –5mbarg due to control malfunction can cause failure of the tank containment. The tank bottom may be sensitive to vacuum and could get lifted upwards.

There are a number of safeguards in place:

a) Continuous monitoring of tank pressure by two sets of pressure measurement;

b) Low pressure alarm;

c) Low-low pressure will trip the boil-off gas compressors and in-tank pumps and thus prevent further fall in tank pressure;

d) Pressure control valve provided to inject external gas from the sendout gas header into the tank;

e) Vacuum relief valves are provided which are typically sized for maximum vapour flow arising from compressors and pumps in operation. The operation of vacuum relief will lead to air-ingress into the tank and thereby avoid collapse of the tank. The operation of vacuum relief is envisaged as a measure of last resort.

1.1.2 Other Tank Related Hazards

Failure of Foundation/Ice Heave

Ice heave could occur in the event of a failure of the base slab heating system over a long period. This may lead to a crack in the base slab leading to failure of the tank base.

The base slab heating is controlled by temperature sensors. Furthermore redundant heaters with automatic switchover and redundant power supply source are provided. Provision is also made to replace the heaters if required while the tank is in service. Even if the heaters were to fail, it will be long time before the ground would freeze leading to potential failure due to ice heave. Operator intervention is possible.

Material Defect/Structural Defect/Construction Defect

Material defect may occur due to wrong materials being used in tank construction. Construction defect may result in poor welding. Structural failure of the concrete outer tank may occur, again due to poor construction or design.

In all of the above cases, quality control procedures including testing requirements during the design and construction and monitoring during operation are the main means to mitigate the hazard.

The design code EN 1473 [4] outlines a number of procedures including the following:

a) Monitoring of concrete, every quarter of the concrete wall or every 5,000m^3 of concrete;

b) Testing of concrete outer wall by air pressure up to 125% of design;

c) Hydrostatic test of the inner tank.

Additional precautions against failure at low temperature include gradual cooling of the tank at a rate of 50°C/hr and gradual introduction of liquid with sufficient waiting period at different levels to monitor any leakage.

Maintenance of In-Tank Pump/Dropped Object

In-tank pumps are provided to pump-out liquid from the tank. This eliminates the need for nozzle penetrations through the tank shell. Maintenance of the in-tank pump will require the lifting of the pump from the tank bottom through the pump well to the tank roof. It is then carried from the tank roof to the ground level for transport to the maintenance workshop. The removal of the pump is undertaken while the tank is in service. The liquid in the pump well is displaced by nitrogen and the pump is then lifted from its position at which point the foot valve (at the bottom of the well, which normally remains in open position due to the weight of the pump) gets closed. This prevents liquid entry into the pump well during the lifting operation.

The main hazard during this operation arises from accidental drop of the pump (which weights about 2 tonnes) due to failure of the sling. This may cause damage to the inner tank base plate leading to potential leakage from the inner tank. It is unlikely to cause damage to the concrete base. This hazard can be mitigated by appropriate lifting procedures, including the use of dual hoist. Any leakage from the inner tank will be contained by the outer tank.

1.1.3 *Tank Failure Frequency*

The usual approach to estimating failure frequencies is to use historical databases of failures of similar facilities. However, there have been no failures of full containment LNG storage tanks to date. Also, the experience is limited to about 5000 tank-years. The available data are therefore insufficient to make statistical estimates of the failure frequencies. The approach in the literature has been to base an assessment on more generic data such as that from single containment tanks and then apply reduction factors and expert judgement to take credit for the additional protection offered by a full containment tank. The Purple Book [5] takes such an approach to derive a frequency for catastrophic release from a full containment tank as 1×10^{-8} per tank-year.

Other studies [6-12] into the failure frequency of single and double containment tanks provide numbers similar to the Purple Book. From these studies it becomes clear that the generic frequency data for 'catastrophic' failures, on which the Purple Book analysis is based, includes any failure exceeding the 'large leak' definition, which is about a 50mm hole. The catastrophic failure frequency of 10^{-8} per tank-year for full containment tanks should therefore be interpreted as inclusive of not only complete instantaneous tank failures but also large leaks.

This is consistent with comments in the Purple Book to the effect that all catastrophic ruptures leading to a release to the atmosphere are partly (50%) modelled as instantaneous release and partly (50%) as a continuous release within 10 minutes.

Based on this, a failure frequency of 1×10^{-8} per tank-year was adopted in the current study. The terminal may eventually have 3 LNG storage tanks and so the failure frequency was taken to be 3×10^{-8} per year.

This failure frequency includes all the causes discussed above, namely embrittlement, overfilling, rollover, overpressure, underpressure, ice heave, material/construction defects and maintenance hazards. It is also common practice [13] to take this frequency as inclusive of natural hazards since the generic failure frequencies calculated in the literature include failures caused by natural events such as earthquakes etc.

1.1.4 *Internal and Process Hazards for Piping and Equipment*

The failure rate of the process areas and piping are well documented and the values used are given in *Annex 13A6*.

1.2 NATURAL HAZARDS

1.2.1 *Seismic Hazard*

GEO studies conducted in the last decades indicate that Hong Kong SAR is a region of low seismicity (e.g., GCO, 1991 [14]; GEO, 2002-2004 [15]). The seismicity in the vicinity of Hong Kong is considered similar to that of areas of Central Europe and the Eastern areas of the USA [16].

For this project, the full containment LNG tanks will be designed per the European Standard EN 1473 (1997) [4] and British Standard BS 7777(1993) [2]. These documents specifically exclude catastrophic failure of full containment tanks designed, fabricated, erected, inspected, and tested in accordance with the requirements contained in the codes. EN 1473 lists scenarios to be considered in the required Quantitative Risk Assessment (QRA) and states that "no collapse is considered for these tank types".

In terms of seismic risk category, LNG facilities are "essential/hazardous facilities", rather than "safety critical facilities" such as nuclear related structures. Hazardous facilities are those that contain large quantities of hazardous materials, but the release of those materials would be contained within the boundaries of the facilities and the impact to the public would be minimal.

For seismic design in the LNG industry, a two-tier design approach is stipulated, within the same framework of the risk category seismic design philosophy used for nuclear facilities [17]. The Operating Basis Earthquake (OBE) is the maximum earthquake for which the structure sustains no permanent damage and restart and safe operation can resume after the earthquake. The OBE event has a return period of 475 years. The Safe Shutdown Earthquake (SSE) is the maximum earthquake for which the structures may sustain some permanent damage, but there is no loss of overall structural integrity and containment of contents. The SSE event has a return period of 10,000 years, which is the same as that stipulated for the highest class nuclear facilities (Class 5). In addition, the prescribed seismic design criteria for LNG tanks includes a load case for an event less frequent than the SSE basis failing the inner tank followed by an operating basis earthquake (OBE) aftershock acting on the outer tank. The potential failure of the tank due to this event is not expected to occur in Hong Kong based on the analysis below.

The full containment LNG tanks for this project will be founded on competent rock or densely piled foundation. Studies conducted by LNG tank manufacturers and constructors (e.g., Technigaz, 2003 [18]) have demonstrated that the full containment tank of similar capacity to that proposed for this project and designed by following EN 1473 and BS 7777 standards has the capacity to maintain its structural and containment integrity for seismic design motions as stipulated in Eurocode 8 [19] having up to 2.6g of peak ground acceleration (PGA) for a rock site. This level of design earthquake motions on the bed rock far exceeds the worst earthquake event ever recorded on a rock outcrop site anywhere in the world. The SSE having a return period of 10,000 years corresponds to PGA of about 0.5g based on latest seismic hazard studies conducted for Hong Kong.

It is noted that a review of the earthquake resistance of LNG tanks to seismic demand was carried out in Japan by a national examination committee following a powerful earthquake with a PGA of 0.8g in southern Hyogo prefecture in 1995 [20]. The review concluded that the currently implemented standards are sufficient to maintain structural integrity of LNG tanks and prevent gas leaks even in an extremely rare and powerful earthquake. Note that an earthquake with a PGA of 0.8g is well within the seismic design capacity for the LNG tanks in this project which will be built to EN 1473 and BS 7777.

In consideration of the seismic design requirements and the capacity and reliability of LNG tanks to resist seismic demand, it is concluded that the proposed full-containment LNG tanks will maintain structural integrity in the Hong Kong environmental.

1.2.2 *Subsidence*

Excessive subsidence or differential settlement of ground may lead to failure of the structures and ultimately potential loss of containment. This hazard is relevant to facilities built on reclamation land or poor ground without proper treatment or proper foundation design. For the South Soko terminal, the original two tanks will be founded on competent rock and hence excessive site subsidence or differential settlement is not expected. The future phase third tank will be built on densely piled foundation founded on the bed rock in the reclaimed area. Such foundation design prevents the occurrence of excessive site subsidence or differential settlement.

Most processing facilities at South Soko will be constructed on competent rock. For reclaimed locations, the pile foundation design will also be adopted to prevent any impact of subsidence or settlement on the equipment and piping.

Based on the above, the foundation design and piping system design address the potential hazard of excessive subsidence and differential settlement of foundation. There is therefore no basis to presume that the facility will be more prone to subsidence than other facilities in the world and hence the generic failure frequencies will cover scenarios involving subsidence.

1.2.3 *Lightning*

Lightning strike can ignite flammable vapour discharges from vents and stacks. Lightning strike has been the one of the causes of petroleum tank fires. However, this is applicable to cone roof tanks and floating roof tanks. In the case of cone roof tanks, the tank vent is in direct communication with the atmosphere. Breath-in and breath-out occurs during withdrawal of liquid from tank and during filling respectively. Vapours in flammable concentration may be generated which upon ignition at the vent tip due to lightning strike can flashback to the liquid inside (flame arrestor provided at the vent prevents such flame flashback). In the case of floating roof tanks, vapours generated due to seal leaks may get ignited.

The above scenarios are not applicable to an LNG tank, which is a dome roof tank and is maintained under pressure of about 50 to 250mbarg. A lightning strike would have no impact on an LNG tank.

1.2.4 Landslides

At the site there is up to 10m of colluvium and weathered rock material over competent rock. The colluvium is up to 2m thick and there are also occasional large boulders.

The excavations made to create the tank platforms will give rise to soil slopes at the upper part with a steeper rock slope below. Any boulders above these slopes will either be removed or secured to the slopes. The soil slopes created by the excavation will be secured by way of soil nails in accordance with Hong Kong standard practice. The existing natural soil slopes above these cut slopes will also be treated and stabilised. The rock slopes will be regularly inspected during excavation and any possible rock failure mode prevented by a combination of drainage measures and mechanical securing by dowels and rock mash as required.

Failure of the soil slopes will have no impact on the LNG storage tanks. The external concrete tank construction can readily withstand the impact of a soil flow material without any compromise to the containment function of the tank.

The risk of failure of the underlying rock slopes is negligible. Rock slopes are at their most dangerous during construction. This is because the exact nature of the state of the rock strength and fissure patterns cannot be discerned with confidence until after the excavation is completed. During the excavation however the rock can be logged and fracture planes readily identified and any possible failure mode treated by mechanical support. The possibility of future adverse water conditions within the rock will also be controlled by drainage measures installed during excavation. The degradation of the rock surface with time is extremely slow and therefore this method of construction effectively guarantees that the rock slope will be permanently stable.

1.2.5 Hill Fires

Hill fires are a fairly common phenomenon in Hong Kong, particularly in the dry season and are generally associated with fires lit accidentally by hikers or activities associated with the Chung Yeung Festival. The South Soko site is situated on a small remote island and so there is no possibility of accidental fires from such activities. The frequency of hill fires is likely to be low on South Soko compared to other regions in Hong Kong.

The terminal will have onsite landscape management to avoid the presence of combustible vegetation near the LNG storage tanks and process areas. This will prevent offsite hill fires from spreading to onsite areas. A study by Giribone [3] shows that the stability of the concrete storage tanks is not jeopardised by a fire scenario with an incident heat flux of 50kW/m^2 (which is higher than the maximum allowable flux of 32 kW/m^2 as per the design code EN 1473) over a period of 8 hours. There is no conceivable mechanism for a hill fire to produce such radiation fluxes given the lack of vegetation near the tanks and process areas.

1.2.6 *Storm Surges and Flooding*

If the LNG storage tanks or piping become submerged under water, it is possible for buoyancy forces to lift the pipes/tanks, causing damage and possible loss of containment.

Flooding from heavy rainfall is not possible due to the coastal location of the 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 unless channelling effects from the coastline exasperate the surge. South Soko's location to the south of Lantau Island will not create such channelling.

The terminal facilities, with the storage tanks located 6m above sea level and process areas 10, above sea level, are therefore protected against any risk from storm surges, waves and other causes of flooding.

1.2.7 *Tsunami*

Similar to storm surges, the main hazard from tsunamis is the rise in sea level and possible floatation of piping and tanks. The highest rise in sea level ever recorded in Hong Kong due to a tsunami was 0.3m high [28], 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. With tanks and equipment positioned 6-10m above sea level, the effect of a tsunami on the terminal is 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, and also the presence of the Philippine Islands and Taiwan which act as an effective barrier against seismic activity in the Pacific [29]. 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. The Design Basis Report [23] considered the effects of tsunamis and demonstrated that a massive earthquake off the coast of the Philippines may produce a tsunami height in Hong Kong of up to 2.5m. Even when combined with extremes in tide level, the sea level at South Soko was shown not to exceed 5 mPD.

The terminal has been designed with due consideration of sea levels, tsunamis, waves and even rising sea levels from global warming. Being located 6-10 mPD, the terminal is protected against all causes of flooding.

1.2.8 *Summary of Natural Hazards*

The terminal site and design of the facility are such that there will be no special risks from natural hazards. Natural hazards are therefore not treated separately in the analysis but are included in the generic failure frequencies (*Annex 13A6*).

1.3 EXTERNAL HAZARDS

1.3.1 *Aircraft Crash*

The South Soko site does not lie within the flight path of Chek Lap Kok (*Figure 1.2)*. Based on these figures, it is seen that the South Soko site is about 14km from the departure flight path and 5km from the downwind leg of the arrival flight path.

Figure 1.2 Flight Paths at Hong Kong International Airport

The frequency of aircraft crash was estimated using the methodology of the HSE [21]. 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 1.3*). The crash frequency per unit ground area (per km^2) is calculated as:

$$g(x,y) = NRF(x,y) \qquad (1)$$

Where N is the number of runway movements per year and 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

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

for $x > -3.275$ km

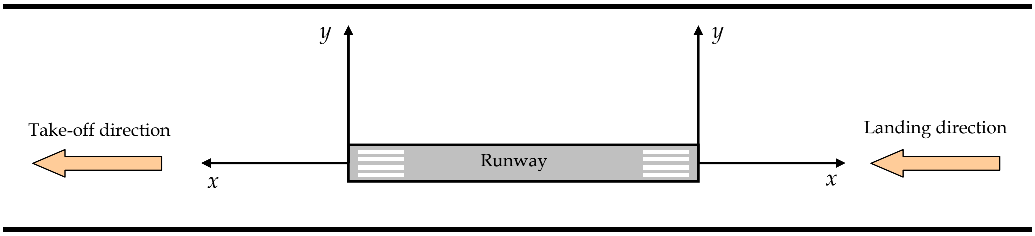
Take-off

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

for $x > -0.6$ km

Equations 2 and *3* are valid only for the specified range of x values. If x lies outside this range, the impact probability is zero.

Figure 1.3 *Aircraft Crash Coordinate System*



NTSB data [22] for fatal accidents in the U.S. involving scheduled airline flights during the period 1986-2005 are given in *Table 1.1*. The 10-year moving average suggests a downward trend with recent years showing a rate of about 2 x 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 [23]. The accident frequency for the approach to landings hence becomes 2.7 x 10^{-8} per flight and for take-off/climb 4.0x10^{-8} per flight. The number of flights at Chep Lap Kok for year 2011 is conservatively estimated at 394,000 (a 50% increase over 2005).

Table 1.1 ***U.S Scheduled Airline Accident Rate [22]***

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	0.2	0.215
2004	0.09	0.173
2005	0.27	0.188

Considering landings on runway 07R for example, the values for *x* and *y* according to *Figure 1.3* are 3.2 and 13.8km respectively. Applying *Equation 2* gives $F_L = 1.7 \times 10^{-5}$ km^{-2}. Substituting this into *Equation 1* gives:

$$g(x, y) = NRF(x, y) = \frac{394{,}000}{8} \times 2.7 \times 10^{-8} \times 1.7 \times 10^{-5} = 2.26 \times 10^{-8} \text{ /year/km}^2$$

The number of plane movements has been divided by 8 to take into account that half of movements are take-offs and only a quarter of landings use runway 07R. 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 15,000m² or 0.015km² (3 tanks of 80m diameter). This gives a frequency for crashes into the tanks associated with landings on runway 07R as 3.4 x 10^{-10} per year. Repeating the calculation for landings and take-offs from all runways gives the results shown in *Table 1.2*.

Table 1.2 Aircraft Crash Frequency onto South Soko LNG Tanks

Runway	Landing (per year)	Take-off (per year)
07R	3.5 x 10^{-10}	0
07L	2.6 x 10^{-10}	0
25L	0	2.6 x 10^{-13}
25R	0	5.7 x 10^{-14}
Total	6.1 x 10^{-10}	3.2 x 10^{-13}

The combined frequency of all take-off and landing crashes onto the LNG tanks from activities on all runways is less than 1 x 10^{-9} per year. The hills on Lantau Island also lie between the airport and South Soko and will provide protection reducing the frequency even further. Aircraft crash is therefore neglected from the analysis. Since the area of the process units is smaller than the tank area, crashes into process areas will be even less likely and are neglected from the analysis.

1.3.2 Helicopter Crash

Helipad Activity

The South Soko site will be 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 facility were assessed.

Data from offshore helicopter activities [24] gives a helipad related helicopter crash frequency of 2.9 x 10^{-6} per flight stage (i.e. per take-off and landing). However, most of these incidents are minor such as heavy landings. For a helicopter incident to damage the facility, it must be a serious, uncontrolled impact. Only accidents involving fatalities were therefore considered in the analysis. 4% of incidents resulted in one or more fatalities and so the frequency of uncontrolled crashes was calculated as 2.9 x 10^{-6} x 0.04 = 1.2 x 10^{-7} per flight stage. For one flight per week using the helipad, the annual crash frequency becomes 1.2 x 10^{-7} x 52 = 6.0 x 10^{-6} /year.

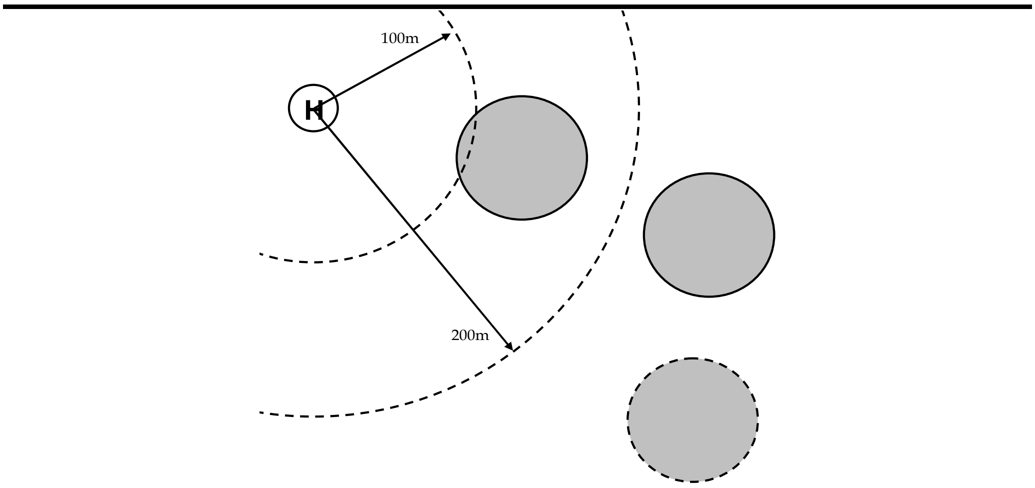
Helicopter accidents during take-off and landing are confined to a small area around the helipad [21]. 93% of accidents occur within 100m of the helipad. The remaining 7% occur between 100 and 200m of the helipad. There have been no serious helipad related incidents resulting in a crash beyond 200m of the helipad.

The distance of the South Soko helipad from the centreline of the nearest LNG storage tank is approximately 130m. This places the storage tank in the 100 to 200m range (*Figure 1.4*) from the helipad and so only 7% of incidents have the potential to reach a storage tank. Assuming that a crash is equally likely to occur in any direction from the helipad, the probability of hitting the nearest tank given an accident can be estimated from the ratio of areas:

$$Prob.\ of\ \ tank\ \ impact = 0.07 \times \frac{\pi r^2}{\pi\left(200^2 - 100^2\right)} = 0.0037 \qquad (4)$$

where r is the LNG storage tank radius, assumed to be 40m. Combining this with the accident frequency of 6.0 x 10^{-6} /year gives the frequency of a helicopter crashing into the nearest storage tank = 2.2 x 10^{-8} /year.

Figure 1.4 ***Position of Helipad Relative to Storage Tanks***

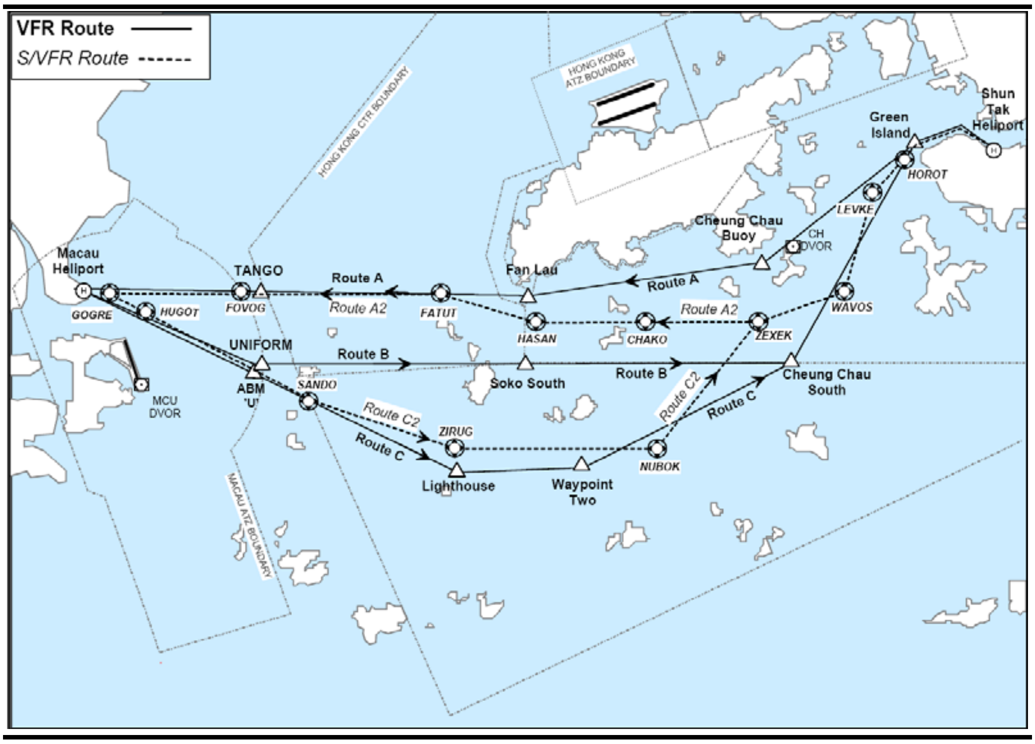


The other LNG storage tanks and process areas lie beyond the 200m radius and hence will not be exposed to any increased risk from helicopter activity at the helipad.

Passing Helicopters

Although take-off and landings present the greatest portion of risk from a flight, South Soko lies close to the flight path for helicopter shuttles plying between Hong Kong and Macau [25] (*Figure 1.5*).

Figure 1.5 *Macau Helicopter Flight Paths*



The CMPT Reports [24] gives a frequency of in-flight accidents of 1.2×10^{-5} per flying hour. However, only 17% of these are severe enough to cause a fatality. Assuming, as before, that incidents involving fatalities are a reasonable measure of uncontrolled crashes that may impact a facility, then the frequency becomes 2.0×10^{-6} per flying hour.

The helicopters shuttling between Hong Kong and Macau are Sikorsky S76C models [26] with a cruising speed of 254 km/h. They complete the ~67km journey in 15-20 minutes. The frequency of crashes on a per kilometre basis may be calculated:

$$\textit{Frequency of uncontrolled crashes} = \frac{2.0 \times 10^{-6}}{254} = 7.9 \times 10^{-9} \quad /\text{km}$$

There are several routes indicated in *Figure 1.5*, depending on the weather and flight direction either to or from Macau. For the purpose of analysis, it was assumed that a helicopter is equally likely to crash anywhere in the area bounded by these flight paths. This area was estimated at 438 km². Based on the flight schedule for the helicopter service provider [26], there are 27 return flights per day. The crash frequency per unit ground area is then calculated from:

$$\textit{Frequency of uncontrolled crashes}$$
$$= \frac{7.9 \times 10^{-9} / km \times 67 km \times 54 \, flights / day \times 365 days}{438 km^2} = 2.4 \times 10^{-5} \, /\text{km}^2/\text{year}$$

The footprint area of 3 LNG storage tanks is approximately 15,000 m^2 or 0.015 km^2. The frequency of a helicopter crashing during the in-flight stage and colliding with an LNG storage tank is therefore 3.6 x 10^{-7} /year. This is an order of magnitude greater than the frequency calculated for helipad related incidents because of the much higher traffic volume of passing helicopters.

Similarly, the footprint area of the process areas was estimated at 10,900m^2, giving a frequency of helicopter impact of 2.6 x 10^{-7} /year.

The South Soko Island consists of two hills with the proposed terminal nestled at the saddle point. The terrain will offer some protection in that a helicopter is more likely to strike the hills than the terminal itself. The above frequency should therefore be regarded as conservative.

The frequency of helicopter crashes into the process area is small compared to the frequency of internal and process related failures. As an example, the vaporisers occupy an area of approximately 6000m^2. A crash into the vaporiser area would have a frequency of 1.4 x 10^{-7} per year based on the above calculations. This would undoubtedly cause damage; however, the generic failure frequency of all vaporisers combined is 8.5 x 10^{-5} per year. The additional hazard from helicopter activities is almost 3 orders of magnitude smaller and may be neglected with negligible difference in the risk calculations. Hazards from helicopters are therefore not treated separately but are covered by the generic failure frequency.

Consequence of Helicopter Impact

There have been several studies related to the possible impacts of aircraft collisions with hazardous facilities such as nuclear power stations. A study by the Nuclear Energy Institute [27] investigated the damage that could be caused by a fully loaded wide-bodied Boeing 767 crashing at 350 mph (560 km/h) into a nuclear reactor containment structure. These containment buildings are cylindrical shaped buildings with a dome roof, typically 140 feet high and 140 feet diameter. They are made of pre-stressed concrete with wall thicknesses from 3.5 to 4.5 feet. This is very similar to the construction of LNG storage tanks, which have a concrete wall of about 0.8m thickness. The conclusions of the report were that the concrete containment would not fail from such an impact.

In another study [13], the consequence of a Boeing 767 commercial aircraft crashing into an LNG storage tank was specifically assessed. It was concluded that aircraft are constructed from mostly soft materials and only the core of the engines is capable of penetrating an LNG full containment tank. Further, the engine would need to impact at near perpendicular incidence otherwise the engine will simply deflect off the tank.

These studies demonstrate the structural strength of the LNG storage tanks. They are designed to withstand major impacts. Naturally, a helicopter crash is very different from a 200 tonne airliner travelling at 560 km/h. Most helicopter crashes have an impact velocity below 50 m/s [21]. A fully loaded 5-tonne Sikorsky S76C with an impact velocity of 50 m/s would have a kinetic energy 390 times less than the Boeing 767 analysed by the Nuclear Energy Institute. It is concluded that a helicopter crash will not cause a failure of the LNG storage tanks.

Summary

Helicopter crashes into the LNG storage tanks have a small but quantifiable frequency, although the impact would not cause a failure of the tank. LNG storage tanks are designed to withstand such an impact and other studies in the literature suggest that the tanks could easily cope with a helicopter crash.

A helicopter crash into the process areas or piping (including the piping on the LNG tanks) could cause damage but the frequency of such events is much lower than generic failure frequencies. The additional risk from helicopter activity is negligible. Scenarios involving helicopter activities were therefore not treated separately but are covered by the generic failure frequency.

1.3.3 External Fire and Explosion Hazards

The LNG tank may be exposed to radiation and fire effects as well as explosion overpressure effects including flying debris arising from ignition of flammable gas leak in process units located adjoining an LNG tank or neighbouring facilities. A study by Giribone et al [3] shows that a full containment tank with outer concrete shell (of about 0.8m thick wall and 0.5m thick roof) can withstand fire and flying debris impacts without any damage to the tank containment.

The study by Giribone shows that the stability of the concrete structure is not jeopardised by a fire scenario with an incident heat flux of 50kW/m^2 (which is higher than the maximum allowable flux of 32 kW/m^2 as per the design code EN 1473) over a period of 8 hours. Although through cracks in the concrete structure may occur, the structural integrity of the tank is not compromised.

The study by Giribone also shows that a flying debris of 2000kg in mass (a typical 4" valve weighs no more than 125kg) travelling at 50m/s causes no significant impact on the concrete structure, though cracks may be created by such an impact. The abovementioned studies [13, 29] suggest that the tanks can withstand considerable greater impact.

Based on the above it can be concluded that the outer concrete structure of a full containment tank provides significant resistance against external fire and explosion hazards. Failure of the tank due to such events will not occur. It may be also be noted here that the extent of process equipment and piping is very limited in a receiving terminal, as compared to an export terminal consisting of a liquefaction plant, and the hazards of fire and explosion events with potential to affect the tank is not significant. Hence external fire and explosion hazards causing damage to the tank is considered to be negligible. In any case, the frequency of tank failure considered in *Section 1.1.3* is considered representative of all potential failure modes.

1.4 INTENTIONAL ACTS

A full scope Safeguards and Security Risk Assessment (SSRA) was conducted in Hong Kong for the Project from 24 to 28 April 2006. The SSRA integrated key elements of the Critical Assets Protection (RAMCAP) method under the US Department of Homeland Security Risk Analysis and Management. Safeguards and Security Risk Assessments are conducted to assess the probability and severity of intentional undesired events to develop countermeasure recommendations that mitigate identified risks. The risk assessment was for a 10-year period from April 2006 to April 2016.

Given the sensitive and confidential nature of the analysis and in order to protect public safety, the complete SSRA report is available only on a need to know basis to GOHK and CAPCO security personnel.

The team who prepared the SSRA reviewed the history of terrorist events on LNG terminal facilities and determined that there has never been a terrorist incident at any LNG terminal or LNG carrier that has resulted in a death or injury to a member of the public. The relative risk of a terrorist induced injury or fatality to the public at a Hong Kong terminal was also compared to that for other terminals around the world, including Asia, Europe and the Americas. The qualitative conclusion of the team is that the risk of a terrorist induced incident having any consequence to public health and safety is extremely low.

The Project was benchmarked against other LNG facilities worldwide in the United States, Europe, and the United Kingdom, where similar qualitative security risk assessments have been conducted. These other risk assessment studies were also presented to the local Authorities and their conclusions were similar to the SSRA report prepared for this project.

Based on the benchmarking comparison on the risk of terrorist threats, the Project was assessed to be at a lower security risk threat level than the other LNG terminals, indicating that the Hong Kong sites are much lower in exposure compared to the other site locations.

The conclusion reached by the SSRA team was that based on the overall low threat environment in Hong Kong and the risk analysis of the worst-case scenario of an intentional act in nature, their recommended risk mitigating measures would help to reduce the scenarios associated risk to a level that is well within levels generally accepted by industry globally, for either a Black Point or South Soko Island terminal. It was also concluded that whilst risk of a terrorist act directed at both sites is extremely low, the consequence of a terrorist event on the public would be greater for an incident at a Black Point terminal or against an LNG carrier on portions of the marine transit route to Black Point than for a South Soko terminal or its marine transit.

The SSRA team assessed the consequences that would result from the terrorist induced scenarios evaluated. Based on the available published studies, the team determined that the consequences of these events did not exceed the worst case events evaluated in the Terminal and Marine QRA studies.

1.5 LOW LEVEL RADIOACTIVE WASTE FACILITY

A low level radioactive waste facility (LLRW) has recently been constructed on North Soko Island. The possibility of escalation events, where accident scenarios at the South Soko terminal impact the LLRW resulting in a release of radioactive material to the environment is considered here.

The LLRW facility is embedded into the rock structure of North Soko, about 1.5km from the proposed LNG terminal site on South Soko. The facility contains low level radioactive waste previously stored at the Queen's Road East Tunnel repository, Wanchai. This waste typically consists of radioactive material from hospitals, educational institutes and industry and is stored in metal drums within the repository.

The facility does not contain combustible materials, merely the steel drums placed in a room with concrete walls. A fire detection system is installed to alert regarding a fire incident. The facility also has fire protection systems for extinguishing fires. Material for storage is delivered just twice a year so there is no permanent presence of people in North Soko.

Potential LNG release scenarios from the South Soko LNG terminal that could result in a flammable gas cloud travelling to North Soko, located 1.5km away, were examined. The only scenario that can produce such a large vapour cloud is a failure of one of the LNG storage tanks and this has a frequency of 3×10^{-8} per year (or once in 33 million years).

If such a vapour cloud were then ignited downwind, the resulting fire would flash back to the release source. Since the flame travels through the cloud quickly, the potential to cause secondary fires at the LLRW facility and escalate to the point where it affects the radioactive waste stored there is very low. This is due to the enclosure of the facility in a concrete/rock structure, absence of any combustible materials in the facility design and the provision of a fire protection system at the LLRW facility. Combining the probability of ignition and secondary fires with the very low LNG release frequency of 3×10^{-8} per year will produce an outcome frequency of well below 1×10^{-9} per year. The risks are therefore less than 10^{-9} per year and this scenario was not considered further in the analysis.

1.6 CONCLUSIONS

Based on a detailed review of the various failure modes along with the safeguards provided, the failure frequency of the full containment LNG tank is taken to be 1×10^{-8} per tank-year. This failure frequency encompasses internal and process causes of failure as well as any natural/external hazards.

External hazards to the LNG storage tanks from aircraft were assessed to have a frequency below 1 x 10^{-9} per year. Helicopter crashes have a small but quantifiable frequency but the tanks are designed to withstand such impacts and so there would be no consequences from such an event. Hence, failure of the storage tanks due to helicopter impact was also excluded from the analysis.

Helicopter impacts into the piping and process areas are a possible scenario, but the frequency of occurrence is small compared to process risks. Helicopter crash scenarios are therefore included in the generic frequencies.

Escalation events affecting the radioactive waste facility on North Soko were also demonstrated to have a frequency below the 1 x 10^{-9} per year threshold and are therefore this scenario was not considered further in the analysis.

REFERENCES

[1] Baker, N., Creed, M., Stratification and Rollover in Gas Storage Tanks, Trans IChemE, Vol. 74, Part B, 1996

[2] BS 7777: Flat-bottomed, vertical, cylindrical storage tanks for low temperature service, BSI, UK 1993

[3] Giribone, R., Claude, J., Comparative Safety Assessment of Large LNG Storage Tanks, Eleventh International Conference on LNG, 1995

[4] EN 1473: Installation and Equipment for Liquefied Natural Gas – Design of onshore installations, BSI, UK, 1993

[5] TNO, Guidelines for Quantitative Risk Assessment (The Purple Book), Report CPR 18E, The Netherlands Organisation of Applied Scientific Research, Voorburg, 1999.

[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.

[7] Taylor, J.R., Risk Analysis for Process Plant, Pipelines and Transport, London: Spon, 1994.

[8] E&P Forum, E&P Forum QRA Datasheet Directory, 15 October 1996.

[9] Davies, T., Harding, A.B., McKay, I.P., Robinson, R.G.J., Wilkinson, A., Bund Effectiveness in Preventing Escalation of Tank Farm Fires, Trans IChem E, Vol 74, Part B, May 1996.

[10] Christensen, R.A. and Eilbert, R.F., Aboveground Storage Tank Survey, EL RN-623, Entropy Limited, Lincoln, MA, 1989.

[11] Batstone, R.J. and Tomi, D.T., Hazard Analysis in Planning Industrial Developments, *Loss Prevention*, **13**, 7, 1980.

[12] Canvey: a second report, HSE, 1991.

[13] Hazards Analysis of a Proposed LNG Import Terminal in the Port of Long Beach, California, Quest Consultants Inc., Aug 2005.

[14] GCO, Review of earthquake data for the Hong Kong region, GCO Publication No. 1/91, Civil Engineering Services Dept., Hong Kong Government, 1991

[15] GEO, Seismic hazard analysis of the Hong Kong region, GEO Report No. 65, Geotechnical Engineering Office, Government of the HKSAR, 2002

[16] 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

[17] ASCE/SEI 43-05, Seismic design criteria for structures, systems, and components in nuclear facilities, ASCE, 2005

[18] Personal communication on tank capacity studies with Technigaz, 2003

[19] Eurocode 8: Design of Structures for Earthquake Resistance, European Committee for Standardisation, 1998

[20] Mizuno, T., Wadano, Y., Terada, N., Tsunomura, T., Demonstrative Safety Assessment of LNG Storage Facility Earthquake Resistance and Reinforcement of Crisis Management at LNG Receiving Terminals, Twelfth International Conference on LNG, 1998

[21] Byrne, J. P., The Calculation of Aircraft Crash Risk in the UK, HSE\R150, 1997.

[22] www.ntsb.gov/aviation/Table6.htm

[23] Annual Review of Aircraft Accident Data: U.S. General Aviation, Calendar Year 2001, National Transport Safety Board.

[24] Spouge, J., A guide to Quantitative Risk Assessment for Offshore Installations, CMPT, 1999.

[25] AIP Hong Kong, Aeronautical Information Publication, Part 2, En-route, ENR 3.4 Helicopter Routes, Civil Aviation Department, Hong Kong, Feb 2004.

[26] www.helihongkong.com

[27] Aircraft Crash Impact Analyses Demonstrate Nuclear Power Plant's Structural Strength, Nuclear Energy Institute, Dec 2002.

[28] www.hko.gov.hk

[29] 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.

Annex 13A6

Frequency Analysis

CONTENTS

1 FREQUENCY ANALYSIS

This Annex contains the details of the Frequency Analysis for the QRA study of the terminal.

1.1 FAILURE FREQUENCIES

A detailed discussion on all the hazard scenarios identified was given in *Annex 13A5*. It was concluded that internal process hazards, natural hazards and external impacts are included in the generic failure frequencies. These failure frequencies are summarised in this section.

Table 1.1 lists all the failure frequencies adopted for the various release scenarios. Codes are assigned for various source terms. Refer to *Annex 13A7* for code definitions.

Table 1.1 LNG Release Event Frequencies

Code	No. of Items	Length of Section (m)	Hole Size (mm)	Initiating Event Frequency	Unit	Reference
L01	1	450	10 25 50 100 FB	3.00E-07 3.00E-07 1.00E-07 1.00E-07 5.00E-08	per meter per year	Hawksley [1]
L02	3	20	10 25 50 100 FB	4.05E-03 4.05E-03 4.05E-03 4.05E-04 4.05E-05	per year	COVO Study [2]
L03	2	300	10 25 50 100 FB	1.00E-07 1.00E-07 7.00E-08 7.00E-08 3.00E-08	per meter per year	Hawksley
L04	1	30	10 25 50 100 FB	3.00E-07 3.00E-07 1.00E-07 1.00E-07 5.00E-08	per meter per year	Hawksley
L05	2	900	10 25 50 100 FB	1.00E-07 1.00E-07 7.00E-08 7.00E-08 3.00E-08	per meter per year	Hawksley
L06	1	N/A	10 25 50 100 FB	1.00E-05 5.00E-06 5.00E-06 1.00E-06 1.00E-06	per year	Crossthwaite et al [3]
G07	1	390	10	1.00E-07	per	Hawksley

Code	No. of Items	Length of Section (m)	Hole Size (mm)	Initiating Event Frequency	Unit	Reference
			25 50 100 FB	1.00E-07 7.00E-08 7.00E-08 3.00E-08	meter per year	
G08	1	108	10 25 50 100 FB	1.00E-07 1.00E-07 7.00E-08 7.00E-08 3.00E-08	per meter per year	Hawksley
G09	1	450	10 25 50 100 FB	1.00E-07 1.00E-07 7.00E-08 7.00E-08 3.00E-08	per meter per year	Hawksley
G10	1	24	10 25 50 100 FB	3.00E-07 3.00E-07 1.00E-07 1.00E-07 5.00E-08	per meter per year	Hawksley
G11	1	720	10 25 50 100 FB	3.00E-07 3.00E-07 1.00E-07 1.00E-07 5.00E-08	per meter per year	Hawksley
G12	1	300	10 25 50 100 FB	3.00E-07 3.00E-07 1.00E-07 1.00E-07 5.00E-08	per meter per year	Hawksley
G13	1	150	10 25 50 100 FB	3.00E-07 3.00E-07 1.00E-07 1.00E-07 5.00E-08	per meter per year	Hawksley
G14	1	20	10 25 50 100 FB	4.05E-03 4.05E-03 4.05E-03 4.05E-04 4.05E-05	per year	COVO Study
P15	1	1	10 25 50 100 FB	1.00E-04 1.00E-04 1.00E-04 1.00E-04 1.00E-05	per year	COVO Study
P16	2	1	10 25 50 100 FB	1.00E-04 1.00E-04 1.00E-04 1.00E-04 1.00E-05	per year	COVO Study
P17	5	10	10 25 50 100 FB	3.00E-07 3.00E-07 1.00E-07 1.00E-07 5.00E-08	per meter per year	Hawksley

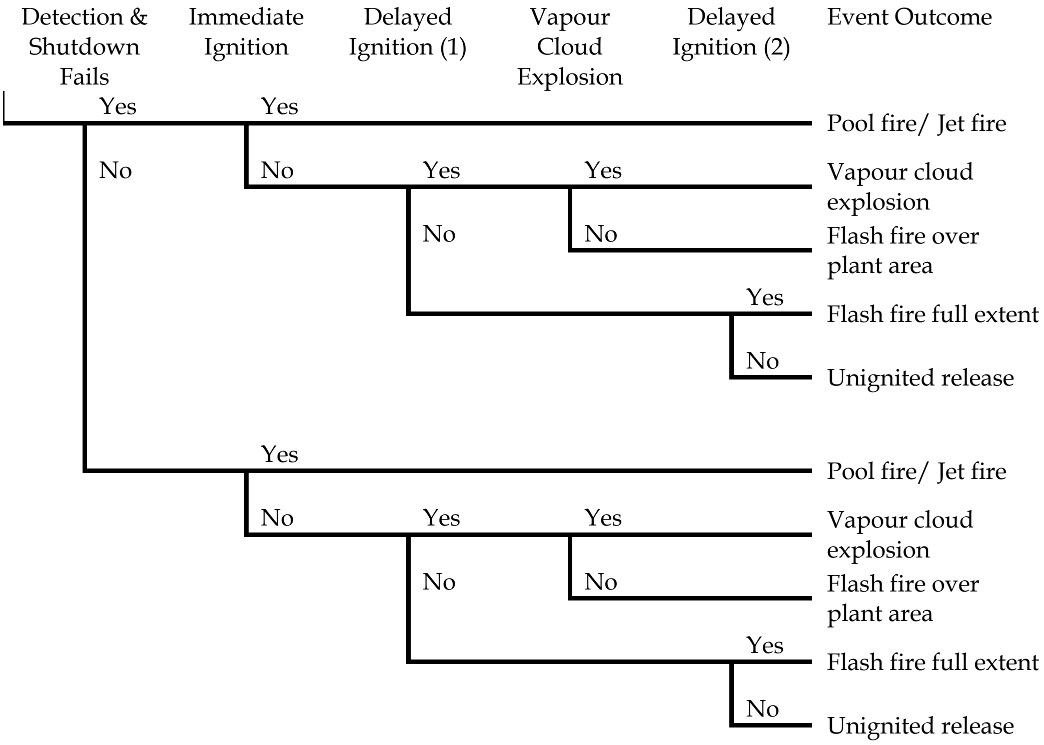
Code	No. of Items	Length of Section (m)	Hole Size (mm)	Initiating Event Frequency	Unit	Reference
P18	5	10	10 25 50 100 FB	3.00E-07 3.00E-07 1.00E-07 1.00E-07 5.00E-08	per meter per year	Hawksley
P19	10	10	10 25 50 100 FB	3.00E-07 3.00E-07 1.00E-07 1.00E-07 5.00E-08	per meter per year	Hawksley
P20	1	150	10 25 50 100 FB	3.00E-07 3.00E-07 1.00E-07 1.00E-07 5.00E-08	per meter per year	Hawksley
P21	1	300	10 25 50 100 FB	1.00E-07 1.00E-07 7.00E-08 7.00E-08 3.00E-08	per meter per year	Hawksley
P22	1	1	10 25 50 100 FB	1.00E-04 1.00E-04 1.00E-04 1.00E-04 1.00E-05	per year	COVO Study
T23	3	N/A	Rupture	1.00E-08	per tank per year	"Purple Book" [4]

1.2 *EVENT TREE ANALYSIS*

The frequency of various outcomes following a loss of containment event is estimated using an event tree model. The various outcomes considered include pool fire, jet fire, flash fire and vapour cloud explosions for liquid releases; jet fire and flash fire for continuous gas releases and fireball and flash fire for instantaneous gas releases. Event Tree Analysis is used to describe and analyse how an initiating event may lead to a number of different outcomes, depending upon such factors as the successful implementation of the various emergency response measures and relevant protective safety systems in place.

A generic event tree used for this study is shown in *Figure 1.1*. The contributing factors taken into account in the event trees are discussed below.

Figure 1.1 *Generic Event Tree*



Detection and Shutdown

For loss of containment events from piping and equipment, it has been assumed that detection and shutdown would occur 90% of the time (based on safety integrity level 1 for emergency shutdown systems which has an associated probability of failure on demand of 0.1).

As discussed in *Annex 13A7* on the consequence analysis, if detection and shutdown is successful, a 2 minute release is assumed based on the Emergency Shutdown Device (ESD) provisions in the design (*Annex 13D*). For shutdown failure, a 10-minute release is assumed. The exception to this is the unloading arms for which 2-minute and 30s releases are considered for isolation failure and isolation successful. The release duration does not have a major influence on the hazard distances determined from dispersion modelling, but slightly different ignition probabilities are assumed for these two cases.

Immediate Ignition

Immediate ignition of an LNG release would result in a pool fire, a jet fire or a fireball (for instantaneous gas releases). For a liquid release under pressure, a jet fire is produced. For a non-momentum liquid release, the liquid is assumed to spill onto the ground producing a pool fire. Gas releases are all pressurised releases and ignition would result in a jet fire. For instantaneous gas releases following a rupture failure, a fire ball is assumed to occur.

In the event of non-ignition, a cloud of natural gas would be formed by the gas release or evaporating liquid pool. A flash fire would occur if this cloud were subsequently ignited.

Delayed Ignition

If immediate ignition does not occur, the dispersing cloud of natural gas may subsequently be ignited. Two delayed ignition scenarios are considered. The first, "delayed ignition 1", takes into account the possibility that ignition could occur within the plant area due to the presence of ignition sources on site. The second, "delayed ignition 2", assumes ignition occurs after the cloud has dispersed to its full (steady state) extent.

Delayed ignition for an LNG storage tank failure was treated a little differently given the much larger scale of the release. Vaporisation from the liquid pool was observed to be highly transient in nature. The liquid pool expands to its maximum extent after several minutes and then begins to shrink again as the LNG pool "dries up". The vapour cloud was observed to expand rapidly with the initial pool expansion. Once vaporisation diminishes, however, a sizable cloud of gas within the flammability limits remains and is convected downwind, gradually shrinking as it goes. Delayed ignition 1 was therefore assigned to the cloud at its maximum footprint area, while delayed ignition 2 was applied to the remnants of the cloud at the maximum downwind extent. Different ignition probabilities were also assigned to LNG tank release (*Section 1.3*).

If delayed ignition does not occur, the vapour cloud disperses with no effect.

Vapour Cloud Explosion

If a delayed ignition occurs within the plant area (delayed ignition 1), the possibility of an explosion occurring within the congested space of the process area is considered.

1.3 IGNITION PROBABILITIES

The overall ignition probabilities used in this study were adapted from the Cox, Lees and Ang model [5] and are summarised in *Table 1.2*.

Table 1.2 Ignition Probabilities from Cox, Lees and Ang Model

Leak size	Ignition probability		Explosion probability given ignition
	Gas release	Liquid release	
Major (1-50 kg/s)	0.07	0.03	0.12
Massive (>50 kg/s)	0.30	0.08	0.3

These ignition probabilities were distributed amongst immediate and delayed ignition. One third of the ignition probability was assumed to be immediate ignition. The remainder was assigned to delayed ignition with about 90% being attributed to delayed ignition 1. The total ignition probabilities assumed in the current study (*Table 1.3*) are therefore similar the values quoted in *Table 1.2* [5]. In *Table 1.3,* 10 and 25mm holes are considered "small leaks", while 50 and 100mm holes are considered "large leaks".

Table 1.3 Ignition Probabilities Assumed

	Immediate Ignition	Delayed Ignition 1	Delayed Ignition 2	Delayed Ignition Probability	Total Ignition Probability
Liquid small leak	0.01	0.035	0.005	0.04	0.05
Liquid large leak/rupture	0.08	0.18	0.02	0.2	0.28
Gas small leak	0.02	0.045	0.005	0.05	0.07
Gas large leak/rupture	0.1	0.2	0.02	0.22	0.32

For isolation failure scenarios, the delayed ignition probabilities given in *Table 1.3* are doubled. The longer duration and larger inventory release from a 10-minute release is assumed to make it more likely that ignition takes place.

LNG Storage Tank Failure Ignition Probabilities

Special consideration was given to the ignition probabilities for LNG storage tank failure scenarios. Given the much larger scale of release for this scenario compared to all others, it is more likely that the vapour cloud will find an ignition source and so it was conservatively assumed that the total ignition probability is 1. The distribution of this probability was made (*Table 1.4*) with consideration of the location of likely ignition sources. Immediate ignition was deemed fairly likely given that ignition sources will be present on site and the fact that the release will affect the whole site. A value of 0.3 was adopted. Delayed ignition 1 is applied to the cloud once it reaches its maximum size. This occurs beyond the plant boundary and because of the lack of population and low marine activity around South Soko, delayed ignition 1 was regarded as less likely and was assigned a value of 0.1. The remaining probability of 0.6 was assigned to delayed ignition 2. Once the vapour cloud is convected a significant distance downwind, it may then find a population centre on neighbouring islands and be ignited. It is likely that there would be other sources such as passing marine traffic for intermediate ignition of the cloud along its travel path, but for conservatism, delayed ignition 2 is applied after the cloud reaches the neighbouring population centres.

Table 1.4 LNG Storage Tank Release Ignition Probabilities

	Ignition Probability
Immediate ignition	0.3
Delayed ignition 1	0.1
Delayed ignition 2	0.6

1.4 OUTCOME FREQUENCIES

A summary of outcome frequencies for all the events considered in the LNG terminal QRA study is listed in *Table 1.5*.

Detail of the nomenclature is as follows:

IS = Isolation Success
IF = Isolation Failure
FF1 = Flash Fire over Plant Area
FF2 = Flash Fire, full extent
PLF = Pool Fire
JTF = Jet Fire
VCE = Vapour Cloud Explosion
FBL = Fire Ball
FB = Full Bore
NE = No Effect

Table 1.5 Outcome Frequencies Summary

Release Event	Release Scenario					
	10mm	25mm	50mm	100mm	IS_FB	IF_FB
L01_FF2	1.42E-10	1.42E-10	1.51E-10	1.51E-10	6.79E-10	7.54E-11
L01_FF1	7.20E-10	7.20E-10	1.16E-09	6.38E-09	5.22E-09	5.80E-10
L01_JTF	6.00E-10	6.00E-10	8.00E-10	8.00E-09		
L01_PLF					3.60E-09	4.00E-10
L01_VCE	3.09E-10	3.09E-10	4.97E-10	2.73E-09	2.24E-09	2.48E-10
L02_FF2	1.93E-06	1.93E-06	1.93E-06	1.93E-07	5.50E-07	6.11E-08
L02_FF1	7.72E-05	7.72E-05	7.72E-05	7.72E-06	6.04E-06	6.71E-07
L02_JTF	4.05E-05	4.05E-05	4.05E-05	4.05E-06		
L02_PLF					2.92E-06	3.24E-07
L03_FF2	4.78E-11	4.78E-11	1.06E-10	1.06E-10	4.07E-10	4.53E-11
L03_FF1	3.47E-10	3.47E-10	1.16E-09	6.38E-09	4.47E-09	4.97E-10
L03_JTF	1.00E-10	1.00E-10	5.60E-10	5.60E-09		
L03_PLF					2.16E-09	2.40E-10
L04_FF2	1.42E-10	1.42E-10	1.51E-10	1.51E-10	6.79E-10	7.54E-11
L04_FF1	7.20E-10	7.20E-10	1.16E-09	6.38E-09	5.22E-09	5.80E-10
L04_JTF	6.00E-10	6.00E-10	8.00E-10			
L04_PLF				8.00E-09	3.60E-09	4.00E-10
L04_VCE	3.09E-10	3.09E-10	4.97E-10	2.73E-09	2.24E-09	2.48E-10
L05_FF2	4.78E-11	4.78E-11	1.06E-10	1.06E-10	4.07E-10	4.53E-11
L05_FF1	3.47E-10	3.47E-10	1.16E-09	6.38E-09	4.47E-09	4.97E-10
L05_JTF	1.00E-10	1.00E-10	5.60E-10	5.60E-09		
L05_PLF					2.16E-09	2.40E-10
L06_FF2	4.78E-09	4.78E-09	7.54E-09	7.54E-09	1.36E-08	1.51E-09
L06_FF1	1.33E-07	1.33E-07	3.19E-07	3.19E-07	1.04E-07	1.16E-08
L06_JTF	1.00E-07	1.00E-07	4.00E-07	4.00E-07		
L06_PLF					7.20E-08	8.00E-09
L06_VCE	5.72E-08	5.72E-08	1.37E-07	1.37E-07	4.47E-08	4.97E-09
G07_FF2	4.68E-11	4.68E-11	1.01E-10	1.01E-10	3.89E-10	4.32E-11

Release Event	Release Scenario					
	10mm	25mm	50mm	100mm	IS_FB	IF_FB
G07_FF1	4.41E-10	4.41E-10	1.26E-09	6.93E-09	4.86E-09	5.40E-10
G07_JTF	2.00E-10	2.00E-10	7.00E-10	7.00E-09		3.00E-10
G07_FBL					2.70E-09	
G08_FF2	4.68E-11	4.68E-11	1.01E-10	1.01E-10	3.89E-10	4.32E-11
G08_FF1	4.41E-10	4.41E-10	1.26E-09	6.93E-09	4.86E-09	5.40E-10
G08_JTF	2.00E-10	2.00E-10	7.00E-10	7.00E-09		3.00E-10
G08_FBL					2.70E-09	
G09_FF2	4.68E-11	4.68E-11	1.01E-10	1.01E-10	3.89E-10	4.32E-11
G09_FF1	4.41E-10	4.41E-10	1.26E-09	6.93E-09	4.86E-09	5.40E-10
G09_JTF	2.00E-10	2.00E-10	7.00E-10	7.00E-09		3.00E-10
G09_FBL					2.70E-09	
G10_FF2	1.40E-10	1.40E-10	1.44E-10	1.44E-10	6.48E-10	7.20E-11
G10_FF1	1.32E-09	1.32E-09	1.80E-09	9.90E-09	8.10E-09	9.00E-10
G10_JTF	6.00E-10	6.00E-10	1.00E-09	1.00E-08	4.50E-09	5.00E-10
G10_FBL					4.50E-09	
G11_FF2	1.40E-10	1.40E-10	1.44E-10	1.44E-10	6.48E-10	7.20E-11
G11_FF1	1.32E-09	1.32E-09	1.80E-09	9.90E-09	8.10E-09	9.00E-10
G11_JTF	6.00E-10	6.00E-10	1.00E-09	1.00E-08		5.00E-10
G11_FBL					4.50E-09	
G12_FF2	1.40E-10	1.40E-10	1.44E-10	1.44E-10	6.48E-10	7.20E-11
G12_FF1	1.32E-09	1.32E-09	1.80E-09	9.90E-09	8.10E-09	9.00E-10
G12_JTF	6.00E-10	6.00E-10	1.00E-09	1.00E-08		5.00E-10
G12_FBL					4.50E-09	
G13_FF2	1.40E-10	1.40E-10	1.44E-10	1.44E-10	6.48E-10	7.20E-11
G13_FF1	1.32E-09	1.32E-09	1.80E-09	9.90E-09	8.10E-09	9.00E-10
G13_JTF	6.00E-10	6.00E-10	1.00E-09	1.00E-08		5.00E-10
G13_FBL					4.50E-09	
G14_FF2	1.90E-06	1.90E-06	1.90E-06	1.90E-07	5.18E-07	5.76E-08
G14_FF1	9.82E-05	9.82E-05	9.82E-05	9.82E-06	6.48E-06	7.20E-07
G14_JTF	8.10E-05	8.10E-05	8.10E-05	8.10E-06		4.00E-07
G14_FBL					3.60E-06	

Release Event	Release Scenario					
	10mm	25mm	50mm	100mm	IS_FB	IF_FB
P15_FF2	4.78E-08	4.78E-08	4.78E-08	4.78E-08	1.36E-07	1.51E-08
P15_FF1	1.91E-06	1.91E-06	1.91E-06	1.91E-06	1.49E-06	1.66E-07
P15_JTF	1.00E-06	1.00E-06	1.00E-06	1.00E-06		8.00E-08
P15_FBL					7.20E-07	
P16_FF2	4.78E-08	4.78E-08	4.78E-08	4.78E-08	1.36E-07	1.51E-08
P16_FF1	1.91E-06	1.91E-06	1.91E-06	1.91E-06	1.49E-06	1.66E-07
P16_JTF	1.00E-06	1.00E-06	1.00E-06	1.00E-06		8.00E-08
P16_FBL					7.20E-07	
P17_FF2	1.40E-10	1.40E-10	1.44E-10	1.44E-10	6.48E-10	7.20E-11
P17_FF1	1.32E-09	1.32E-09	1.80E-09	9.90E-09	8.10E-09	9.00E-10
P17_JTF	6.00E-10	6.00E-10	1.00E-09	1.00E-08		5.00E-10
P17_FBL					4.50E-09	
P18_FF2	1.40E-10	1.40E-10	1.44E-10	1.44E-10	6.48E-10	7.20E-11
P18_FF1	1.32E-09	1.32E-09	1.80E-09	9.90E-09	8.10E-09	9.00E-10
P18_JTF	6.00E-10	6.00E-10	1.00E-09	1.00E-08		5.00E-10
P18_FBL					4.50E-09	
P19_FF2	1.42E-10	1.42E-10	1.51E-10	1.51E-10	6.79E-10	7.54E-11
P19_FF1	7.20E-10	7.20E-10	1.16E-09	6.38E-09	5.22E-09	5.80E-10
P19_JTF	6.00E-10	6.00E-10				
P19_PLF			8.00E-10	8.00E-09	3.60E-09	4.00E-10
P19_VCE	3.09E-10	3.09E-10	4.97E-10	2.73E-09	2.24E-09	2.48E-10
P20_FF2	1.42E-10	1.42E-10	1.51E-10	1.51E-10	6.79E-10	7.54E-11
P20_FF1	1.03E-09	1.03E-09	1.66E-09	9.11E-09	7.45E-09	8.28E-10
P20_JTF	6.00E-10	6.00E-10	8.00E-10			
P20_PLF				8.00E-09	3.60E-09	4.00E-10
P21_FF2	4.78E-11	4.78E-11	1.06E-10	1.06E-10	4.07E-10	4.53E-11
P21_FF1	3.47E-10	3.47E-10	1.16E-09	6.38E-09	4.47E-09	4.97E-10
P21_JTF	1.00E-10	1.00E-10	5.60E-10	5.60E-09		
P21_PLF					2.16E-09	2.40E-10
P22_FF2	4.78E-08	4.78E-08	4.78E-08	4.78E-08	1.36E-07	1.51E-08
P22_FF1	1.91E-06	1.91E-06	1.91E-06	1.91E-06	8.10E-09	1.66E-07

Release Event	Release Scenario					
	10mm	25mm	50mm	100mm	IS_FB	IF_FB
P22_JTF	1.00E-06	1.00E-06	1.00E-06	1.00E-06		8.00E-08
P22_FBL					7.20E-07	

Release Event	Release Scenario	
	Low Level	High Level
T23_FF2	1.56E-09	4.44E-09
T23_FF1	2.60E-10	7.40E-10
T23_PLF	7.80E-10	2.22E-09

REFERENCES

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

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

[3] Crossthwaite, P.J., Fitzpatrick, R.D. & Hurst, N.W. (1988), Risk Assessment for the Siting of Developments Near Liquefied Petroleum Gas Installations, IChemE Symposium Series No 110.

[4] TNO (1999), Guidelines for Quantitative Risk Assessment (The Purple Book), Report CPR 18E, The Netherlands Organisation of Applied Scientific Research, Voorburg.

[5] Cox, Lees and Ang, Classification of Hazardous Locations, IChemE.

Annex 13A7

Consequence Analysis

CONTENTS

1 CONSEQUENCE ANALYSIS

This Annex provides details of all the assumptions and data used in the Consequence Analysis.

In the analysis, the source terms of the release are defined for the various failure scenarios, conditions and dimensions specified. The outputs of the source term modelling are then used for computational analysis of the release consequences, based on the selected release parameters. The modelling is performed using the *PHAST* suite of models.

1.1 SOURCE TERM MODELLING

The process facility was divided into 23 isolatable sections. The following information is specified for each section:

- Phase of the fluid (liquid/gas)
- Nature of section (piping/pumps/vessels/unloading arms)
- Number of equipment items
- Length of section (m)
- Pipe diameter (mm)
- Temperature (°C)
- Pressure (bara)
- Density of the fluid (kg/m^3)
- Inventory of the section (kg)
- Pumping rate (kg/s)

Table 1.1 lists the details adopted for each process section.

Discharge Rate

For catastrophic failures from liquid piping systems, the pumping rate is taken as the discharge rate. It is further assumed that such a release would have minimal momentum, air entrainment and vaporisation and hence would form a liquid pool on the ground. If ignited, this will result in a pool fire, otherwise the pool will vaporise to give a vapour cloud.

Table 1.1 Release Source Term Information

Code	Scenario Name	Fluid Phase	Nature of Section	No. of Items	Length of Section (m)	Pipe Diameter (mm)	Pressure (bara)	Temperature (°C)	Density (kg/m³)	Inventory (kg)	Pumping Rate (kg/s)
L01	Liquid Piping from Tank to HP Pump	Liquid	Piping	1	450	500	7.50	-161.5	464	40,977	248
L02	Liquid Unloading Arm	Liquid	Unloading Arm	3	20	400	5.50	-161.5	464	1,166	601
L03	Liquid Transfer Pipe from Jetty to Shore End	Liquid	Piping	2	300	700	5.50	-161.5	464	53,543	601
L04	Liquid from HP Pump Discharge to Vaporisers (ORV/SCV)	Liquid	Piping	1	30	400	106	-155.2	464	1,748	251
L05	Liquid Transfer Pipe from Shore End to Tank	Liquid	Piping	2	900	700	5.50	-161.5	464	160,630	601
L06	Liquid in Recondenser	Liquid	Process Vessel	1	N/A	N/A	6.50	-160.5	463	46,300	100
G07	Gas from Metering Station to Battery Limit	Gas	Piping	1	390	750	102	5.0	79.4	13,680	251
G08	Gas from Vaporisers (ORV/SCV) Outlet to Metering Station	Gas	Piping	1	108	750	104	5.8	80.8	3,851	251
G09	Vapour Piping from Tank to Compressor	Gas	Piping	1	450	600	1.08	-110.0	1.43	182	2.93
G10	Gas Piping from Compressor to Recondenser	Gas	Piping	1	24	400	6.80	57.0	4.46	13	2.93
G11	Recycle Gas Piping from Compressor to Ship (till Shore End)	Gas	Piping	1	720	500	1.05	-120.2	1.49	211	4.74
G12	Recycle Gas Piping from Compressor to Ship (Shore End to Jetty)	Gas	Piping	1	300	500	1.05	-120.2	1.49	88	4.74

Code	Scenario Name	Fluid Phase	Nature of Section	No. of Items	Length of Section (m)	Pipe Diameter (mm)	Pressure (bara)	Temperature (°C)	Density (kg/m³)	Inventory (kg)	Pumping Rate (kg/s)
G13	Gas Piping from HP Compressor Discharge to Vaporiser Outlet	Gas	Piping	1	30	150	104	5.8	80.8	43	0.78
G14	Vapour Unloading Arm	Gas	Unloading Arm	1	20	400	1.05	-120.2	1.49	4	4.54
P15	Ship Compressor	Gas	Pump	1	1	450	23.0	35.0	16.2	51	3.00
P16	BOG Compressor	Gas	Pump	1	1	400	6.80	57.0	4.46	11	1.50
P17	SCV Inlet/Outlet Piping	Gas	Piping	5	10	400	106	5.8	82.3	103	25.0
P18	ORV Inlet/Outlet Piping	Gas	Piping	5	10	400	106	5.8	82.3	103	50.3
P19	HP Pump Suction/Discharge Piping	Liquid	Piping	10	10	400	106	-155.2	464	583	51.6
P20	In-Tank Pump Discharge Piping (on Tank Roof up to ESD Valve)	Liquid	Piping	1	150	400	7.30	-161.5	464	8,742	87.0
P21	Piping at Jetty between ESD Valves	Liquid	Piping	1	300	600	5.50	-161.5	464	39,338	601
P22	HPBOG Compressor	Gas	Pump	1	1	450	102	35.0	71.7	228	0.78
T23	LNG Storage Tank	Liquid	Tank	3	N/A	N/A	1.08	-161.5	464	83,520,000	N/A

The discharge rate from holes (other than catastrophic rupture) is calculated by the release models within *PHAST*, based on the hole size and process conditions listed in *Table 1.1*. For discharge rates below the pumping rate, it is assumed that the system will maintain some pressure and the releases will be a momentum release or liquid jet. If ignited, this will result in a jet fire, otherwise the jet will entrain air, vaporise and disperse to give a vapour cloud. If the discharge rate for a given hole size is calculated to be higher than the pumping rate, then the pumping rate is taken as the release rate. It is further assumed that such cases will have lost pressure and hence the release will be a non-momentum release resulting in a liquid pool on the ground, in a similar manner as a catastrophic failure.

For gas releases, all releases will be pressurised releases. The system pressure will fall gradually upon isolation leading to time varying discharge rate. The 'initial' discharge rate is used as a steady state release for the duration of release. If ignited immediately, it would result in a fire ball or jet fire, otherwise the gas would disperse as a vapour cloud.

1.2 HOLE SIZE

A range of hole sizes are considered in the analysis, including 10mm, 50mm, 100mm and full bore ruptures. Catastrophic rupture of process vessels is also considered.

1.3 RELEASE DURATION

Two release durations are considered for releases from piping:

- 2 minute release
- 10 minute release

Due to the provision of gas, low temperature and fire detectors and an emergency shutdown system for the terminal, it is assumed that releases can be detected and shutdown initiated within about 2 minutes. Detection and shutdown may however, fail or be delayed. To account for this case, a 10 minute release scenario is also considered.

For releases from process vessels, e.g. the recondenser, the entire inventory is assumed to be released instantaneously.

For unloading arm failures, a shorter release time is assumed due to the presence of personnel in the vicinity who can initiate emergency shutdown (in addition to the fire and gas detection system) and also due to the provision of detectors for excessive movement of the arm which will initiate an automatic shutdown. Two release durations are considered:

- 30 seconds release
- 2 minute release

For unloading arm failures, only one unloading arm failure is considered. Even for the case of common cause failures such as excessive movement or carrier drifting away, the probability of failure of emergency release coupling of more than one is considered to be insignificant. The 2-minute release duration therefore represents the case of failure of isolation of one arm. Duration longer than 2 minutes is not considered significant given that the transfer pumps on the carrier can be stopped, which will stop any further release.

1.4 *CONSEQUENCE MODELS USED*

Table 1.2 shows the list of release scenarios along with the corresponding consequence model used in the consequence modelling software, *PHAST*.

Table 1.2 Release Scenarios and Consequence Models Applied

Release Scenario	Release Type	Model Applied in PHAST
10mm leak	Leak	Leak
25mm leak	Leak	Leak
50mm leak	Leak	Leak
100mm leak	Leak	Leak
Full bore rupture, instantaneous release	Rupture	Catastrophic Rupture
Full bore rupture, continuous release	Rupture	Leak

Liquid and gas leaks from holes smaller than full bore rupture are modelled using the "leak" model within PHAST. This is essentially a steady state calculation which determines the dispersion of the liquid or gas jet based on a steady discharge rate taken as the initial discharge rate. This is a reasonable representation of reality given that the time needed to reach a fully developed plume is typically less than a minute. There is therefore little difference between a 10-minute release, a 2-minute release and even a 30s release.

Liquid releases from a full bore rupture or large hole, such that a non-momentum release occurs, gives a liquid pool the size of which does depend on the inventory released and hence the release duration. If isolation is successful, the inventory is taken to be the entire contents of that section of piping or process vessel. It is assumed to be released instantaneously using the "catastrophic rupture" model with PHAST. This model calculates the transient pool size taking into consideration gravitation, vaporisation and surface tension effects. For isolation failure a 10-minute release at the pumping rate is used for the pool calculations.

Gas releases from a catastrophic rupture are assumed to give a fire ball if ignited immediately; otherwise a dispersing gas plume is formed. If isolation fails, a continuous jet fire is assumed to occur.

Tank Failure Modelling

A catastrophic failure of an LNG storage tanks is modelled as an instantaneous release. Although a catastrophic failure releasing 100% of the tank contents instantaneously is not realistic, there is little difference in the consequence results compared to say a release over several minutes. Modelling the release as instantaneous is therefore a conservative approach to cover all catastrophic failures.

Due to the coastal location of the site and the natural gradient of the terrain, a large release would form a liquid pool that quickly flowed into the ocean. The boundary wall would contain much of this and thereby limit the vaporisation rate and hence the hazard distances. A conservative approach is again adopted and an uncontained release directly on water is assumed.

The inventory in the tanks will vary. A tank will be near full after unloading from a carrier and will gradually be emptied. Based on tank size, throughput and operating philosophy, the tanks were conservatively estimated to be full 74% of the time and half full the remaining 26% of the time. Two scenarios were therefore modelled for tank failure: a full tank and a half tank.

Vapour Cloud Explosions

The TNO Multi Energy model is used for modelling overpressures. The potential for vapour cloud explosions (VCE) is considered only for liquid releases in the process areas. Gas releases are not considered because natural gas is buoyant and is unlikely to remain confined near the ground. Liquid releases however, form a dense vapour that can persist near the ground. An unconfined release will not produce any overpressure (explode) upon ignition. Some degree of confinement is required and this is possible only in the process areas, althoughthe degree of congestion is low.

A volume of 60m x 36m x 5m = 10800 m^3 is assumed to be representative of the congested volume, based on the site layout. The stoichiometric mixture for hydrocarbons is typically $0.1kg/m^3$ giving a required mass of hydrocarbons of 1 tonne within the congested volume. Since the degree of congestion is small and not all releases will be completely confined within this volume, VCE was only considered for LNG releases with an inventory greater than about 2 t.

A summary of the modelling input parameters used for PHAST are listed in *Table 1.3*.

Table 1.3 Modelling Input Parameters

BLEVE Parameters		
Maximum SEP for a BLEVE	400.00	kW/m2
Fireball radiation intensity level 1	7.00	kW/m2
Fireball radiation intensity level 2	14.00	kW/m2
Fireball radiation intensity level 3	21.00	kW/m2
Mass Modification Factor	3.00	
Fireball Maximum Exposure Duration	30.00	s
Ground Reflection	Ground Burst	
Ideal Gas Modeling	Model as real gas	
Discharge Parameters		
Continuous Critical Weber number	12.50	
Instantaneous Critical Weber number	12.50	
Venting equation constant	24.82	
Relief valve safety factor	1.20	
Minimum RV diameter ratio	1.00	
Critical pressure greater than flow phase	0.34	bar
Maximum release velocity	500.00	m/s
Minimum drop size allowed	0.00	mm
Maximum drop size allowed	10.00	mm
Default Liquid Fraction	1.00	fraction
Continuous Drop Slip factor	1.00	
Instantaneous Drop Slip factor	1.00	
Pipe-Fluid Thermal Coupling	0.00	
Number of Time Steps	100.00	
Maximum Number of Data Points	1,000.00	
Non-Return Valve velocity head losses	0.00	
Pipe roughness	0.046	mm
Shut-Off Valve velocity head losses	0.00	
Excess Flow Valve velocity head losses	0.00	
Default volume changes	3.00	/hr
Line length	10.00	m
Elevation	1.00	m
Atmospheric Expansion Method	Closest to Initial Conditions	
Tank Roof Failure Model Effects	Instantaneous Effects	
Outdoor Release Direction	Horizontal	
Dispersion Parameters		
Dense cloud parameter gamma (continuous)	0.00	
Dense cloud parameter gamma (instant)	0.30	
Dense cloud parameter k (continuous)	1.15	
Dense cloud parameter k (instantaneous)	1.15	
Jet entrainment coefficient alpha1	0.17	
Jet entrainment coefficient alpha2	0.35	
Ratio instantaneous/continuous sigma-y	1.00	
Ratio instantaneous/continuous sigma-z	1.00	
Distance multiple for full passive entrainment	2.00	
Quasi-instantaneous transition parameter	0.80	
Impact parameter - plume/ground	0.80	
Expansion zone length/source diameter ratio	0.01	
Drop/expansion velocity for inst. release	0.80	
Drag coefficient between plume and ground	1.50	

Drag coefficient between plume and air	0.00	
Default bund height	0.00	m
Maximum temperature allowed	626.85	degC
Minimum temperature allowed	-263.15	degC
Minimum release velocity for cont. release	0.10	m/s
Minimum integration step size (Instantaneous)	0.10	s
Maximum integration step size (Instantaneous)	1,000.00	s
Minimum integration step size (Continuous)	0.10	m
Maximum integration step size (Continuous)	100.00	m
Maximum distance for dispersion	50,000.00	m
Maximum height for dispersion	1,000.00	m
Minimum cloud depth	0.02	m
Expansion energy cutoff for droplet angle	0.69	kJ/kg
Droplet evaporation thermodynamics model	Rainout, Non-equilibrium	
Flag for mixing height	Constrained	
Accuracy for integration of dispersion	0.00	
Accuracy for droplet integration	0.00	
Richardson number criterion for cloud lift-off	-20.00	
Flag to reset rainout position	Do not reset rainout position	
Surface over which the dispersion occurs	Water	
Minimum Vapor Fraction for Convection	0.00	fraction
Coefficient of Initial Rainout	0.00	
Minimum Continuous Release Height	0.00	m
Flag for finite duration correction	Finite Duration Correction	
Near Field Passive Entrainment Parameter	1.00	
Jet Model	Morton et.al.	
Maximum Cloud/Ambient Velocity Difference	0.10	
Maximum Cloud/Ambient Density Difference	0.02	
Maximum Non-passive entrainment fraction	0.30	
Maximum Richardson number	15.00	
Core Averaging Time	18.75	s
Ground Drag Model	New (Recommended)	
Flag for Heat/Water vapor transfer	Heat and Water	
Richardson Number for passive transition above pool	0.02	
Pool Vaporization entrainment parameter	1.50	
Modeling of instantaneous expansion	Standard Method	
Minimum concentration of interest	0.00	fraction
Maximum distance of interest	10,000.00	m
Model In Use	Best Estimate	
Maximum Initial Step Size	10.00	m
Minimum Number of Steps per Zone	5.00	
Factor for Step Increase	1.20	
Maximum Number of Output Steps	1,000.00	

Flammables Parameters

Height for calculation of flammable effects	0.00	m
Flammable result grid step in X-direction	10.00	m
LFL fraction to finish	0.85	
Flammable angle of inclination	0.00	deg
Flammable inclination	Variable	
Flammable mass calculation method	Mass between LFL and UFL	

Flammable Base averaging time	18.75	s
Cut Off Time for Short Continuous Releases	20.00	s
Observer type radiation modelling flag	Planar	
Probit A Value	-36.38	
Probit B Value	2.56	
Probit N Value	1.33	
Height for reports	Centreline Height	
Angle of orientation	0.00	deg
Relative tolerance for radiation calculations	0.02	fraction
General Parameters		
Maximum release duration	3,600.00	s
Height for concentration output	0.00	m
Jet Fire Parameters		
Maximum SEP for a Jet Fire	400.00	kW/m2
Jet Fire Averaging Time	20.00	s
Jet fire radiation intensity level 1	7.00	kW/m2
Jet fire radiation intensity level 2	14.00	kW/m2
Jet fire radiation intensity level 3	21.00	kW/m2
Rate Modification Factor	3.00	
Jet Fire Maximum Exposure Duration	30.00	s
Model Correlation Type	Shell	
Pool Fire Parameters		
Min. pool duration for pool fire risk(Cont. releases)	10.00	s
Pool fire radiation intensity level 1	7.00	kW/m2
Pool fire radiation intensity level 2	14.00	kW/m2
Pool fire radiation intensity level 3	21.00	kW/m2
Pool Fire Maximum Exposure Duration	30.00	s
Pool Vaporization Parameters		
Toxics Cut-off rate for pool evaporation	0.00	kg/s
Flammable Cut-off rate for pool evaporation	0.10	kg/s
Concentration Power	1.00	
Maximum No. Pool Evaporation Rates	10.00	
Pool minimum thickness	5.00	mm
Surface thermal conductivity	0.00	kJ/m.s.degK
Surface roughness factor	2.63	
Surface thermal diffusivity (per second)	0.00	m2/s
Status of Bund	No bund present	
Weather Parameters		
Atmospheric pressure	1.01	bar
Atmospheric molecular weight	28.97	
Atmospheric specific heat at constant pressure	1.00	kJ/kg.degK
Wind speed reference height (m)	10.00	m
Temperature reference height (m)	0.00	m
Cut-off height for wind speed profile (m)	1.00	m
Wind speed profile	Power Law	
Atmospheric Temperature and Pressure Profile	Temp.Logarithmic; Pres.Linear	
Atmospheric temperature	23.00	degC
Relative humidity	0.77	fraction

Surface Roughness Parameter	0.043	
Surface Roughness Length	0.912	mm
Roughness or Parameter	Parameter	
Dispersing surface temperature	23.00	degC
Default surface temperature of bund	23.00	degC
Solar radiation flux	0.50	kW/m2
Building Exchange Rate	4.00	/hr
Tail Time	1,800.00	s

1.5 CONSEQUENCE END-POINT CRITERIA

The end-point criteria are used to define the impact level at which a fatality could result.

Thermal Radiation

The following equation [1] is used to determine impacts of thermal radiation from pool fires and jet fires to persons unprotected by clothing.

$$Y = -36.38 + 2.56 \ln (t\, I^{4/3}) \quad (1)$$

where I is the radiant thermal flux (W/m^2) and Y is the probit function which is related to the probability of fatality. This equation gives the data points presented in *Table 1.4*, assuming a 30-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 x 1 + 1/3 x 50 = 17%;

- 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 x 90 + 1/3 x 50 = 77%.

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

Table 1.4 Levels of Harm for 30s Exposure to Heat Fluxes

Incident Thermal Flux (kW/m^2)	Fatality Probability for 30s Exposure	Equivalent Fatality Probability for Area between Radiation Flux Contours
7.3	1%	
		17%
14.4	50%	
		77%
20.9	90%	
		97%
35.5	99.9%	

Vapour Cloud Dispersion / Flash Fire

With regard to flash fires, the criterion chosen is that a 100% fatality is assumed for any person outdoors within the flash fire envelope. In this study, the extent of the flash fire is assumed to be the dispersion distance to 85% of the LFL for a conservative evaluation.

Overpressure Effects

The impact on humans due to overpressure from a vapour cloud explosion is modelled as follows:

- Overpressure level 5 psi : 50% fatality
- Overpressure level 2 psi : 1% fatality

1.6 CONSEQUENCE RESULTS

A complete list of hazard distances obtained from the consequence modelling is provided in *Table 1.5*.

Table 1.5 South Soko Consequence Results

Section		Phase L/G	Leak size (mm)	Hazard effects	End point criteria	Hazard extent (m) Weather conditions F, 2 m/s	D, 3 m/s	D, 7 m/s	B, 2.5 m/s
L01	Liquid Piping from Tank to HP Pump	L	10	Jet fire	35.5 kW/m2	29	26	21	28
					20.9 kW/m2	27	25	23	25
					14.4 kW/m2	30	28	25	29
					7.3 kW/m2	35	33	29	34
				Flash fire	0.85 LFL	33	32	26	31
				Vapour cloud explosion	2 psi	63	63	63	63
			25	Jet fire	35.5 kW/m2	63	57	46	60
					20.9 kW/m2	67	63	55	65
					14.4 kW/m2	71	67	59	70
					7.3 kW/m2	79	76	67	78
				Flash fire	0.85 LFL	88	101	108	99
				Vapour cloud explosion	2 psi	63	63	63	63
			50	Jet fire	35.5 kW/m2	114	102	82	107
					20.9 kW/m2	126	117	102	121
					14.4 kW/m2	134	125	110	129
					7.3 kW/m2	150	140	125	144
				Flash fire	0.85 LFL	171	189	236	187
				Vapour cloud explosion	2 psi	63	63	63	63
			100	Jet fire	35.5 kW/m2	203	182	147	191
					20.9 kW/m2	232	215	188	223
					14.4 kW/m2	247	230	203	237
					7.3 kW/m2	275	259	232	266
				Flash fire	0.85 LFL	312	356	461	350
				Vapour cloud explosion	2 psi	63	63	63	63
			Full bore (isoln. succ.)	Pool fire	35.5 kW/m2	15	15	15	15

					20.9 kW/m2	61	64	70	62
					14.4 kW/m2	80	83	86	82
					7.3 kW/m2	121	121	120	121
				Flash fire	0.85 LFL	782	561	653	389
				Vapour cloud explosion	2 psi	63	63	63	63
			Full bore (isoln. fail.)	Pool fire	35.5 kW/m2	15	15	15	15
					20.9 kW/m2	61	64	70	62
					14.4 kW/m2	80	83	86	82
					7.3 kW/m2	121	121	120	121
				Flash fire	0.85 LFL	464	514	694	507
				Vapour cloud explosion	2 psi	63	63	63	63
L02	Liquid Unloading Arm	L	10	Jet fire	35.5 kW/m2	28	25	21	27
					20.9 kW/m2	26	24	22	25
					14.4 kW/m2	29	27	24	28
					7.3 kW/m2	34	32	28	33
				Flash fire	0.85 LFL	34	32	25	32
			25	Jet fire	35.5 kW/m2	62	55	45	58
					20.9 kW/m2	65	60	53	62
					14.4 kW/m2	70	65	57	67
					7.3 kW/m2	79	73	65	76
				Flash fire	0.85 LFL	87	102	107	100
			50	Jet fire	35.5 kW/m2	110	99	80	104
					20.9 kW/m2	122	112	98	117
					14.4 kW/m2	130	121	106	125
					7.3 kW/m2	145	136	121	140
				Flash fire	0.85 LFL	171	191	231	193
			100	Jet fire	35.5 kW/m2	196	176	142	185
					20.9 kW/m2	224	207	181	215
					14.4 kW/m2	239	222	196	229
					7.3 kW/m2	266	250	225	257

				Flash fire	0.85 LFL	315	355	455	347
			Full bore (isoln. succ.)	Pool fire	35.5 kW/m2	21	20	16	23
					20.9 kW/m2	83	82	76	91
					14.4 kW/m2	110	106	93	119
					7.3 kW/m2	165	156	129	177
				Flash fire	0.85 LFL	413	170	147	107
			Full bore (isoln. fail.)	Pool fire	35.5 kW/m2	21	20	16	23
					20.9 kW/m2	83	82	76	91
					14.4 kW/m2	110	106	93	119
					7.3 kW/m2	165	156	129	177
				Flash fire	0.85 LFL	715	801	1102	785
L03	Liquid Transfer Pipe from Jetty to Shore End	L	10	Jet fire	35.5 kW/m2	28	25	21	27
					20.9 kW/m2	26	24	22	25
					14.4 kW/m2	29	27	24	28
					7.3 kW/m2	34	32	28	33
				Flash fire	0.85 LFL	34	32	25	32
			25	Jet fire	35.5 kW/m2	62	55	45	58
					20.9 kW/m2	65	60	53	62
					14.4 kW/m2	70	65	57	67
					7.3 kW/m2	79	73	65	76
				Flash fire	0.85 LFL	87	102	107	100
			50	Jet fire	35.5 kW/m2	110	99	80	104
					20.9 kW/m2	122	112	98	117
					14.4 kW/m2	130	121	106	125
					7.3 kW/m2	145	136	121	140
				Flash fire	0.85 LFL	171	191	231	193
			100	Jet fire	35.5 kW/m2	196	176	142	185
					20.9 kW/m2	224	207	181	215
					14.4 kW/m2	239	222	196	229
					7.3 kW/m2	266	250	225	257

				Flash fire	0.85 LFL	315	355	455	347
			Full bore (isoln. succ.)	Pool fire	35.5 kW/m2	21	20	16	23
					20.9 kW/m2	83	82	76	91
					14.4 kW/m2	110	106	93	119
					7.3 kW/m2	165	156	129	177
				Flash fire	0.85 LFL	733	587	666	400
			Full bore (isoln. fail.)	Pool fire	35.5 kW/m2	21	20	16	23
					20.9 kW/m2	83	82	76	91
					14.4 kW/m2	110	106	93	119
					7.3 kW/m2	165	156	129	177
				Flash fire	0.85 LFL	715	801	1102	785
L04	Liquid from HP Pump Discharge to Vaporisers (ORV/ SCV)	L	10	Jet fire	35.5 kW/m2	45	41	33	43
					20.9 kW/m2	47	44	38	45
					14.4 kW/m2	51	47	41	49
					7.3 kW/m2	57	53	47	55
				Flash fire	0.85 LFL	37	37	37	37
				Vapour cloud explosion	2 psi	63	63	63	63
			25	Jet fire	35.5 kW/m2	100	90	73	94
					20.9 kW/m2	111	103	89	107
					14.4 kW/m2	118	109	95	113
					7.3 kW/m2	130	121	107	125
				Flash fire	0.85 LFL	104	106	114	104
				Vapour cloud explosion	2 psi	63	63	63	63
			50	Jet fire	35.5 kW/m2	182	163	132	171
					20.9 kW/m2	207	191	165	199
					14.4 kW/m2	218	202	176	209
					7.3 kW/m2	240	224	199	231
				Flash fire	0.85 LFL	220	227	249	223
				Vapour cloud explosion	2 psi	63	63	63	63
			100	Pool fire	35.5 kW/m2	30	30	30	30

					20.9 kW/m2	62	65	73	64
					14.4 kW/m2	82	85	89	84
					7.3 kW/m2	124	124	123	124
				Flash fire	0.85 LFL	323	339	372	334
				Vapour cloud explosion	2 psi	63	63	63	63
			Full bore (isoln. succ.)	Pool fire	35.5 kW/m2	30	30	30	30
					20.9 kW/m2	62	65	73	64
					14.4 kW/m2	82	85	89	84
					7.3 kW/m2	124	124	123	124
				Flash fire	0.85 LFL	503	228	259	159
				Vapour cloud explosion	2 psi	63	63	63	63
			Full bore (isoln. fail.)	Pool fire	35.5 kW/m2	30	30	30	30
					20.9 kW/m2	62	65	73	64
					14.4 kW/m2	82	85	89	84
					7.3 kW/m2	124	124	123	124
				Flash fire	0.85 LFL	323	339	372	334
				Vapour cloud explosion	2 psi	63	63	63	63
L05	Liquid Transfer Pipe from Shore End to Tank	L	10	Jet fire	35.5 kW/m2	28	25	21	27
					20.9 kW/m2	26	24	22	25
					14.4 kW/m2	29	27	24	28
					7.3 kW/m2	34	32	28	33
				Flash fire	0.85 LFL	34	32	25	32
			25	Jet fire	35.5 kW/m2	62	55	45	58
					20.9 kW/m2	65	60	53	62
					14.4 kW/m2	70	65	57	67
					7.3 kW/m2	79	73	65	76
				Flash fire	0.85 LFL	87	102	107	100
			50	Jet fire	35.5 kW/m2	110	99	80	104
					20.9 kW/m2	122	112	98	117
					14.4 kW/m2	130	121	106	125

					7.3 kW/m2	145	136	121	140
				Flash fire	0.85 LFL	171	191	231	193
			100	Jet fire	35.5 kW/m2	196	176	142	185
					20.9 kW/m2	224	207	181	215
					14.4 kW/m2	239	222	196	229
					7.3 kW/m2	266	250	225	257
				Flash fire	0.85 LFL	315	355	455	347
			Full bore (isoln. succ.)	Pool fire	35.5 kW/m2	21	20	16	23
					20.9 kW/m2	83	82	76	91
					14.4 kW/m2	110	106	93	119
					7.3 kW/m2	165	156	129	177
				Flash fire	0.85 LFL	913	945	1190	613
			Full bore (isoln. fail.)	Pool fire	35.5 kW/m2	21	20	16	23
					20.9 kW/m2	83	82	76	91
					14.4 kW/m2	110	106	93	119
					7.3 kW/m2	165	156	129	177
				Flash fire	0.85 LFL	715	801	1102	785
L06	Liquid in Recondenser	L	10	Jet fire	35.5 kW/m2	28	25	20	26
					20.9 kW/m2	25	24	21	24
					14.4 kW/m2	28	27	24	28
					7.3 kW/m2	33	31	27	32
				Flash fire	0.85 LFL	25	24	20	24
				Vapour cloud explosion	2 psi	63	63	63	63
			25	Jet fire	35.5 kW/m2	60	54	44	57
					20.9 kW/m2	64	60	52	62
					14.4 kW/m2	69	64	56	66
					7.3 kW/m2	77	72	64	74
				Flash fire	0.85 LFL	74	75	79	75
				Vapour cloud explosion	2 psi	63	63	63	63
			50	Jet fire	35.5 kW/m2	108	97	79	102

					20.9 kW/m2	121	112	97	116
					14.4 kW/m2	128	119	104	123
					7.3 kW/m2	142	133	119	137
				Flash fire	0.85 LFL	146	160	187	154
				Vapour cloud explosion	2 psi	63	63	63	63
			100	Jet fire	35.5 kW/m2	194	174	141	183
					20.9 kW/m2	223	206	180	214
					14.4 kW/m2	236	219	193	227
					7.3 kW/m2	261	245	220	252
				Flash fire	0.85 LFL	277	303	370	297
				Vapour cloud explosion	2 psi	63	63	63	63
			Full bore (isoln. succ.)	Pool fire	35.5 kW/m2	20	20	20	20
					20.9 kW/m2	42	44	50	43
					14.4 kW/m2	55	57	60	56
					7.3 kW/m2	84	84	84	84
				Flash fire	0.85 LFL	929	590	673	399
				Vapour cloud explosion	2 psi	63	63	63	63
			Full bore (isoln. fail.)	Pool fire	35.5 kW/m2	20	20	20	20
					20.9 kW/m2	42	44	50	43
					14.4 kW/m2	55	57	60	56
					7.3 kW/m2	84	84	84	84
				Flash fire	0.85 LFL	277	303	370	297
				Vapour cloud explosion	2 psi	63	63	63	63
G07	Gas from Metering Station to Battery Limit	G	10	Jet fire	35.5 kW/m2	20	18	15	19
					20.9 kW/m2	19	17	16	18
					14.4 kW/m2	20	17	18	20
					7.3 kW/m2	24	22	21	23
				Flash fire	0.85 LFL	13	13	12	13
			25	Jet fire	35.5 kW/m2	46	41	33	43
					20.9 kW/m2	46	43	38	44

					14.4 kW/m2	49	46	42	47
					7.3 kW/m2	56	53	49	54
				Flash fire	0.85 LFL	39	39	40	38
			50	Jet fire	35.5 kW/m2	84	75	61	79
					20.9 kW/m2	87	81	73	84
					14.4 kW/m2	93	87	79	90
					7.3 kW/m2	105	99	92	102
				Flash fire	0.85 LFL	87	87	92	85
			100	Jet fire	35.5 kW/m2	153	137	111	144
					20.9 kW/m2	163	152	136	157
					14.4 kW/m2	174	163	147	168
					7.3 kW/m2	196	186	171	190
				Flash fire	0.85 LFL	188	189	203	185
			Full bore (isoln. succ.)	Fireball	35.5 kW/m2	69	69	69	69
					20.9 kW/m2	226	226	226	226
					14.4 kW/m2	276	276	276	276
					7.3 kW/m2	385	385	385	385
				Flash fire	0.85 LFL	48	49	68	46
			Full bore (isoln. fail.)	Jet fire	35.5 kW/m2	187	167	135	176
					20.9 kW/m2	200	187	168	193
					14.4 kW/m2	213	200	181	206
					7.3 kW/m2	241	228	211	234
				Flash fire	0.85 LFL	243	244	263	239
G08	Gas from Vaporisers (ORV/SCV) Outlet to Metering Station	G	10	Jet fire	35.5 kW/m2	20	18	15	19
					20.9 kW/m2	19	18	16	18
					14.4 kW/m2	21	19	18	20
					7.3 kW/m2	24	23	21	23
				Flash fire	0.85 LFL	13	13	12	13
			25	Jet fire	35.5 kW/m2	46	41	33	43
					20.9 kW/m2	46	43	39	45

					14.4 kW/m2	50	47	42	48
					7.3 kW/m2	56	53	49	55
				Flash fire	0.85 LFL	39	40	40	38
			50	Jet fire	35.5 kW/m2	85	76	61	80
					20.9 kW/m2	88	82	74	84
					14.4 kW/m2	93	88	80	89
					7.3 kW/m2	106	100	92	100
				Flash fire	0.85 LFL	87	88	93	86
			100	Jet fire	35.5 kW/m2	154	138	112	145
					20.9 kW/m2	164	150	138	158
					14.4 kW/m2	175	161	149	169
					7.3 kW/m2	198	182	173	192
				Flash fire	0.85 LFL	190	190	206	187
			Full bore (isoln. succ.)	Fireball	35.5 kW/m2	45	45	45	45
					20.9 kW/m2	153	153	153	153
					14.4 kW/m2	187	187	187	187
					7.3 kW/m2	261	261	261	261
				Flash fire	0.85 LFL	30	32	45	30
			Full bore (isoln. fail.)	Jet fire	35.5 kW/m2	187	168	136	176
					20.9 kW/m2	200	187	168	193
					14.4 kW/m2	214	201	182	206
					7.3 kW/m2	242	229	211	234
				Flash fire	0.85 LFL	243	244	263	238
G09	Vapour Piping from Tank to Compressor	G	10	Jet fire	35.5 kW/m2	3	2	2	2
					20.9 kW/m2	0	0	0	0
					14.4 kW/m2	0	0	0	0
					7.3 kW/m2	0	0	0	0
				Flash fire	0.85 LFL	2	2	2	2
			25	Jet fire	35.5 kW/m2	6	5	4	5
					20.9 kW/m2	0	0	0	0

					14.4 kW/m2	3	3	0	3
					7.3 kW/m2	5	5	5	5
				Flash fire	0.85 LFL	4	5	4	4
			50	Jet fire	35.5 kW/m2	10	9	7	10
					20.9 kW/m2	7	7	7	7
					14.4 kW/m2	9	9	8	9
					7.3 kW/m2	11	11	10	11
				Flash fire	0.85 LFL	8	8	7	8
			100	Jet fire	35.5 kW/m2	19	17	14	18
					20.9 kW/m2	17	16	15	16
					14.4 kW/m2	19	18	17	19
					7.3 kW/m2	22	21	20	21
				Flash fire	0.85 LFL	19	17	13	16
			Full bore (isoln. succ.)	Fireball	35.5 kW/m2	16	16	16	16
					20.9 kW/m2	59	59	59	59
					14.4 kW/m2	72	72	72	72
					7.3 kW/m2	101	101	101	101
				Flash fire	0.85 LFL	130	130	231	86
			Full bore (isoln. fail.)	Jet fire	35.5 kW/m2	35	31	25	33
					20.9 kW/m2	35	34	31	34
					14.4 kW/m2	38	36	34	37
					7.3 kW/m2	44	42	39	43
				Flash fire	0.85 LFL	48	50	48	47
G10	Gas Piping from Compressor to Recondenser	G	10	Jet fire	35.5 kW/m2	5	5	4	5
					20.9 kW/m2	0	0	0	0
					14.4 kW/m2	3	3	0	3
					7.3 kW/m2	5	5	4	5
				Flash fire	0.85 LFL	3	3	3	3
			25	Jet fire	35.5 kW/m2	12	11	9	11
					20.9 kW/m2	10	9	8	9

					14.4 kW/m2	11	11	10	11
					7.3 kW/m2	13	13	12	13
				Flash fire	0.85 LFL	7	7	7	7
			50	Jet fire	35.5 kW/m2	22	20	16	21
					20.9 kW/m2	21	20	18	20
					14.4 kW/m2	23	21	19	22
					7.3 kW/m2	26	25	23	26
				Flash fire	0.85 LFL	15	14	13	14
			100	Jet fire	35.5 kW/m2	27	24	20	25
					20.9 kW/m2	26	21	22	25
					14.4 kW/m2	28	22	24	27
					7.3 kW/m2	32	26	28	31
				Flash fire	0.85 LFL	19	19	18	18
			Full bore (isoln. succ.)	Fireball	35.5 kW/m2	7	7	7	7
					20.9 kW/m2	25	25	25	25
					14.4 kW/m2	31	31	31	31
					7.3 kW/m2	44	44	44	44
				Flash fire	0.85 LFL	4	5	7	4
			Full bore (isoln. fail.)	Jet fire	35.5 kW/m2	27	24	20	25
					20.9 kW/m2	26	21	22	25
					14.4 kW/m2	28	22	24	27
					7.3 kW/m2	32	26	28	31
				Flash fire	0.85 LFL	19	19	18	18
G11	Recycle Gas Piping from Compressor to Ship (till Shore End)	G	10	Jet fire	35.5 kW/m2	2	2	2	2
					20.9 kW/m2	0	0	0	0
					14.4 kW/m2	0	0	0	0
					7.3 kW/m2	0	0	0	0
				Flash fire	0.85 LFL	2	2	2	2
			25	Jet fire	35.5 kW/m2	6	4	4	5
					20.9 kW/m2	0	0	0	0

					14.4 kW/m2	0	0	0	0
					7.3 kW/m2	5	5	4	5
				Flash fire	0.85 LFL	4	4	4	4
			50	Jet fire	35.5 kW/m2	10	9	7	9
					20.9 kW/m2	7	7	6	7
					14.4 kW/m2	8	8	8	8
					7.3 kW/m2	11	11	10	11
				Flash fire	0.85 LFL	8	8	7	8
			100	Jet fire	35.5 kW/m2	18	16	13	17
					20.9 kW/m2	16	15	15	16
					14.4 kW/m2	18	18	16	18
					7.3 kW/m2	22	21	19	21
				Flash fire	0.85 LFL	19	17	12	16
			Full bore (isoln. succ.)	Fireball	35.5 kW/m2	17	17	17	17
					20.9 kW/m2	62	62	62	62
					14.4 kW/m2	75	75	75	75
					7.3 kW/m2	105	105	105	105
				Flash fire	0.85 LFL	153	131	218	91
			Full bore (isoln. fail.)	Jet fire	35.5 kW/m2	44	39	32	41
					20.9 kW/m2	46	44	40	45
					14.4 kW/m2	50	47	44	48
					7.3 kW/m2	57	54	51	55
				Flash fire	0.85 LFL	73	78	82	73
G12	Recycle Gas Piping from Compressor to Ship (Shore End to Jetty)	G	10	Jet fire	35.5 kW/m2	2	2	2	2
					20.9 kW/m2	0	0	0	0
					14.4 kW/m2	0	0	0	0
					7.3 kW/m2	0	0	0	0
				Flash fire	0.85 LFL	2	2	2	2
			25	Jet fire	35.5 kW/m2	5	5	4	5
					20.9 kW/m2	0	0	0	0

					14.4 kW/m2	0	0	0	0
					7.3 kW/m2	5	4	4	5
				Flash fire	0.85 LFL	4	4	4	4
			50	Jet fire	35.5 kW/m2	10	9	7	9
					20.9 kW/m2	7	6	6	6
					14.4 kW/m2	8	8	8	8
					7.3 kW/m2	11	10	10	11
				Flash fire	0.85 LFL	8	8	7	8
			100	Jet fire	35.5 kW/m2	18	16	13	17
					20.9 kW/m2	16	15	14	16
					14.4 kW/m2	18	17	16	18
					7.3 kW/m2	21	21	19	21
				Flash fire	0.85 LFL	19	16	12	16
			Full bore (isoln. succ.)	Fireball	35.5 kW/m2	13	13	13	13
					20.9 kW/m2	47	47	47	47
					14.4 kW/m2	57	57	57	57
					7.3 kW/m2	80	80	80	80
				Flash fire	0.85 LFL	129	107	166	73
			Full bore (isoln. fail.)	Jet fire	35.5 kW/m2	44	39	32	41
					20.9 kW/m2	46	44	40	45
					14.4 kW/m2	50	47	44	48
					7.3 kW/m2	57	54	51	55
				Flash fire	0.85 LFL	73	78	82	73
G13	Gas Piping from HP Compressor Discharge to Vaporiser Outlet	G	10	Jet fire	35.5 kW/m2	15	13	11	14
					20.9 kW/m2	13	12	11	12
					14.4 kW/m2	14	14	12	14
					7.3 kW/m2	17	16	15	17
				Flash fire	0.85 LFL	9	9	8	9
			25	Jet fire	35.5 kW/m2	15	13	11	14
					20.9 kW/m2	13	12	11	12

					14.4 kW/m2	14	14	12	14
					7.3 kW/m2	17	16	15	17
				Flash fire	0.85 LFL	9	9	8	9
			50	Jet fire	35.5 kW/m2	15	13	11	14
					20.9 kW/m2	13	12	11	12
					14.4 kW/m2	14	14	12	14
					7.3 kW/m2	17	16	15	17
				Flash fire	0.85 LFL	9	9	8	9
			100	Jet fire	35.5 kW/m2	15	13	11	14
					20.9 kW/m2	13	12	11	12
					14.4 kW/m2	14	14	12	14
					7.3 kW/m2	17	16	15	17
				Flash fire	0.85 LFL	9	9	8	9
			Full bore (isoln. succ.)	Fireball	35.5 kW/m2	10	10	10	10
					20.9 kW/m2	37	37	37	37
					14.4 kW/m2	46	46	46	46
					7.3 kW/m2	64	64	64	64
				Flash fire	0.85 LFL	6	7	9	6
			Full bore (isoln. fail.)	Jet fire	35.5 kW/m2	15	13	11	14
					20.9 kW/m2	13	12	11	12
					14.4 kW/m2	14	14	12	14
					7.3 kW/m2	17	16	15	17
				Flash fire	0.85 LFL	9	9	8	9
G14	Vapour Unloading Arm	G	10	Jet fire	35.5 kW/m2	2	2	2	2
					20.9 kW/m2	0	0	0	0
					14.4 kW/m2	0	0	0	0
					7.3 kW/m2	0	0	0	0
				Flash fire	0.85 LFL	2	2	2	2
			25	Jet fire	35.5 kW/m2	6	5	4	5
					20.9 kW/m2	0	0	0	0

					14.4 kW/m2	0	0	0	0
					7.3 kW/m2	5	5	4	5
				Flash fire	0.85 LFL	4	4	4	4
			50	Jet fire	35.5 kW/m2	10	9	7	9
					20.9 kW/m2	7	7	6	7
					14.4 kW/m2	8	8	8	8
					7.3 kW/m2	11	11	10	11
				Flash fire	0.85 LFL	8	8	7	8
			100	Jet fire	35.5 kW/m2	18	16	13	17
					20.9 kW/m2	16	15	15	16
					14.4 kW/m2	18	18	16	18
					7.3 kW/m2	22	21	19	21
				Flash fire	0.85 LFL	19	17	12	16
			Full bore (isoln. succ.)	Fireball	35.5 kW/m2	5	5	5	5
					20.9 kW/m2	17	17	17	17
					14.4 kW/m2	21	21	21	21
					7.3 kW/m2	30	30	30	30
				Flash fire	0.85 LFL	54	51	77	31
			Full bore (isoln. fail.)	Jet fire	35.5 kW/m2	43	38	31	40
					20.9 kW/m2	45	42	39	44
					14.4 kW/m2	48	46	42	47
					7.3 kW/m2	55	53	49	54
				Flash fire	0.85 LFL	71	76	78	70
P15	Ship Compressor	G	10	Jet fire	35.5 kW/m2	9	8	7	9
					20.9 kW/m2	7	6	6	7
					14.4 kW/m2	8	8	7	8
					7.3 kW/m2	10	10	9	10
				Flash fire	0.85 LFL	6	6	6	6
			25	Jet fire	35.5 kW/m2	21	19	15	20
					20.9 kW/m2	20	19	17	16

					14.4 kW/m2	22	20	19	17
					7.3 kW/m2	25	24	22	24
				Flash fire	0.85 LFL	14	14	12	13
			50	Jet fire	35.5 kW/m2	27	24	20	26
					20.9 kW/m2	26	25	22	25
					14.4 kW/m2	28	27	24	28
					7.3 kW/m2	33	31	29	32
				Flash fire	0.85 LFL	20	19	18	19
			100	Jet fire	35.5 kW/m2	27	24	20	26
					20.9 kW/m2	26	25	22	25
					14.4 kW/m2	28	27	24	28
					7.3 kW/m2	33	31	29	32
				Flash fire	0.85 LFL	20	19	18	19
			Full bore (isoln. succ.)	Fireball	35.5 kW/m2	11	11	11	11
					20.9 kW/m2	39	39	39	39
					14.4 kW/m2	48	48	48	48
					7.3 kW/m2	67	67	67	67
				Flash fire	0.85 LFL	6	7	10	7
			Full bore (isoln. fail.)	Jet fire	35.5 kW/m2	27	24	20	26
					20.9 kW/m2	26	25	22	25
					14.4 kW/m2	28	27	24	28
					7.3 kW/m2	33	31	29	32
				Flash fire	0.85 LFL	20	19	18	19
P16	BOG Compressor	G	10	Jet fire	35.5 kW/m2	5	5	4	5
					20.9 kW/m2	0	0	0	0
					14.4 kW/m2	3	3	0	3
					7.3 kW/m2	5	5	4	5
				Flash fire	0.85 LFL	3	3	3	3
			25	Jet fire	35.5 kW/m2	12	11	9	11
					20.9 kW/m2	10	9	8	9

					14.4 kW/m2	11	11	10	11
					7.3 kW/m2	13	13	12	13
				Flash fire	0.85 LFL	7	7	7	7
			50	Jet fire	35.5 kW/m2	20	18	15	19
					20.9 kW/m2	19	18	16	18
					14.4 kW/m2	21	19	18	20
					7.3 kW/m2	24	23	21	23
				Flash fire	0.85 LFL	13	13	12	12
			100	Jet fire	35.5 kW/m2	20	18	15	19
					20.9 kW/m2	19	18	16	18
					14.4 kW/m2	21	19	18	20
					7.3 kW/m2	24	23	21	23
				Flash fire	0.85 LFL	13	13	12	12
			Full bore (isoln. succ.)	Fireball	35.5 kW/m2	6	6	6	6
					20.9 kW/m2	24	24	24	24
					14.4 kW/m2	30	30	30	30
					7.3 kW/m2	42	42	42	42
				Flash fire	0.85 LFL	4	4	6	4
			Full bore (isoln. fail.)	Jet fire	35.5 kW/m2	20	18	15	19
					20.9 kW/m2	19	18	16	18
					14.4 kW/m2	21	19	18	20
					7.3 kW/m2	24	23	21	23
				Flash fire	0.85 LFL	13	13	12	12
P17	SCV Inlet/Outlet Piping	G	10	Jet fire	35.5 kW/m2	21	18	15	19
					20.9 kW/m2	19	18	16	18
					14.4 kW/m2	21	20	18	20
					7.3 kW/m2	24	23	21	23
				Flash fire	0.85 LFL	14	13	12	13
			25	Jet fire	35.5 kW/m2	47	42	34	44
					20.9 kW/m2	47	44	39	45

					14.4 kW/m2	50	47	43	48
					7.3 kW/m2	57	54	50	55
				Flash fire	0.85 LFL	40	40	41	39
			50	Jet fire	35.5 kW/m2	70	63	51	66
					20.9 kW/m2	71	66	61	68
					14.4 kW/m2	77	72	66	75
					7.3 kW/m2	88	83	76	85
				Flash fire	0.85 LFL	68	70	73	68
			100	Jet fire	35.5 kW/m2	70	63	51	66
					20.9 kW/m2	71	66	61	68
					14.4 kW/m2	77	72	66	75
					7.3 kW/m2	88	83	76	85
				Flash fire	0.85 LFL	68	70	73	68
			Full bore (isoln. succ.)	Fireball	35.5 kW/m2	14	14	14	14
					20.9 kW/m2	49	49	49	49
					14.4 kW/m2	60	60	60	60
					7.3 kW/m2	84	84	84	84
				Flash fire	0.85 LFL	8	9	12	9
			Full bore (isoln. fail.)	Jet fire	35.5 kW/m2	70	63	51	66
					20.9 kW/m2	71	66	61	68
					14.4 kW/m2	77	72	66	75
					7.3 kW/m2	88	83	76	85
				Flash fire	0.85 LFL	68	70	73	68
P18	ORV Inlet/Outlet Piping	G	10	Jet fire	35.5 kW/m2	21	18	15	19
					20.9 kW/m2	19	18	16	18
					14.4 kW/m2	21	20	18	20
					7.3 kW/m2	24	23	21	23
				Flash fire	0.85 LFL	14	13	12	13
			25	Jet fire	35.5 kW/m2	47	42	34	44
					20.9 kW/m2	47	44	39	45

					14.4 kW/m2	50	47	43	48
					7.3 kW/m2	57	54	50	55
				Flash fire	0.85 LFL	40	40	41	39
			50	Jet fire	35.5 kW/m2	85	76	62	80
					20.9 kW/m2	89	83	74	85
					14.4 kW/m2	94	89	80	91
					7.3 kW/m2	107	101	93	104
				Flash fire	0.85 LFL	89	90	95	87
			100	Jet fire	35.5 kW/m2	93	83	67	87
					20.9 kW/m2	97	90	81	93
					14.4 kW/m2	103	97	88	100
					7.3 kW/m2	116	111	102	113
				Flash fire	0.85 LFL	99	100	106	97
			Full bore (isoln. succ.)	Fireball	35.5 kW/m2	14	14	14	14
					20.9 kW/m2	49	49	49	49
					14.4 kW/m2	60	60	60	60
					7.3 kW/m2	84	84	84	84
				Flash fire	0.85 LFL	8	9	12	9
			Full bore (isoln. fail.)	Jet fire	35.5 kW/m2	93	83	67	87
					20.9 kW/m2	97	90	81	93
					14.4 kW/m2	103	97	88	100
					7.3 kW/m2	116	111	102	113
				Flash fire	0.85 LFL	99	100	106	97
P19	HP Pump Suction/ Discharge Piping	L	10	Jet fire	35.5 kW/m2	45	41	33	43
					20.9 kW/m2	47	44	38	45
					14.4 kW/m2	51	47	41	49
					7.3 kW/m2	57	53	47	55
				Flash fire	0.85 LFL	37	37	37	37
				Vapour cloud explosion	2 psi	63	63	63	63
			25	Jet fire	35.5 kW/m2	100	90	73	94

					20.9 kW/m2	111	103	89	107
					14.4 kW/m2	118	109	95	113
					7.3 kW/m2	130	121	107	125
				Flash fire	0.85 LFL	104	106	114	104
				Vapour cloud explosion	2 psi	63	63	63	63
			50	Pool fire	35.5 kW/m2	14	14	14	14
					20.9 kW/m2	29	31	36	30
					14.4 kW/m2	39	41	43	40
					7.3 kW/m2	59	59	59	59
				Flash fire	0.85 LFL	147	149	161	147
				Vapour cloud explosion	2 psi	63	63	63	63
			100	Pool fire	35.5 kW/m2	14	14	14	14
					20.9 kW/m2	29	31	36	30
					14.4 kW/m2	39	41	43	40
					7.3 kW/m2	59	59	59	59
				Flash fire	0.85 LFL	147	149	161	147
				Vapour cloud explosion	2 psi	63	63	63	63
			Full bore (isoln. succ.)	Pool fire	35.5 kW/m2	14	14	14	14
					20.9 kW/m2	29	31	36	30
					14.4 kW/m2	39	41	43	40
					7.3 kW/m2	59	59	59	59
				Flash fire	0.85 LFL	410	128	135	90
				Vapour cloud explosion	2 psi	63	63	63	63
			Full bore (isoln. fail.)	Pool fire	35.5 kW/m2	14	14	14	14
					20.9 kW/m2	29	31	36	30
					14.4 kW/m2	39	41	43	40
					7.3 kW/m2	59	59	59	59
				Flash fire	0.85 LFL	147	149	161	147
				Vapour cloud explosion	2 psi	63	63	63	63
P20	In-Tank Pump	L	10	Jet fire	35.5 kW/m2	30	27	22	29

	Discharge Piping (on Tank Roof up to ESD Valve)				20.9 kW/m2	28	26	24	27
					14.4 kW/m2	31	30	26	30
					7.3 kW/m2	37	34	31	35
				Flash fire	0.85 LFL	36	34	29	35
			25	Jet fire	35.5 kW/m2	66	59	48	62
					20.9 kW/m2	70	65	57	67
					14.4 kW/m2	75	70	61	72
					7.3 kW/m2	84	79	70	81
				Flash fire	0.85 LFL	94	106	116	106
			50	Jet fire	35.5 kW/m2	118	105	85	111
					20.9 kW/m2	131	121	105	125
					14.4 kW/m2	139	129	114	134
					7.3 kW/m2	155	145	130	150
				Flash fire	0.85 LFL	177	202	249	199
			100	Pool fire	35.5 kW/m2	18	18	18	18
					20.9 kW/m2	38	41	46	40
					14.4 kW/m2	51	53	56	52
					7.3 kW/m2	77	77	77	77
				Flash fire	0.85 LFL	299	340	437	335
			Full bore (isoln. succ.)	Pool fire	35.5 kW/m2	18	18	18	18
					20.9 kW/m2	38	41	46	40
					14.4 kW/m2	51	53	56	52
					7.3 kW/m2	77	77	77	77
				Flash fire	0.85 LFL	477	365	343	286
			Full bore (isoln. fail.)	Pool fire	35.5 kW/m2	18	18	18	18
					20.9 kW/m2	38	41	46	40
					14.4 kW/m2	51	53	56	52
					7.3 kW/m2	77	77	77	77
				Flash fire	0.85 LFL	299	340	437	335
P21	Piping at Jetty	L	10	Jet fire	35.5 kW/m2	28	25	21	27

	between ESD Valves				20.9 kW/m2	26	24	22	25
					14.4 kW/m2	29	27	24	28
					7.3 kW/m2	34	32	28	33
				Flash fire	0.85 LFL	34	32	25	32
			25	Jet fire	35.5 kW/m2	62	55	45	58
					20.9 kW/m2	65	60	53	62
					14.4 kW/m2	70	65	57	67
					7.3 kW/m2	79	73	65	76
				Flash fire	0.85 LFL	87	102	107	100
			50	Jet fire	35.5 kW/m2	110	99	80	104
					20.9 kW/m2	122	112	98	117
					14.4 kW/m2	130	121	106	125
					7.3 kW/m2	145	136	121	140
				Flash fire	0.85 LFL	171	191	231	193
			100	Jet fire	35.5 kW/m2	196	176	142	185
					20.9 kW/m2	224	207	181	215
					14.4 kW/m2	239	222	196	229
					7.3 kW/m2	266	250	225	257
				Flash fire	0.85 LFL	315	355	455	347
			Full bore (isoln. succ.)	Pool fire	35.5 kW/m2	21	20	16	23
					20.9 kW/m2	83	82	76	91
					14.4 kW/m2	110	106	93	119
					7.3 kW/m2	165	156	129	177
				Flash fire	0.85 LFL	782	542	650	387
			Full bore (isoln. fail.)	Pool fire	35.5 kW/m2	21	20	16	23
					20.9 kW/m2	83	82	76	91
					14.4 kW/m2	110	106	93	119
					7.3 kW/m2	165	156	129	177
				Flash fire	0.85 LFL	715	801	1102	785
P22	HP BOG Compressor	G	10	Jet fire	35.5 kW/m2	16	14	11	15

					20.9 kW/m2	14	13	12	13
					14.4 kW/m2	15	14	13	15
					7.3 kW/m2	18	17	16	18
				Flash fire	0.85 LFL	10	10	9	9
			25	Jet fire	35.5 kW/m2	16	14	11	15
					20.9 kW/m2	14	13	12	13
					14.4 kW/m2	15	14	13	15
					7.3 kW/m2	18	17	16	18
				Flash fire	0.85 LFL	10	10	9	9
			50	Jet fire	35.5 kW/m2	16	14	11	15
					20.9 kW/m2	14	13	12	13
					14.4 kW/m2	15	14	13	15
					7.3 kW/m2	18	17	16	18
				Flash fire	0.85 LFL	10	10	9	9
			100	Jet fire	35.5 kW/m2	16	14	11	15
					20.9 kW/m2	14	13	12	13
					14.4 kW/m2	15	14	13	15
					7.3 kW/m2	18	17	16	18
				Flash fire	0.85 LFL	10	10	9	9
			Full bore (isoln. succ.)	Fireball	35.5 kW/m2	18	18	18	18
					20.9 kW/m2	63	63	63	63
					14.4 kW/m2	77	77	77	77
					7.3 kW/m2	108	108	108	108
				Flash fire	0.85 LFL	11	12	15	11
			Full bore (isoln. fail.)	Jet fire	35.5 kW/m2	16	14	11	15
					20.9 kW/m2	14	13	12	13
					14.4 kW/m2	15	14	13	15
					7.3 kW/m2	18	17	16	18
				Flash fire	0.85 LFL	10	10	9	9
T23	Tank Catastrophic	L	Full bore (high tank	Pool fire	35.5 kW/m2	1611	1597	1585	1599

	Rupture		level)		20.9 kW/m2	1585	1581	1582	1579
					14.4 kW/m2	1910	1899	1877	1900
					7.3 kW/m2	2567	2545	2482	2550
				Flash fire (full extent)	0.85 LFL	4800	4100	3600	3900
				Flash fire (max. downwind)	0.85 LFL	17386	5392	8545	3960
			Full bore (low tank level)	Pool fire	35.5 kW/m2	1205	1199	1182	1200
					20.9 kW/m2	1242	1244	1236	1242
					14.4 kW/m2	1505	1501	1472	1501
					7.3 kW/m2	2039	2026	1958	2030
				Flash fire (full extent)	0.85 LFL	3500	3100	3000	3000
				Flash fire (max. downwind)	0.85 LFL	13157	6197	4500	3083

REFERENCES

[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.

Annex 13B

Quantitative Risk Assessment: Pipeline

CONTENTS

1 *INTRODUCTION*

This annex covers details of the Quantitative Risk Assessment (QRA) for the subsea pipeline from South Soko to Black Point Power Station. Details of the methodology are presented here whilst the results and conclusions are given in the main report, *Section 13*.

2 DATA COLLECTION AND REVIEW

The following information was reviewed and formed the basis of the study:

- Basis of Design Report, Aker Kvaerner [1];
- Drawing 8028-PLD-008 detailing the pipeline route, trenching and backfilling details, Aker Kvaerner [2];
- Input to EIA Study Report on pipeline design, Aker Kvaerner [3];
- Marine vessel density data, BMT [4];
- Marine traffic data in Hong Kong waters, Marine Department (MD) [5,6];
- UK Loss of Containment Database for Offshore Pipelines [7]; and
- Hydrographic & Geophysical Survey of the Seabed, EGS [8].

3 PIPELINE AND MARINE DATA

This section of the report describes the subsea pipeline, its environment and details of marine traffic along the proposed route.

3.1 SUBSEA PIPELINE

The proposed pipeline takes a subsea route from the LNG terminal at South Soko, passing around the western edge of Lantau Island to Black Point Power Station (*Figure 3.1*). The pipeline will cross the waterways of the Adamasta Channel and Urmston Road (not a designated channel) and have a total length of about 38 km. The seabed for much of the route is classed as very soft clay [8].

The proposed pipeline system will consist of a single 30” OD (762mm outer diameter) API 5L Grade X65 pipeline, with wall thickness of 1” (25.4mm). It is designed to have a peak flow rate of 1000 MSCFD (million standard cubic feet per day) with a supply pressure of 101barg. The pipeline will have an asphalt enamel coat and wrap and sacrificial anodes for external corrosion protection and an outer layer of reinforced concrete for buoyancy control and to provide mechanical protection during pipeline installation and trenching operations. The pipeline is designed in accordance with the DNV 1981 design code [9]. A summary of the pipeline details is given in *Table 3.1*.

Table 3.1 Summary of Pipeline Details

Parameter	Details
Location	South Soko Island to Black Point Power Station
Length	38.3 km
Outside diameter	30” (762mm)
Nominal wall thickness	1” (25.4mm)
Line pipe grade	API 5L grade X65
External coating	Asphalt enamel coat & wrap and steel reinforced concrete
Internal coating	Epoxy
Cathodic protection	Aluminium based sacrificial anodes
Design flowrate	1000 MSCFD
Design pressure	111 barg
LNG terminal delivery pressure	101 barg
Minimum terminal delivery pressure	85 barg
Minimum delivery pressure to BPPS	38 barg
Pressure assumed for analysis	101 barg
Minimum operating temperature	5 °C
Maximum operating temperature	85 °C
Temperature assumed for this study	20 °C
Water depth	1.6 – 25 m
Seabed soil	Very soft clay becoming firmer with depth
Pipeline protection	3m cover with rock armour backfill of varying thickness
Design life	30 years

The composition of the gas is mainly methane (87.57-96.13 mol%). The composition of the gas is such that no internal corrosion is expected.

The water depth along the route varies between 1.6 and 25m, with much of the route characterised by shallow water below 6m deep. The pipeline will be buried 3m below the seabed with varying levels of rock armour protection (*Figures 3.1* and *3.2*). Type 1 trenching will be used for the shallow water areas away from the busy marine fairways. The type 1 trench involves jetting with 1m of rock armour backfill and 2m of natural backfill (to the top of the pipeline). This provides protection for anchors up to 2 tonnes, essentially protecting against anchors from all ships below about 10,000 dwt. Trench type 2A is used on the shore approach to South Soko Island and consists of pre-trenching with 3m of armour rock backfill. Trench type 2B, used on the BPPS approach utilizes 1.5m of rock backfill. These are also designed for protection from 2 tonne anchors and any future dredging work.

The waterways of Urmston Road and the Adamasta Channel will have type 3A or 3B trenches. These consist of pre-trenching with 3m of rock backfill. The only difference between 3A and 3B is that the seabed will be dredged so that the top of the rock armour is at least -17m for type 3A. For the purpose of this study, they are essentially similar and are designed to protect against 20 tonne anchors. This covers the full range of ships currently operating in Hong Kong and also those expected in future.

Figure 3.1 Pipeline Route

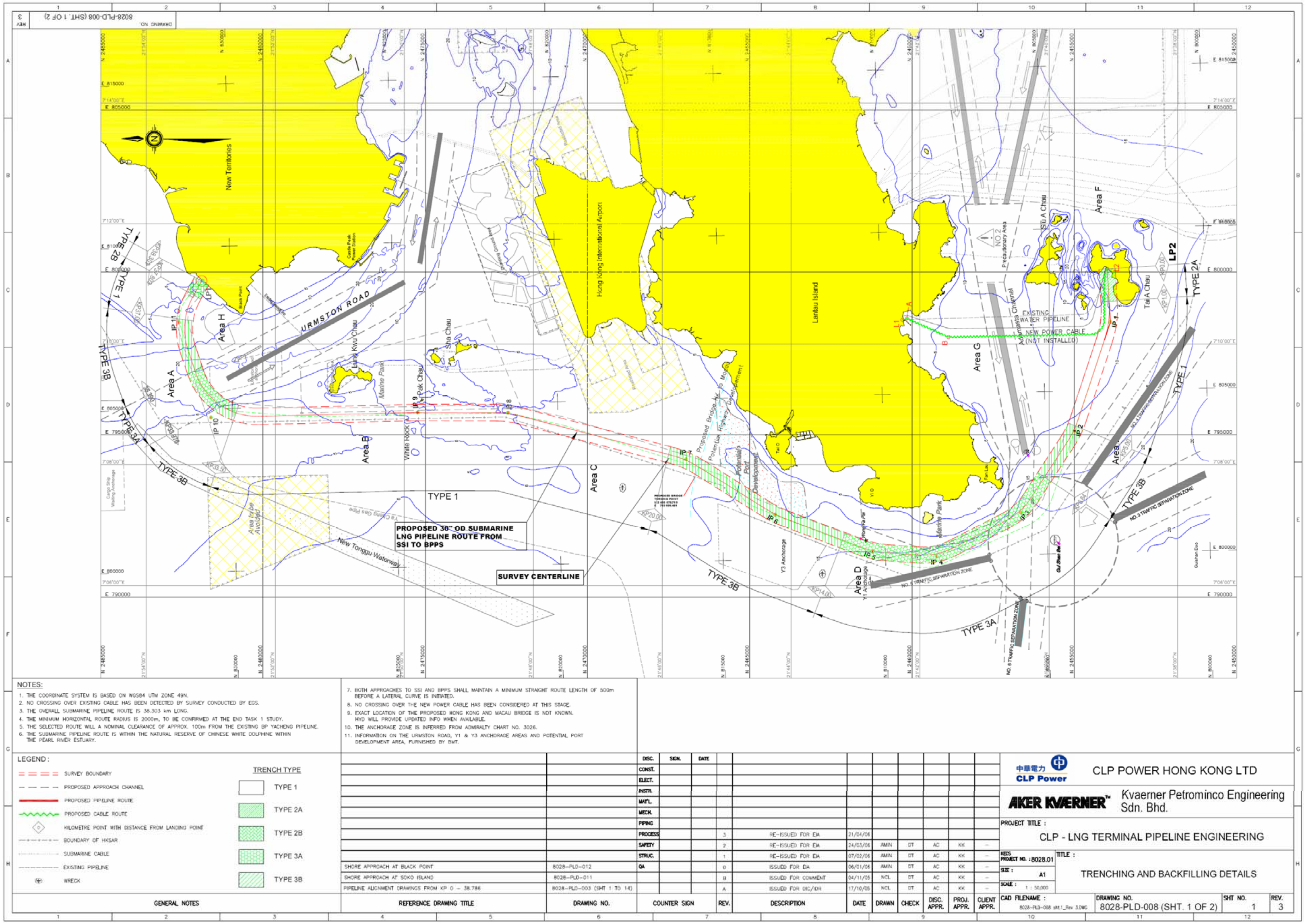
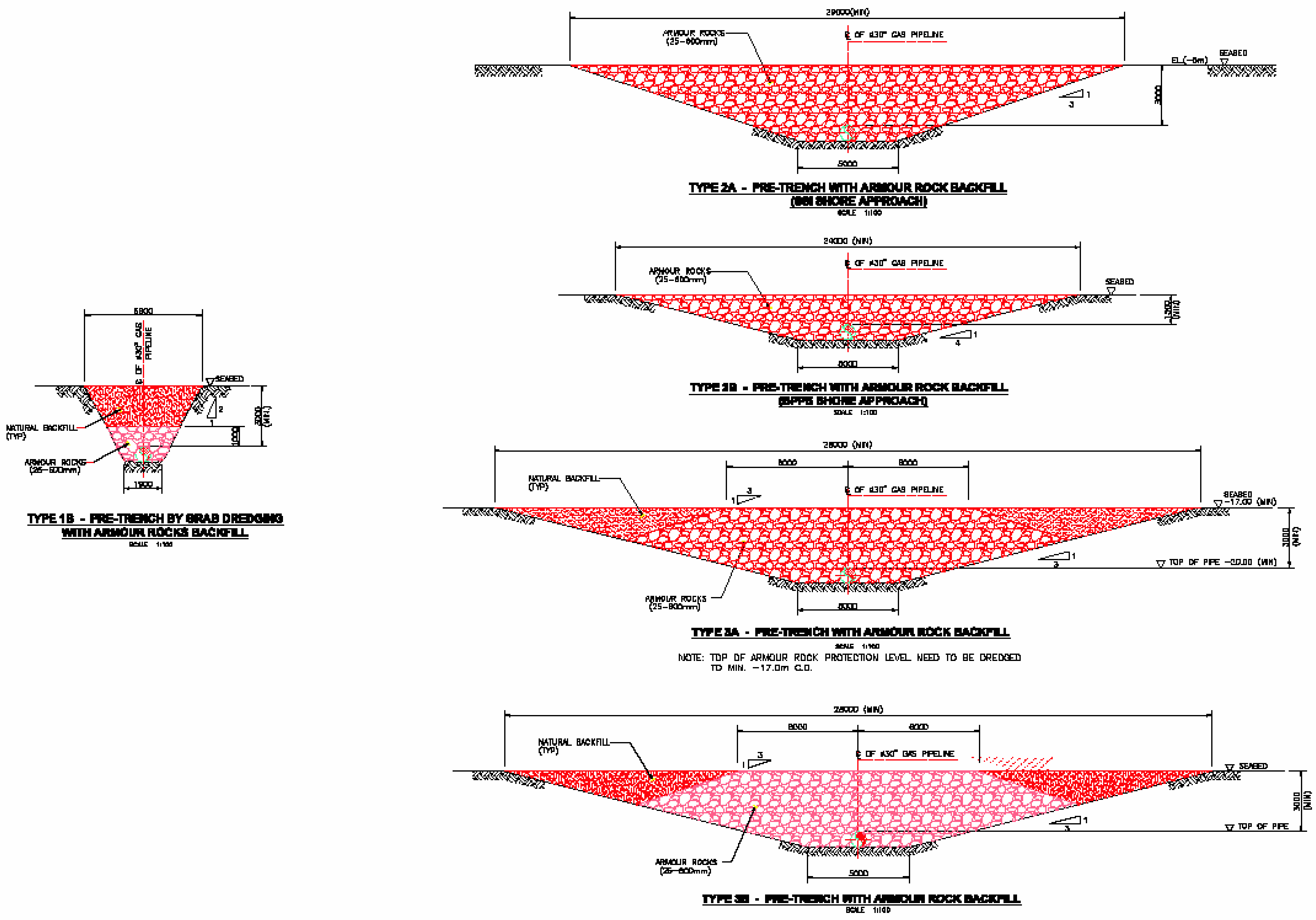


Figure 3.2 Pipeline Trench Types



3.2 MARINE TRAFFIC

The marine traffic influences the risks from the pipeline in two ways:

- It increases the potential for damage due to interference such as anchor drop/drag incidents; and
- In the event of a pipeline failure, marine traffic could exacerbate the consequential effects causing fatalities.

The marine vessel traffic volume was surveyed by BMT [4] using tracks of vessel movements obtained from radar. The important details pertinent to the current study are repeated here for completeness.

3.2.1 *Marine Vessel Activity along Pipeline Route*

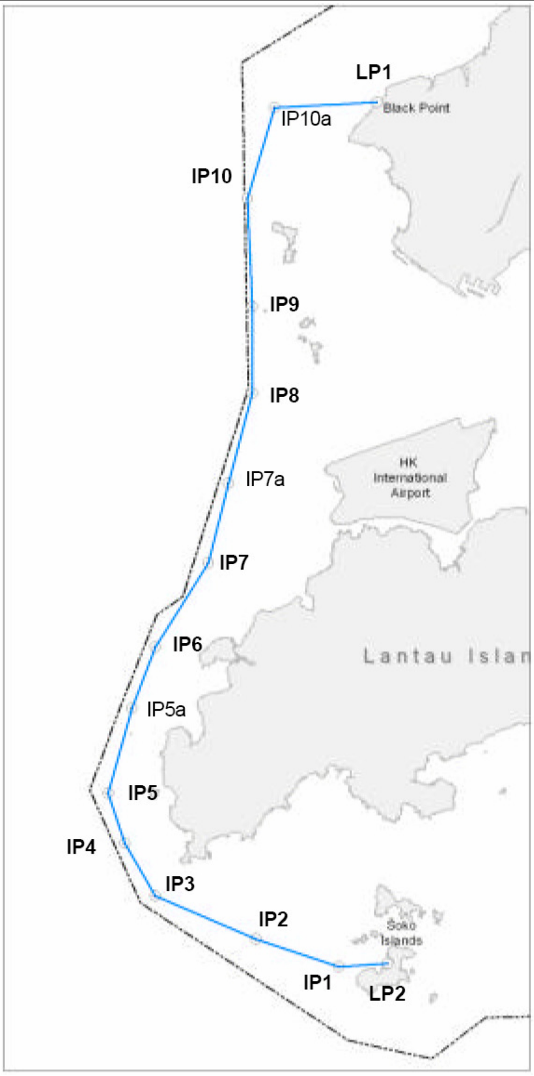
The marine traffic report [4] divides the pipeline route into sections using ‘gate posts’ that roughly correspond to key locations along the pipeline route. These same gate posts are adopted in the current study (*Figure 3.3*).

The South Soko approach (LP2-IP1) is characterised by local fishing activities and the movement of small craft. The pipeline heads westwards and crosses the Adamasta Channel between gates IP2-IP4. The marine traffic in this area is dominated by fast ferries and rivertrade activity. These fast ferries service Macau and Zhuhai and travel at 40-45 knots. There is also a traffic separation scheme (TSS) and turning buoy in this area. Section IP4-IP5a around the western edge of Lantau Island consists mainly of fishing vessels currently. IP5a-IP7 passes by the Y3 Anchorage area. It is understood that this anchorage is used by large oil tankers transferring their load to smaller vessels that service the Pearl River [10]. There is very little information available regarding this since the anchorage is outside Hong Kong waters, but the presence of such activity is confirmed by the existence of anchor marks on the seabed [8]. There are also plans to develop a container terminal (CT10) in this area. Although these plans are very tentative at the moment, a high level of pipeline protection (type 3B) is maintained through this section.

IP7-IP10 is used by fishing vessels and rivertrade vessels en route between Tuen Mun and Macau/Zhuhai. The water is shallow in this region, ranging from 4-8m deep. This precludes its use by large draft vessels. This section also runs along the edge of the Sha Chau/Lung Kwu Chau Marine Park.

Gate post IP10a lies near the centre of Urmston Road. This is the main route for container ships, rivertrade vessels and fast ferries plying between Hong Kong and the ports of the Eastern Pearl River Delta.

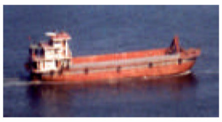
Figure 3.3 Reference Points for Proposed Pipeline



3.2.2 *Vessel Types*

The marine traffic consultant has calculated the marine traffic volume between pairs of gate posts based on radar tracks [4]. The vessel speeds and apparent size from the radar returns are interpreted into 6 marine vessel categories (*Table. 3.2*). The same categories are used for the current study.

Table 3.2 Vessel Classes Adopted for Assessment

Class	Type	Typical Length (m)	Typical Beam (m)	Typical Draft (m)	Typical Displace -ment (tonnes)	Typical Anchor Size (tonnes)
"A1" - Fishing Vessels & Small craft		5 – 30	2 – 7.5	1 - 3	1 – 400	< 1
"B1" - Rivertrade coastal vessels		35 – 75	8 - 12	2.5 – 4.5	1,500	< 2
"C1" - Ocean-going Vessels		75 – 350	12 - 45	4 - 15	1,500 – 150,000	2 – 15
"A2" - Fast Launches and Fast Ferries		10 – 30	3 - 7.5	1 – 2.5	1 - 150	< 0.1
"B2" - Fast Ferries		30 - 50	7.5 - 12	1.5 - 2.5	100 – 150	< 0.5
"C2" - Fast Ferries & Ocean-going Vessel	*As above*					

Based on this vessel classification, the population used in this study are as given in *Table 3.3*. The maximum population of fast ferries is assumed to be 450, based on the maximum capacity of the largest ferries operating on routes to Macau and Pearl River ports. However, the average load factor of fast ferries to Macau is 52% and Pearl River ports is 37% [11] while the overall average load factor considering all ferries is about 50% [10]. Hence, a distribution in ferry population was assumed as indicated in *Table 3.3*. This distribution gives an 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' (see *Section 3.2.3*). These are assumed to be small vessels with a population of 5.

Table 3.3 Vessel Population

Class	Population	
Fishing vessel	5	
Rivertrade coastal vessels	5	
Ocean-going vessels	21	
Fast launches	5	
Fast ferries	450 (largest ferries in peak hours, 4 hours a day)	3.75% of trips
	350 (average ferry in peak hours, 4 hours a day)	3.75% of trips
	280 (80% capacity, peak hours, 4 hours a day)	22.5% of trips
	175 (50% capacity, daytime operation, 9 hours a day)	52.5% of trips
	105 (30% capacity, late evening, 4 hours a day)	12.5% of trips
	35 (10% capacity, night time, 7 hours a day)	5.0% of trips
Other	5	

3.2.3 *Traffic Volume*

The traffic volume as provided by BMT [4] is given in *Table 3.4*. This is for the year 2003. BMT also provide predictions for the years 2011 and 2021 (*Table 3.5*). In this study, 2011 is used as the base case and 2021 as the future scenario. Two future scenarios are considered: with and without the development of the Tonggu Waterway.

The data in *Table 3.4* required further interpretation. Vessel class A2 is described as fast launches and fast ferries. The population of a fast launch is very different from that of a fast ferry and so a more precise breakdown is required. Some of these A2 fast ferries clearly belong in class B2 with the other fast ferries. Taking into consideration the timetable of ferries serving Macau and the Pearl River ports and information provided by the marine consultant [10], it was assumed that 55% of fast vessels along Urmston Road and 75% of fast vessels along the Adamasta Channel are fast ferries. For intermediate sections, such as near Sha Chau, an intermediate value of 65% was assumed.

Class C2 is described as fast ferries and ocean-going vessels. Since all fast ferries have now been accounted for, class C2 are assumed to comprise of cargo ships only. This is consistent with assumptions made in the marine activity report [4,10].

The data shows a small number of ocean-going vessels (class C1 and C2) along the route between gates IP6 and IP10. The shallow water along these sections negates the possibility that these are large vessels. They must be vessels at the smallest end of the distribution of ocean-going vessels, no more than 100m long [10]. More likely, they are rivertrade vessels. They were therefore treated as smaller vessels in the analysis by reclassifying them as either rivertrade or 'other' vessels.

Table 3.4 Traffic Volume across Gate Sections (Daily Average, 2003)

Vessel Class											Total
Vessel Speed range (m/s)				0 - 5			5 – 25			Other	
Vessel Length range (m)				0 - 30	30 – 75	75+	0 - 30	30 – 75	75+		
From		To		*"A1"* - Fishing Vessels & Small craft	*"B1"* - Rivertrade coastal vessels	*"C1"* - Ocean-going Vessels	*"A2"* - Fast Launches and Fast Ferries	*"B2"* - Fast Ferries	*"C2"* – Fast Ferries& Ocean-going Vessel		
ID	KP (approx)	ID	KP (approx)								
LP2	**0**	**IP1**	**2**	0	0	0	1	0	0	0	**1**
IP1	**2**	**IP2**	**7**	34	2	0	16	5	5	3	**65**
IP2	**7**	**IP3**	**11**	113	16	2	248	60	3	2	**444**
IP3	**11**	**IP4**	**16**	12	0	0	6	0	0	1	**19**
IP4	**16**	**IP5**	**19**	6	0	0	1	1	1	1	**10**
IP5	**19**	**IP6**	**22**	98	14	3	45	7	2	4	**173**
IP6	**22**	**IP7**	**25**	30	10	1	20	10	3	10	**84**
IP7	**25**	**IP8**	**28**	10	2	2	10	2	1	4	**31**
IP8	**28**	**IP9**	**34**	61	10	1	50	34	6	5	**167**
IP9	**34**	**IP10**	**37**	209	258	42	133	133	46	13	**834**
IP10	**37**	**LP1**	**38**	63	7	3	38	4	0	0	**115**
Total				**636**	**319**	**54**	**568**	**256**	**67**	**43**	**1943**

Note: Values >5 per day rounded to nearest 5.
Daily values based on total 9 day record / 9 (some rounding applies).

Table 3.5 Traffic Growth Forecast

Vessel Type	2011 compared to 2003	2021 compared to 2003
Ocean-going Vessel	-5%	+10%
Rivertrade Coastal Vessel	+5%	+15%
Fast Ferry	+10%	+30%
Fishing Vessel/ Small Craft/ Fast launch	+5%	+15%
Others	+5%	+15%

3.3 SEGMENTATION OF THE ROUTE

Based on the above discussions, the pipeline route was divided into 12 sections for analysis (*Table 3.6*, *Figure 3.4*). The first section is from LP2 to IP1, named South Soko Approach. Similarly the second section is chosen between gates IP1 and IP2, and named West Soko. The Adamasta channel spans IP2 to IP4 and so these are grouped into one section for analysis. Similar grouping is performed for the remainder of the pipeline.

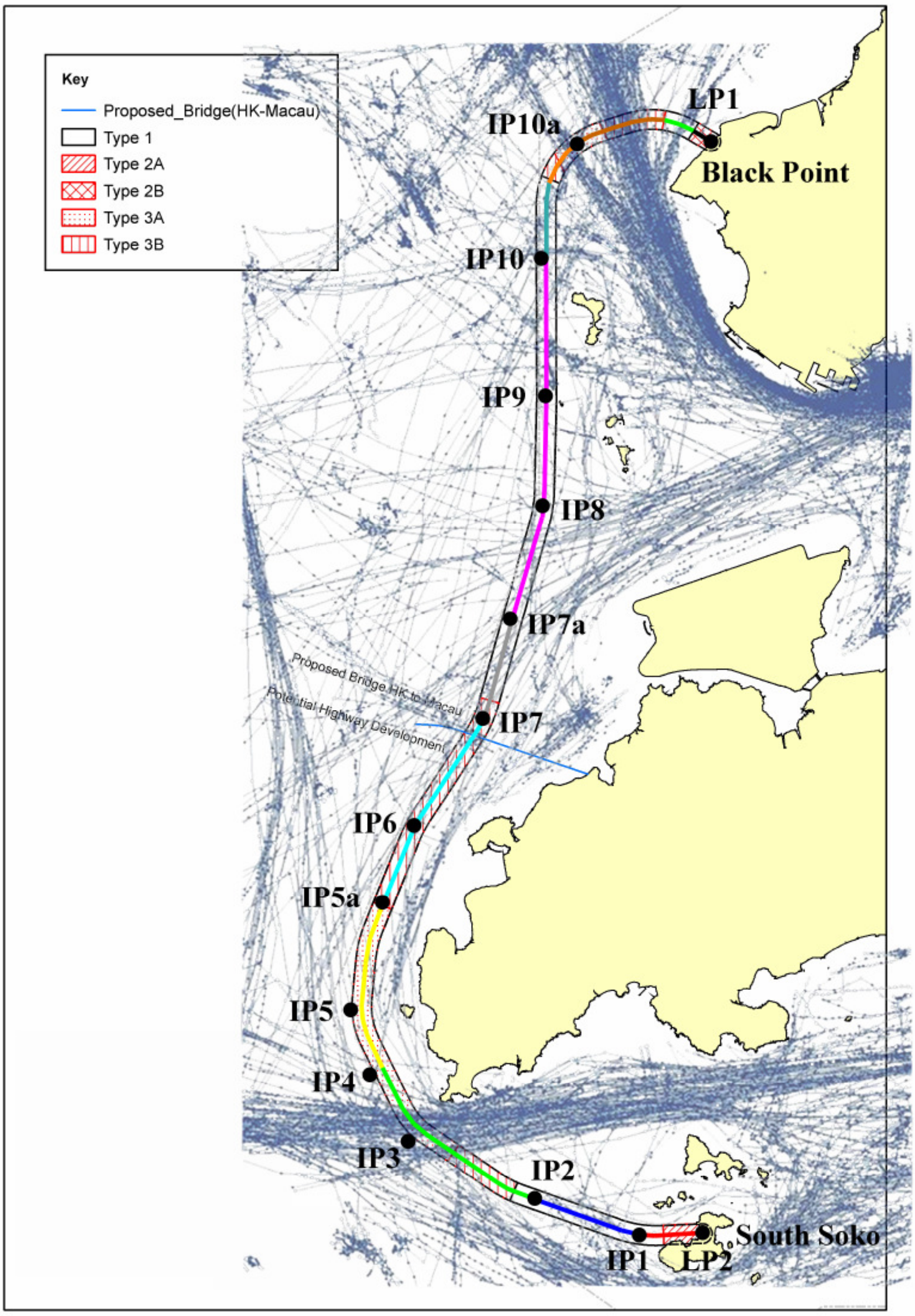
Gate IP10a warranted extra interpretation since it lies in the centre of Urmston Road. The section from IP10 to IP10a spans a change in rock armour protection from type 1 to type 3A/B. A careful examination of the radar tracks from marine vessels (overlaid in *Figure 3.4*) shows a higher density of vessels along this section pass close to gate IP10a i.e. within Urmston Road where there is greater rock armour protection on the pipeline. This section was therefore split into two, denoted North Lung Kwu Chau and Urmston Road West, and some assumptions made regarding the distribution of vessels between the two parts. It was assumed that roughly equal numbers of vessels traverse each part, the shorter length of the Urmston Road West section therefore getting a higher density of ships as observed in the radar tracks. Large vessels such as ocean-going vessels were assumed to pass entirely through Urmston Road West since the water would be too shallow in North Lung Kwu Chau.

Similarly, the final section of pipeline from IP10a to LP1 was split into 3 sub-sections to reflect changes in rock armour protection on the pipeline. These were named Urmston Road Central, Urmston Road East and Black Point Approach. Based on the radar tracks, about 95% of vessels were assumed to pass within Urmston Road Central. Of the remaining 5% of vessels, most were assumed to traverse the Urmston Road East section.

Table 3.6 Pipeline Segmentation

	Section	Gate		Kilometre Post		Length (km)	Typ. Water depth (m)	Trench type
		From	To	From	To			
1	South Soko Approach	LP2	IP1	0	1.6	1.6	5	2A
2	West Soko	IP1	IP2	1.6	4.5	2.9	8	1
3	Adamasta Channel	IP2	IP4	4.5	9.8	5.3	25	3B/3A
4	West Lantau	IP4	IP5a	9.8	14.2	4.4	20	3A
5	Tai O	IP5a	IP7	14.2	19.5	5.3	17	3B
6	North Lantau	IP7	IP7a	19.5	22.2	2.7	7	1
7	Sha Chau	IP7a	IP10	22.2	31.6	9.4	6	1
8	North Lung Kwu Chau	IP10		31.6	33.5	1.9	4	1
9	Urmston Road West		IP10a	33.5	34.7	1.2	20	3B/3A
10	Urmston Road Central	IP10a		34.7	37.0	2.3	20	3A/3B
11	Urmston Road East			37.0	37.8	0.8	5	1
12	Black Point Approach		LP1	37.8	38.3	0.5	4	2B

Figure 3.4 Segmentation of the Route



Based on the above discussion, the marine traffic volume used in the present analysis is summarized in *Table 3.7*. Additional ocean-going vessels were injected into Urmston Road as indicated in the marine consultant report [4].

Table 3.7 ***Traffic Volume Assumed for Base Case 2011***

Section		Traffic volume (ships per day) Fishing	River-trade	Ocean-going	Fast Launch	Fast ferry	Other	Total
1	South Soko Approach	0	0	0	1	0	0	1
2	West Soko	21	0	0	2	6	4	33
3	Adamasta Channel	126	16	7	83	260	4	496
4	West Lantau	11	2	3	4	9	4	33
5	Tai O	42	1	4	7	12	4	70
6	North Lantau	37	12	0	5	11	6	71
7	Sha Chau	79	22	0	28	44	27	200
8	North Lung Kwu Chau	21	3	0	24	31	8	87
9	Urmston Road West	21	2	6	23	30	2	84
10	Urmston Road Central	250	265	144	117	150	5	931
11	Urmston Road East	11	13	0	5	7	2	38
12	Black Point Approach	2	3	0	2	0	0	7
	Total	621	339	164	301	560	66	2051

Tables of traffic volume for the 2021 future scenarios were created in a similar manner. These are given in the main text (*Section 13.9.3*).

3.3.1 *Ocean-Going Vessel Distribution*

All classes of ship, with the exception of ocean-going vessels, have anchor sizes below 2 tonnes (*Table 3.2*), and it is noted that the entire length of the proposed pipeline will have rock armour protection designed to protect against at least 2 tonne anchors. Ocean-going vessels cover a very wide range of size. A breakdown of the size distribution for this class of marine vessels is given in *Table 3.8* [4, 10]. These vessels are predominantly found in Urmston Road which has type 3A/B rock armour protection to protect against anchors up to 20 tonnes. From the size distribution, it can be seen that the majority of these ships are below about 100,000 tonnes displacement and so the majority of anchors are below about 10 to 12 tonnes.

Table 3.8 ***Size Distribution of Ocean-Going Vessels***

Size Range (dwt) †	Displacement (tonnes)*	Length (m)	Anchor Size (tonne)	Proportion of Ships (%)
1,500 – 25,000	1,500 – 35,000	75 – 200	2 – 5	60
25,000 – 75,000	35,000 – 110,000	200 – 300	5 – 12	35
75,000 – 100,000	110,000 – 150,000	300 – 350	12 – 15	5

† Dead Weight (dwt) = Cargo + Fuel + Water + others
* Displacement = Total Weight = Hull + Machinery + Outfit + Dead Weight
Displacement has been assumed to be ~ 1.4 x dwt

4 HAZARD IDENTIFICATION

This section identifies the main hazards from the subsea gas pipeline during the operational phase. Hazard identification is based on a literature review as well as HAZID studies conducted for the proposed pipeline.

4.1 LITERATURE REVIEW

4.1.1 *Incident Databases and Pipeline Reports*

The Consultants (ERM) have examined incident databases such as the MHIDAS [12] and the IChemE Accident Database [13]. Only two pipeline incidents in offshore Vietnam have been reported in the Asia-Pacific region. These occurred at White Tiger and Vung Tau, both in 1994 and both were caused by anchor damage. No injuries were reported.

Relevant reports on major subsea pipeline failures (that caused fatality) by the National Transportation Safety Board have also been reviewed [14, 15]. A summary of a few main incidents from these sources are included in the following paragraphs.

Tiger Pass, Louisiana, 1996

On October 23, 1996, in Tiger Pass, Louisiana, the crew of the dredge *Dave Blackburn* dropped a stern spud (a spud is a large steel shaft that is dropped into the river bottom to serve as an anchor and a pivot during dredging operations) into the bottom of the channel in preparation for continued dredging operations. The spud struck and ruptured a 12" diameter submerged natural gas steel pipeline. The pressurised (about 930 psig) natural gas released from the pipeline enveloped the stern of the dredge and an accompanying tug. Within seconds of reaching the surface, the natural gas ignited and the resulting fire destroyed the dredge and the tug. All 28 crew members from the dredge and tug escaped into water or onto nearby vessels. No fatalities resulted.

The incident occurred due to incorrect information on the location of the gas pipeline that was passed on by the gas company to the dredging operator. The investigation report on the incident (by the National Transportation Safety Board) recommended that all pipelines crossing navigable waterways are accurately located and marked permanently.

Mississippi River Delta, 1979

In an incident in the Mississippi River Delta in 1979, four workers drowned attempting to escape a fire that resulted when a crane barge dropped a mooring spud into an unmarked high pressure natural gas pipeline.

Louisiana, 1987

In July 1987, while working in shallow waters off Louisiana, a fishing vessel, the menhaden purse seiner Sea Chief struck and ruptured an 8" natural gas liquids pipeline operating at 480 psi. The resulting explosion killed two crew members. Divers investigating found that the pipe, installed in 1968, was covered with only 6" of soft mud, having lost its original 3-foot cover of sediments.

Sabine Pass, Texas, 1989

A similar accident occurred in October 1989. The menhaden vessel Northumberland struck a 16" gas pipeline in shallow water near Sabine Pass, Texas. The vessel was engulfed in flames; 11 of the 14 crew members died. The pipeline, installed in 1974 with 8 to 10 feet of cover, was found to be lying on the bottom, with no cover at all.

4.1.2 *Pipeline Failure Databases*

There are a few international failure databases for gas and liquid transmission pipelines which are useful in identifying potential hazards and estimating the frequency of loss of containment incidents.

The most comprehensive database on offshore gas pipeline failures is available in a report published by the UK Health and Safety Executive entitled 'PARLOC 2001' [7]. The most recent version of this database covers incidents from the 1960s up to 2000. The information in this database is based on data obtained from regulatory authorities in the UK, Norway, the Netherlands, Denmark and Germany, Operators in the UK, Dutch and Danish sectors and published sources. The main causes of pipeline failure, as identified from a review of the PARLOC 2001 data, are listed in *Table 4.1*. Based on this, it can be seen that anchor/impact followed by internal corrosion are the main contributors to subsea pipeline failures.

A similar database on incidents involving offshore pipelines in the US has also been referred to [16]. This is based on incidents that are required to be reported to the US Department of Transportation (DOT) under the Federal Regulations. Out of 109 incidents reported during the period 1985 to 1994, only one incident involved a fatality, and only one incident involved leak ignition. The main causes of pipeline failure, as identified from a review of the US DOT database, are listed in *Table 4.2*. Based on this, it can be seen that third party damage and internal corrosion (characteristic of well fluid pipelines) are the main contributors to subsea pipeline failures.

Table 4.1 Causes of Subsea Pipeline Incidents from PARLOC 2001 [7]

Main cause	Detail	No. of Incidents of Loss of Containment		
		Platform Safety Zone(1)	Subsea Well Safety Zone(2)	Mid-line
ANCHOR	Supply Boat	6	-	-
	Rig or Construction	-	-	-
	Other/ Unknown	0	-	2
	Total	*6*	-	*2*
IMPACT	Trawl	-	-	6
	Dropped Object	-	-	-
	Wreck	-	-	1
	Construction	1	-	-
	Other/ Unknown	-	-	1
	Total	*1*	-	*8*
CORROSION	Internal	3	4	7
	External	1	-	2
	Unknown	1	-	2
	Total	*5*	*4*	*11*
STRUCTURAL	Expansion	-	-	-
	Buckling	-	-	-
	Total	-	-	-
MATERIAL	Weld Defect	2	-	1
	Steel Defect	2	1	1
	Total	*4*	*1*	*2*
NATURAL HAZARD	Vibration	-	-	-
	Storm	-	-	-
	Scour	-	-	-
	Subsidence	-	-	-
	Total	-	-	-
FIRE/ EXPLOSION	*Total*	-	-	-
CONSTRUCTION	*Total*	-	-	-
MAINTENANCE	*Total*	-	-	-
OTHERS	*Total*	*2*	*1*	*4*
TOTAL		18	6	27

(1) Platform safety zone and subsea safety zone refer to pipelines located within 500m of an offshore platform and subsea well respectively

(2) Mid-line refers to pipelines located more than 500m from a platform or subsea well.

Table 4.2 Causes of Subsea Pipeline Incidents from US DOT Database [16]

Cause of Failure	Description of Cause	No. of Incidents	% of Total Incidents	Incidents Considered (1)
1. EXTERNAL FORCE		25	29.8%	24
Earth Movement	Subsidence, landslides	2	2.4%	2
Heavy Rains/Floods	Washouts, floatation, scouring	1	1.2%	
Third Party		21	25.0%	21
Previously Damaged Pipe	Where encroachment occurred in the past	1	1.2%	1
2. CORROSION		45	53.6%	3
External Corrosion	Failure of coating/CP	3	3.6%	3
Internal Corrosion		42	50.0%	
3. WELDS & MATERIALS		4	4.8%	4
Defective Fabrication Weld	Welds in branch connections, hot taps, weld-o-lets, sleeve repairs	2	2.4%	2
Defective Girth Weld		2	2.4%	2
4. EQUIPMENT & OPERATIONS		3	3.6%	
Equipment Failure	Malfunction of control or relief equipment, failure of threaded components, gaskets & seals	3	3.6%	
5. OTHERS		7	8.3%	7
Unknown		7	8.3%	7
TOTAL		**84**	**100%**	**38**

1. Only these incidents are considered relevant to the proposed pipeline.

4.1.3 *Incident Records and Protection Measures for Pipelines in Hong Kong Waters*

A review of existing and proposed subsea pipelines in Hong Kong waters including the level of protection provided are reviewed in the following paragraphs.

Subsea Pipelines

Existing subsea pipelines in Hong Kong waters are as follows:

- The 28" *natural gas pipeline* from Yacheng Field, South China Sea (90km south of Hainan Island) to CLP's Black Point power station was constructed in 1994/95. The total pipeline length is 778km. Within Hong Kong waters, the length of pipeline is about 5km and the water depth varies from 4m to 25m. The pipeline is trenched with a minimum of 1m rock armour protection at sections where it crosses the shipping route Urmston Road and at the anchorage areas near the shore. Similar protection (i.e. 1m rock armour and 1m backfill) is also provided outside Hong Kong waters at the Lingding channel crossing and Jiuzhou channel crossing. The pipeline is laid on the seabed for the remaining length. There has been no incident of damage reported in Hong Kong waters although an incident occurred during construction when the unprotected section of the pipeline was buckled by the anchor lines of the barge laying the rock armour.

- the 20" dual *aviation fuel pipelines* between Sha Chau jetty and the airport (about 5km length), installed in 1997, are laid in a 2.2m trench and provided with sand cover plus rock armour protection. The water depth along the route varies from 4-7m. There has been no incident of damage reported;

- the Airport Authority propose to construct another 5km submarine *aviation fuel pipeline* from Sha Chau jetty to the new tank farm in Tuen Mun. The pipeline will be crossing the Urmston Road shipping route and similar protection as for the existing pipelines (i.e. rock armour protection) is proposed. It is understood that the rock armour protection will be designed for 22 tonne anchors;

- the *town gas* subsea pipelines are also reported to have no damage record. These pipelines are laid at a depth of 2 to 3m below seabed and protected by engineering backfill materials;

- the Hong Kong Electric Company recently laid a pipeline from its Lamma Power Station Extension to Shenzhen LNG Terminal. The pipeline is jetted to 3m below seabed and protected with rock armour in high risk areas near the anchorages and shore approaches; and

- the recently installed *town gas* subsea pipeline from Shenzhen to Tai Po is jetted to 3m below seabed with additional rock armour protection in high risk areas.

By comparison, the proposed CAPCO pipeline will be laid in waters between 4 and 25m deep. The pipeline will be provided with 3m of rock cover except in areas of shallow water where it will have 1m of rock cover. These rock cover requirements are based on water depth (which determines the size of vessels) and marine traffic volume. The measures proposed are in line with, or exceed, comparable pipeline installations.

4.2 *HAZID REPORT*

A Hazard Identification (HAZID) workshop was held on 15th February 2006 as part of this QRA Study for the pipeline. Representatives from CLP Power, ExxonMobil and BMT participated in the hazard sessions. Various hazards considered relevant for this pipeline are discussed in the worksheets presented in *Table 4.3*.

Table 4.3 HAZID Worksheet

System: 1. Pipeline – General

Subsystem: 1. Third party

Hazards/ Keywords	Description/ Causes	Consequences	Safeguards	Recommendations
1. Anchor Drag	1. Emergency anchoring for vessel underway due to loss of steerage, power or control, either due to mechanical problems or due to collision events.	1. Possibility of damage to external coating, damage to pipe requiring remedial action.	1. Engineered rock protection with respect to vessel sizes/types.	1. Periodic survey along the route to be carried out to ensure integrity of the protection.
			2. Depth of cover.	
	2. Drag from anchorage areas under storm condition.	2. Potential loss of containment leading to gas release. Impact on passing vessels and shore population. Vessel involved in the incidents may sink due to loss of buoyancy caused by the gas bubbling.	3. Route avoiding anchorage areas.	
			4. Concrete external coating.	
			5. Heavy wall pipe in shore approaches.	
		3. Disturbance to the rock cover protection. Possible exposure of the pipe.	6. Marking marine charts of the pipeline route.	
	3. Anchoring by vessels outside anchorages.		7. Shore population is at least 3km away along the route except near the shore approach.	

System: 1. Pipeline – General

Subsystem: 1. Third party

Hazards/ Keywords	Description/ Causes	Consequences	Safeguards	Recommendations
2. Anchor Drop	1. Same as cause 1 & 3 of anchor drag hazard	1. Same as consequence 1, 2 & 3 of anchor drag hazard but less severe.	1. Same as for anchor drag hazard.	
3. Dropped Object	1. Loss of cargo 2. Construction activities	1. Same as consequence 1, 2 & 3 of anchor drag hazard but less severe.	1. Same as safeguards 1, 2, 4, 5, & 7 of anchor drag hazard.	
4. Dumping	1. Dumping of construction waste and other bulk materials outside of designated dumping grounds.	1. Minor surface damage.	1. Same as safeguards 1, 2, 4, 5, & 7 of anchor drag hazard.	
5. Grounding	1. Navigation error, loss of control due to mechanical or adverse weather.	1. Same as consequence 1,2 & 3 of anchor drag hazard. 2. Displacement of the pipeline leading to exposure	1. Burial depth appropriate to the type of shipping activities	
6. Vessel Sinking	1. Collision, foundering.	1. Same as consequence 1, 2 & 3 of anchor drag hazard.	1. Route avoids shipping channel where possible.	

System: 1. Pipeline – General

Subsystem: 1. Third party

Hazards/ Keywords	Description/ Causes	Consequences	Safeguards	Recommendations
7. Fishing & Trawling	1. Operation of trawl board and other fishing/trawl gear.	1. No damage to the pipeline.	1. Pipeline is buried to 3m below the seabed with rock cover flush with seabed. With respect to shore area at BPPS, it is buried to 1.5m with rock cover flush with seabed.	
8. Dredging	1. Impact from dredge bucket or drag head. Expected location of maintenance dredging are Adamasta Channel, along the Urmston road, along the TSS	1. Same as consequence 1, 2 & 3 of anchor drag hazard but less severe.	1. Burial depth appropriate to the type of shipping activities. 2. Engineered rock protection with respect to vessel sizes/types. 3. Depth of cover. 4. Marking marine charts of the pipeline route. 5. Concrete external coating.	
9. Service crossing or other services in the vicinity	1. No crossings envisaged			
10. HZMB Construction	1. Piling for bridge structures near the pipeline, dredging, construction vessel movement, anchoring and dropped object	1. Same as consequence 1,2 & 3 of anchor drag hazard	1. Interface with HZMB project owner to co-ordinate designs and schedule 2. Engineered rock protection with respect to vessel sizes/types. 3. Depth of cover.	2. Develop and implement procedures for safeguarding the pipeline during HZMB construction

System: 1. Pipeline – General

Subsystem: 1. Third party

Hazards/ Keywords	Description/ Causes	Consequences	Safeguards	Recommendations
			4. Concrete external coating.	
11. HZMB Operation	1. Vehicle fall off the bridge	1. Same as consequence 1 & 3 of anchor drag hazard	1. Same as safeguards 1, 2 & 4 of anchor drag hazard	

System: 1. Pipeline – General

Subsystem: 2. Natural

Hazards/ Keywords	Description/ Causes	Consequences	Safeguards	Recommendations
1. Scouring	1. Current and wave actions	1. Possible reduction of cover	1. Alignment is away from areas of high currents	
			2. Engineered rock cover	
			3. Periodic surveys along the route	
2. Seismic event	1. Low seismic area	1. No damage	1. None required	
3. Subsidence	1. No issue			

System: 1. Pipeline – General

Subsystem: 3. Construction

Hazards/ Keywords	Description/ Causes	Consequences	Safeguards	Recommendations
1. Damage to pipeline during construction	1. Damage after pipelay	1. Possible release if gas taken in	1. Pre-commissioning procedures to ensure integrity of pipeline before gas-in	

System: 1. Pipeline – General

Subsystem: 4. Operational

Hazards/ Keywords	Description/ Causes	Consequences	Safeguards	Recommendations
1. Internal corrosion	1. No issue for regassified LNG since it is clean and dry gas			
2. External corrosion	1. Sea-water; corrosive environment	1. Loss of wall thickness leading to potential leak	1. Coating system 2. Sacrificial anode system 3. Designed for intelligent pigging	
3. Pressure cycling	1. Pipeline pressure will vary with time of day, loads etc	1. Metal fatigue leading to crack	1. Design will consider pressure cycles	
4. Material defect/ construction defect		1. Possible leaks	1. Quality control during manufacture and construction	

System: 1. Pipeline – General

Subsystem: 5. Interface at Terminal End

Hazards/ Keywords	Description/ Causes	Consequences	Safeguards	Recommendations
1. South Soko option will include a pig launching facility. This includes piping and valving which is covered in the TQRA				

System: 1. Pipeline – General

Subsystem: 6. Interface at GRS End in BPPS

Hazards/ Keywords	Description/ Causes	Consequences	Safeguards	Recommendations
1. To be covered as part of GRS				

System: 2. Pipeline - Future Developments

Subsystem: 1. All

Hazards/ Keywords	Description/ Causes	Consequences	Safeguards	Recommendations
1. Potential future CT10 construction	1. Dredging to create a new access channel, building of sea wall in proximity to the pipeline, construction vessel movement, introduction of more shipping activity, anchoring	1. Damage to pipeline	1. Current alignment is based on existing seabed profile. Flexibility for alternative measures to be designed	
2. Tonggu channel	1. As currently shown, this channel is outside HK waters	1. No impact along the proposed route		

System: 3. GRS

Subsystem: 1. All

Hazards/ Keywords	Description/ Causes	Consequences	Safeguards	Recommendations
1. Leak from tappings, flanges and piping	1. Corrosion, mechanical failure, etc	1. Potential loss of containment	1. Gas and fire detection	

System: 3. GRS

Subsystem: 1. All

Hazards/ Keywords	Description/ Causes	Consequences	Safeguards	Recommendations
	2. Maloperation during maintenance (including dropped object), pigging		2. Shutdown system	
			3. Operating and maintenance procedures	
2. Overpressure downstream of letdown valve		1. Potential loss of containment	1. Active/monitor and slam shut system	

4.3 *HAZARDOUS PROPERTIES OF NATURAL GAS*

The natural gas to be transmitted by the pipeline predominantly contains methane (87.6 - 96.1 mol%). Other components of the gas include ethane (3.4 – 7.6 mol%), propane (0.4 - 3.1%) and butane (0.07 – 1.7%). It is a flammable gas that is lighter than air (buoyant). The properties of natural gas are summarised in *Table 4.4*.

Table 4.4 Properties of Natural Gas

Property	Natural Gas
Synonyms	Methane
State	Gas
Molecular Weight	16.7 - 18.7
Density (kg/m^3)	0.55 (at atmospheric conditions)
Flammable Limits (%)	5 - 15
Auto-ignition Temperature (°C)	540

4.4 *DISCUSSION ON SUBSEA PIPELINE HAZARDS*

The incident records highlight the potential for damage to subsea pipelines from marine activity such as fishing, dredging and anchoring as well as the potential for the vessel (that caused damage) to become involved in the fire that follows.

A review of subsea pipeline incidents in Europe and the US suggests that third party damage (including anchor and impact incidents) and internal corrosion are the main contributors to subsea pipeline failures.

It is noted that the above databases covers a large proportion of well fluid pipelines where internal corrosion is relevant as compared to clean natural gas transported from an LNG terminal as considered in this study.

Most existing pipelines in Hong Kong waters have some rock cover protection in addition to being buries, although it is noted that these pipelines are either crossing shipping channels or laid in waters with high levels of marine activity.

A brief description of the main causes of failure of a subsea pipeline is included in the following paragraphs.

4.4.1 *External Impacts*

Anchor drop/drag is the dominant cause of potential failure or damage to a subsea pipeline. This occurs when a ship anchor is dropped inadvertently across the pipeline. The type of damage that could be caused will vary depending on the size of anchor and other factors such as pipeline protection.

Anchor Drop

The decision for a mariner when to drop an anchor depends on the particular circumstances and the proximity of the pipeline route to the flow of marine traffic, port/harbour areas and designated anchorage locations. In fairways, traffic will normally be underway where the necessity to drop anchor is expected to be low. Consistent with normal practice, the pipeline route will be identified on nautical charts. The mariner is then provided with the necessary information to avoid anchoring where the pipeline could be damaged.

Emergency situations may arise such as machinery failure or collision thereby limiting the choice where to drop anchor. Such a decision will, as part of a mariner's responsibility, be influenced by the particular circumstances and the pipeline route delineated on the navigation chart.

Anchorage area Y3 is believed to be used by oil tankers transferring their load to smaller vessels. Although it is expected that vessels should be aware of all subsea installations (including gas pipelines) since these are marked on the admiralty nautical charts, erroneous dropping of anchor (i.e. error in position at the time of deployment) are known to occur. Under adverse weather conditions, it is also possible for a vessel anchored at the anchorage area to drift with its anchor dragging along the seabed.

Anchoring activity along the pipeline route is taken into consideration in the analysis when assigning failure frequencies for anchor damage (*Section 5.3*)

Anchor Drag

Anchor drag occurs due to poor holding ground or adverse environmental conditions affecting the holding power of the anchor. The drag distance depends on properties of the seabed soil, the mass of ship and anchor and the speed of the vessel. If there is a subsea pipeline along the anchor drag path, anchor dragging onto the pipeline may result in localised buckling or denting of the pipeline, or over-stressing from bending if the tension on the anchor is sufficient to laterally displace the pipeline. A dragged anchor may also hook onto a pipeline during retrieval causing damage as a result of lifting the pipeline.

Anchor dragging is taken into consideration when assigning anchor damage frequencies in the analysis (*Section 5.3*).

Vessel Sinking

Vessel sinking in the vicinity of the pipeline may cause damage to the pipeline resulting in loss of containment. Vessel sinking will depend on the intensity of marine activity in a given area. For the years 1990 to 2005, there were 446 incidents of vessel sinking in Hong Kong waters [17]. This averages 28 cases per year. Most of the recorded incidents occurred in Victoria Harbour and the Ma Wan Channel and involved mainly smaller vessels of less than 1,000 dwt, which will have less impact on a pipeline buried 3m below the seabed. The probability that a vessel sinking incident will impact the proposed pipeline is therefore considered to be low, in comparison to anchor impact damage. Additionally, pipeline damage due to vessel sinking is included in the historical pipeline failure data for external impact used in this study (see *Table 4.1*).

Dropped Objects

A further detailed dropped object risk assessment will be carried out after final design definition of the Pipeline route, and interface issues with HZMB Bridge and BCF.

The dropped object risks to the sub-sea pipeline are already included in the Pipeline QRA ref: Annex 13B Section 4.4.1. Further analysis of the risk from dropped objects will be carried out after final design definition of the pipeline route, and interface issues with the Hong Kong-Zhuhai-Macau (HKZM) Bridge and BCF established. For the construction of the HKZM Bridge, CAPCO will consider the largest bridge segments advised by Highways/NT Region as 100 tonnes. Procedures will be developed to safeguard the pipeline during bridge construction.

Objects other than anchors may be dropped from vessels passing over the pipeline or vessels operating in the vicinity, e.g. those carrying out construction of new subsea installations, new harbour developments, etc. The dropped objects may include construction tubulars, shipping containers, construction/maintenance equipment, etc.

The pipeline will be lowered to 3m below seabed and protected by at least 1m of rock armour. Given the likely sizes of dropped objects and the level of pipeline protection provided, loss of containment due to dropped objects is not considered to be a significant contributor to the risk and is not included in the analysis.

Aircraft Crash

The pipeline route runs within 3.7km of the threshold of runway 07L at Chep Lap Kok Airport. Although rare, the possibility exists for aircraft to crash on final approach to landing, or shortly after take-off. Such a crash may be onto the pipeline, albeit with a small probability.

The water along this section of the pipeline route is about 7m deep with the pipeline buried 3m below the seabed and protected by 1m of rock armour and 2m of natural backfill. Aircraft are constructed from light weight materials such that even a fully loaded Boeing 747 weighs only 400 tonnes. Aircraft also readily breakup on impact with water, scattering the debris over a larger area.

Given that the pipeline is buried and protected and aircraft have limited weight, it is considered not possible for an aircraft to damage the pipeline.

Fishing Activity

Based on the BMT report [4], there is active fishing along much of the proposed pipeline route. Many of the techniques involve towing of a variety of equipment along the seabed. Pipeline damage from fishing gear can occur due to impact, snagging of nets or trawl door on the pipeline or a "pull over" sequence. Impact loads mainly cause damage to the coating whilst pull over situations can cause much higher loads, which could lead to damage of the steel pipeline itself.

The vessels of concern are stern trawlers with lengths up to 30m. Considering the size and weight of trawl gear and since the pipeline will be lowered to 3m below seabed and protected by rock armour for the entire route, pipeline damage due to trawling activities are not possible and are not considered further.

Dredging Activities

Dredging vessels could cause damage due to dredging operations involving cutting heads. They could also cause damage to the pipeline by anchoring.

It is assumed that dredging operations will be closely monitored and controlled and therefore there is no potential for pipeline damage due to dredging.

4.4.2 *Spontaneous Failures*

Corrosion

Corrosion is one of the main contributors to pipeline failures. Corrosion is attributed mainly to the environment in which they are installed (external) and the substances they carry (internal).

The proposed pipeline will be protected against external corrosion by sacrificial anodes in addition to an asphalt coating. However, ineffective corrosion protection due to a failure or breakdown of the protection system could cause external corrosion resulting in general or local loss of wall thickness leading to pipeline failure.

Historically, internal corrosion is a greater cause of pipeline failure compared to external corrosion. However, the proposed pipeline will transport gas that does not contain components that induce corrosion such as water/moisture, carbon dioxide, hydrogen sulphide, etc. This will largely alleviate the effects of internal corrosion.

Despite these considerations, loss of containment due to corrosion (both internal and external) remains a possibility and is included in the analysis.

Mechanical Failure

Mechanical failure of the pipeline could occur for various reasons, including material defect, weld failure, etc. Stringent procedures for pipeline material procurement, welding and hydrotesting should largely mitigate against these hazards. In any case, it remains a credible scenario and is included in the frequency data.

4.4.3 *Natural Hazards*

Natural hazards such as subsidence, earthquake and typhoon may cause varying degrees of damage to pipelines.

Soft soil can sometimes suffer from localised liquefaction which can result in pipelines floating out of their trenches. The pipeline will be designed to withstand such loads, based on detailed seabed investigations.

Environmental loads (currents and waves) on the pipeline during the construction phase can compromise the lateral and vertical on-bottom stability of the pipeline on the seabed. This problem becomes more acute in shallower waters (near the shore) where the pipeline attracts a higher level of environmental loads. The pipeline will be designed to withstand these environmental loads. Once it is jetted/lowered to 3m below the seabed, it would not be exposed directly to 100 year return wave loads.

Based on the above considerations, pipeline damage due to natural hazards is considered negligible and is not assessed further in this study.

5 FREQUENCY ANALYSIS

5.1 OVERVIEW

This section presents the base failure frequency data for the hazards identified as having damage potential in *Section 4*. The approach to frequency analysis is based on the application of historical data worldwide for similar systems, modified suitably to reflect local factors such as proximity of the pipeline route to busy shipping channels and anchorages.

Event tree analysis was used to determine the probabilities of various hazard outcomes (such as flash fire) occurring, following a release.

5.2 HISTORICAL DATA

The international database that is most comprehensive in its coverage of subsea pipelines is PARLOC 2001 [7]. The most recent version of this database which was used in this study covers incidents from the 1960s until 2000. Incidents recorded in the database have been classified according to several categories, including:

- Failure location, i.e. risers, pipelines within 500m of an offshore platform, pipelines within 500m of a subsea well and mid-line (pipelines located more than 500m from a platform or a subsea well). Failure data pertaining to risers is not relevant to this study and has therefore been excluded;
- Pipeline contents. The database includes both oil and gas pipelines. Where the contents in the pipeline have an impact on failure rate, such as corrosion, only incidents pertaining to gas pipelines are considered; and
- Pipeline type, i.e. steel pipelines (both pipe body and fittings) and flexible lines. Only failures involving the pipe body of steel pipelines are considered here.

A breakdown of the incidents recorded in PARLOC 2001 by failure location is shown in *Table 5.1.* The number of incidents of loss of containment that have occurred within 500m of a platform or a subsea well is almost equal to the number of incidents that have occurred away from it (i.e. mid-line). The higher failure rate in the vicinity of an offshore installation (an order of magnitude higher than mid-line) is due to the effect of increased ship/barge movements in the vicinity and the potential for anchor damage as a result.

The proximity of some sections of the proposed pipeline route to high marine traffic environment could be regarded as similar to the environment in the vicinity of the platform safety zone although it is not strictly comparable.

Table 5.1 Failure Rate Based on PARLOC 2001 [7]

Region of Pipeline	Operating Experience	No. of Incidents	Failure Rate
Mid-line	297,565 km-years	27	9.1×10^{-5} /km/year
Platform safety zone	16,776 years (8,388 km-years)*	18	1.1×10^{-3} /year (2.1×10^{-3} /km/year)
Subsea well safety zone	2,586 years (1,293 km-years)*	6	2.3×10^{-3} /year (4.6×10^{-3} /km/year)
Total	307,246 km-years*	51	1.66×10^{-4} /km/year

* The number of years in the case of platform and subsea well safety zone is multiplied by 0.5km of safety zone to obtain corresponding km-years

The main causes of pipeline failure are summarised in *Table 5.2*, based on the causes identified in PARLOC 2001. As discussed earlier, anchor/impact followed by internal corrosion are the main contributors to pipeline failure.

Table 5.2 Main Contributors to Subsea Pipeline Failure (PARLOC 2001)

Cause	Platform Safety Zone	Subsea Well Safety Zone	Mid-line	Total
Anchor/Impact	7 (39%)	-	10 (37%)	17 (33%)
Internal corrosion	3 (17%)	4 (67%)	7 (26%)	14 (27%)
Corrosion -others	2 (11%)	-	4 (15%)	6 (12%)
Material defect	4 (22%)	1 (17%)	2 (7%)	7 (14%)
Others	2 (11%)	1 (17%)	4 (15%)	7 (14%)
Total	18	6	27	51

5.2.1 *Analysis of Failure Causes*

The failure frequency derived from the PARLOC 2001 data is further filtered to discount those factors that do not apply to the proposed pipeline. In the case of factors that could have greater influence on the failure rate for the proposed pipeline (such as anchor/impact), appropriate increase factors are adopted.

Corrosion and Material Defect

Based on experience in Europe (*Table 5.2*), internal corrosion tends to be a greater problem than external corrosion. For the proposed pipeline, failures due to internal corrosion are expected to be less likely as the gas handled is clean, unlike gas transported from wells/platforms which may contain moisture and hydrogen sulphide. Also, it is assumed that the condition of the pipeline will be monitored periodically and maintenance work carried out as necessary.

Failures due to defects in materials and welds are also expected to be lower than implied by the historical record due to technological improvements. The database for PARLOC 2001 dates back to the 1960s; there have been significant improvements in pipe material and welding over the last 10 to 20 years. An 80% reduction is therefore assumed for all forms of corrosion and material defects.

Taking the mid-line data as the most representative for the proposed pipeline, the failure rate is therefore derived as 13 incidences in 297,565 km-years with 80% reduction, giving 8.7 x 10^{-6} /km/year.

The PARLOC 96 report [18] provides a breakdown of loss of containment incidents due to corrosion and material defect for gas pipelines greater than 5km in length. The failure rate for such pipelines is lower at 5.9 x 10^{-6} /km/year (0.7 failures in 119,182 km-years; the km-years are lower because only gas pipelines are considered). This value is considered more appropriate for the proposed pipeline. Unfortunately, a more current value could not be extracted from PARLOC 2001 due to a difference in presentation format of the data. However, a downward trend in failure frequencies is to be expected as technology improves and so 5.9 x 10^{-6} /km/year is considered to be reasonable. Incorporating an 80% reduction again gives a corrosion/defect frequency of 1.18 x 10^{-6} /km/year.

Anchoring/Impact Incidents

There is a significant difference in the failure rate due to anchor/impact incidents for pipelines within 500m of an offshore platform (8.3 x 10^{-4}/km/year) as compared to mid-line (3.4 x 10^{-5} /km/year). A further breakdown of incidents based on pipeline diameter is given in *Table 5.3*.

Table 5.3 Frequency of Loss of Containment Incidents due to Anchor/Impact- Breakdown by Pipe Diameter & Location

Location	Frequency (per km per year) <10" diameter	10 to 16" diameter	18 to 24" diameter	24 to 40" diameter
Mid-line	1.53 x 10^{-4}	2.26 x 10^{-5}	1.76 x 10^{-5}	1.37 x 10^{-5}
Safety zone	6.68 x 10^{-4}	1.94 x 10^{-3}	4.24 x 10^{-4}	8.6 x 10^{-4}

It is seen from the above that the failure rate (for mid-line) for larger diameter pipelines is lower by an order of magnitude in comparison to smaller diameter pipelines.

As discussed previously, it is considered that the likelihood of pipeline damage due to anchor/impact incidents may be related to the level of marine activity (this is taken to be a combination of marine traffic and anchoring activity). The frequency of pipeline failure due to these causes has therefore been derived as a function of three levels of marine activity: high, medium and low. Frequency values are based on the large diameters pipes of 24-40" as given in *Table 5.3* since these are the most relevant to the proposed CAPCO pipeline.

For locations with high marine activity, a frequency of 8.6×10^{-4} /km/year is adopted. For low marine activity, 1.37×10^{-5} /km/year is used. An intermediate value of 10^{-4} /km/year is also applied to locations with medium levels of marine activity. This is discussed further in *Section 5.3* where alternative calculations based on emergency anchor deployment frequency are also presented for comparison.

These failure frequencies from PARLOC assume minimal protection for the pipeline. The proposed CAPCO pipeline will be provided with rock armour protection over its entire length. To allow for this, the failure frequencies are reduced by appropriate factors as discussed in *Section 5.4*.

Other Causes

"Other" causes include blockages, procedural errors, pressure surges etc. As with corrosion, improvements in technology and operating practices are expected to reduce this significantly and so a general 90% reduction is assumed for failures due to other causes. This gives a frequency of 1.34×10^{-6}/km/year (4 cases in 297,565 km-years with 90% reduction).

5.3 ALTERNATE APPROACH TO ANCHOR DAMAGE FREQUENCY

While international data is commonly applied to infer failure rates for Hong Kong subsea pipelines, in this section an alternative approach is adopted for comparison. This is based on the marine traffic incident rate, since such incidents are more likely to result in emergency anchoring. In the first instance, the effects of rock armour protection are neglected to allow these calculations to be compared with historical data from PARLOC. The effects of rock armour protection are then incorporated as described is *Section 5.4*.

5.3.1 Frequency of Anchor Drop

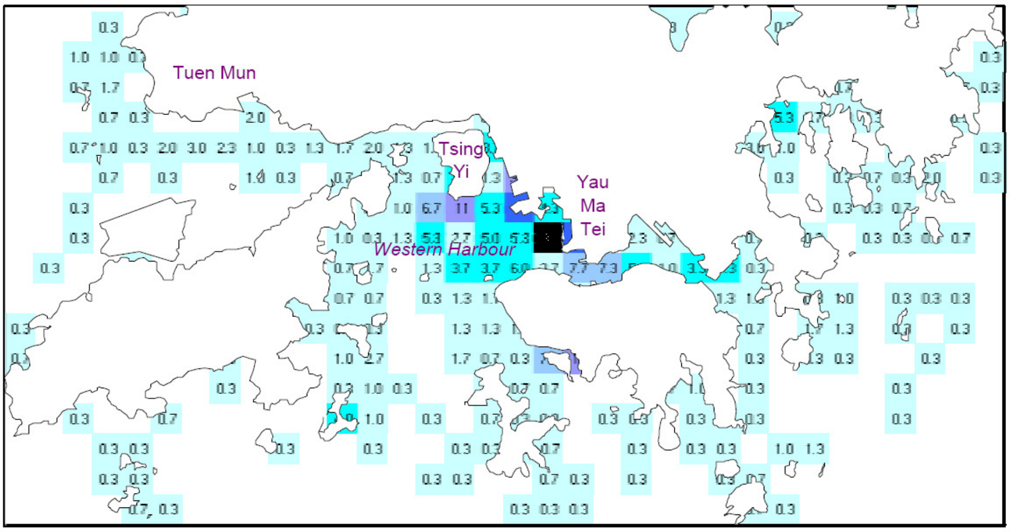
Emergency Conditions

Vessels may drop anchor due to emergency conditions such as fog, storm, or due to collisions or machinery failure. The likelihood of anchoring due to adverse weather conditions is expected to be low especially for the larger vessels who will determine whether dropping an anchor is the safest option. Furthermore, knowledge of vessel position from onboard navigation systems should prevent inadvertent dropping of an anchor onto a pipeline delineated on the navigation chart.

To estimate the frequency of emergency anchoring, data from the Marine Department of Hong Kong [6] is used. The distribution of incidents of all types (*Figure 5.1*) shows that most incidents are concentrated in the harbour regions near Yau Ma Tei, Tsing Yi and Tuen Mun. The region near the proposed pipeline indicates low incident rates for much of the pipeline but slightly higher values near Urmston Road. This is due to the higher traffic density in this area. An average value of 0.3 for the period from 2001 to 2003 clearly refers to a single incident that occurred during this 3-year period. The size of each cell in *Figure 5.1* is one arc-minute of latitude and longitude, or approximately 1.86 x 1.73 = 3.2 km^2. A value of 0.3 refers then to an incident frequency rate of 0.09 /km^2/year. For comparison, the total number of incidents from 1990-2004 in the 1830 km^2 area of Hong Kong waters was 5161 [17]. This gives an average of 0.19 /km^2/year. So, the incident rate along much of the proposed pipeline route is lower than average, while the fairway of Urmston Road is a little higher than average.

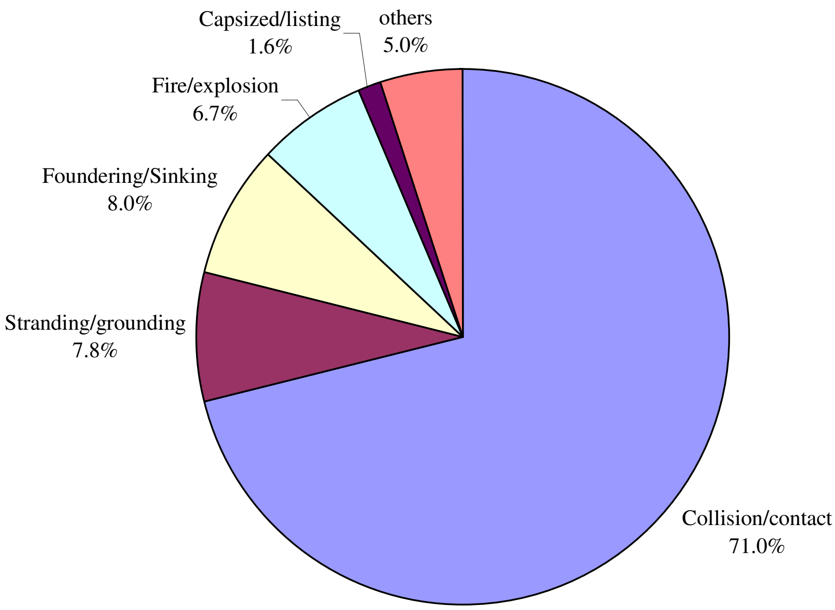
Based on the above discussion, an incident rate of 0.1 /km^2/year is assumed for most of the pipeline and 0.3 /km^2/year is assumed for Urmston Road. Although few incidents are shown for the Adamasta Channel, the higher traffic volume here is assumed to give a higher incident rate and so 0.3 /km^2/year is assumed for this region also.

Figure 5.1 Average Annual Incident Distribution (2001-2003)



The distribution by types of incidents (*Figure 5.2*) shows that most incidents are collisions or contact. Not all incidents will result in an anchor drop. Most collisions, for example, are not serious. It is assumed therefore that only 10% of incidents will result in an emergency anchor drop.

Figure 5.2 Distribution of Incident Types (1990-2004)



Once the anchor is dropped, it may fall directly on the pipeline causing damage. A greater concern is the possibility of an anchor being dragged across the seabed and into the pipeline. In an emergency situation such as mechanical failure, it is possible that the vessel is still moving when the anchor is deployed. Since anchors can be dragged significant distances, the resulting pipeline contact frequencies tend to be higher compared to a simple anchor drop. In most instances, however, the ship master's first action will be to reduce speed to near stationary and then drop anchor if necessary. For the purpose of this analysis, it was assumed that 90% of ships drop anchor at near rest (1 knot), while the other 10% drop anchor at 4 knots due to mechanical failure and the uncontrolled advance of the vessel.

The efficiency of an anchor is defined according to its holding capacity:

$$\text{Holding capacity} = \text{anchor weight} \times \text{efficiency}$$

The efficiencies for different classes of anchor [20] are given in *Table 5.4*. It is believed that types E and F are common on large commercial vessels.

Table 5.4 Anchor Efficiency

Class	Efficiency
A	33-55
B	17-25
C	14-26
D	8-15
E	8-11
F	4-6
G	<6

This definition can be used to calculate the drag distance. The work done in dragging an anchor through some distance must be equal to the change in kinetic energy in bringing the ship to rest.

Anchors are designed to penetrate into the seabed for maximum holding capacity. As an anchor is dragged across the seabed, it will begin to penetrate into the mud; the softer the soil, the greater the penetration. Maximum holding capacity is only reached once the maximum penetration depth has been reached i.e. the efficiency is a function of penetration depth. As a conservative approach, the lowest efficiency anchor, type E, is assumed for the calculations. The efficiency is halved again to allow for the varying restraining force with depth. The efficiency is therefore assumed to be 2. *Table 5.5* gives some drag distances resulting from these calculations.

It can be seen that most vessels will drag an anchor for less than about 20m. Ocean-going vessels can drag an anchor over significantly greater distances due to the larger mass and hence kinetic energy of the ship. This class of ship is subdivided into different sizes to reflect the distribution of ships expected along the proposed pipeline route (see *Table 3.8*). A 150,000 tonne ship is the largest of ships visiting Hong Kong and this provides the upper limit to the drag distance of about 170m.

Table 5.5 Drag Distances

Class	**Size Range (dwt)**	**Displacement (tonnes)**	**Anchor (tonnes)**	**Drag Distance (m)**
Fishing vessel		400	1	7
Rivertrade coastal vessels		1,500	2	13
Ocean-going vessels	1,500 – 25,000	1,500 – 35,000 (60%)	2 – 5	13 – 118
	25,000 – 75,000	35,000 – 110,000 (35%)	5 - 12	118 – 154
	75,000 – 100,000	110,000 – 150,000 (5%)	12 - 15	154 – 168
Fast Launches		150	0.1	25
Fast ferries		150	0.5	5
Other		200	0.2	17

The frequency of anchor drag impact can then be calculated as:

$$\textit{Impact freq} = \textit{incident freq } (/year/km^2) \times \textit{probability of anchor drop} \times \textit{drag distance}/1000 \qquad (1)$$

where the drag distance is in meters. This gives the impact frequency per km of pipeline per year. If an impact occurs, the damage may not be severe enough to cause containment failure. Based on PARLOC 2001, approximately 22% of anchor /impact incidents result in containment failure when considering all pipe diameters. Larger pipes, however, fail three times less often. This suggests that 7% of incidents would result in a loss of containment.

This approach was applied to each section of the pipeline and to each class of vessel. The marine traffic incident rate was assumed to apply equally to all classes of vessel.

The hydrographic survey [8] identifies seabed conditions as very soft clay for most of the route. Under these conditions, significant anchor penetration can occur [20]. For example, a 15 tonne anchor can penetrate to 17m, and a 2 tonne anchor can penetrate to 9m. These data apply to high efficiency anchors and less penetration is to be expected for the commonly used types E and F, but nevertheless, it is likely that a wide range of anchors sizes will be able to achieve 3m penetration during emergency anchoring scenarios and hence may interact with the proposed pipeline.

MARAD Study

An alternative to using the incident frequency from *Figure 5.1* is to use data from the MARAD study [19] which reported that the frequency of collisions in Hong Kong waters of ocean-going vessels as 56 per million vessel-km. Since only 71% of incidents are collisions, this value of 56 per million vessel-km was scaled upwards to estimate the number of incidents of all types. 90% of these incidents resulted in only minor damage and so again it is assumed that only 10% will result in an emergency anchor drop. The approach is then similar to that described above for anchor dragging.

Routine Anchoring

Estimating anchor drop frequencies from marine vessel incidents fails to take into account routine anchoring. Routine anchoring is not expected in the busy fairways but may take place at other positions along the pipeline route. The EGS seabed survey [8] indicates the presence of trawling marks from fishing activities and also anchor marks. This data was used also to estimate anchoring frequencies.

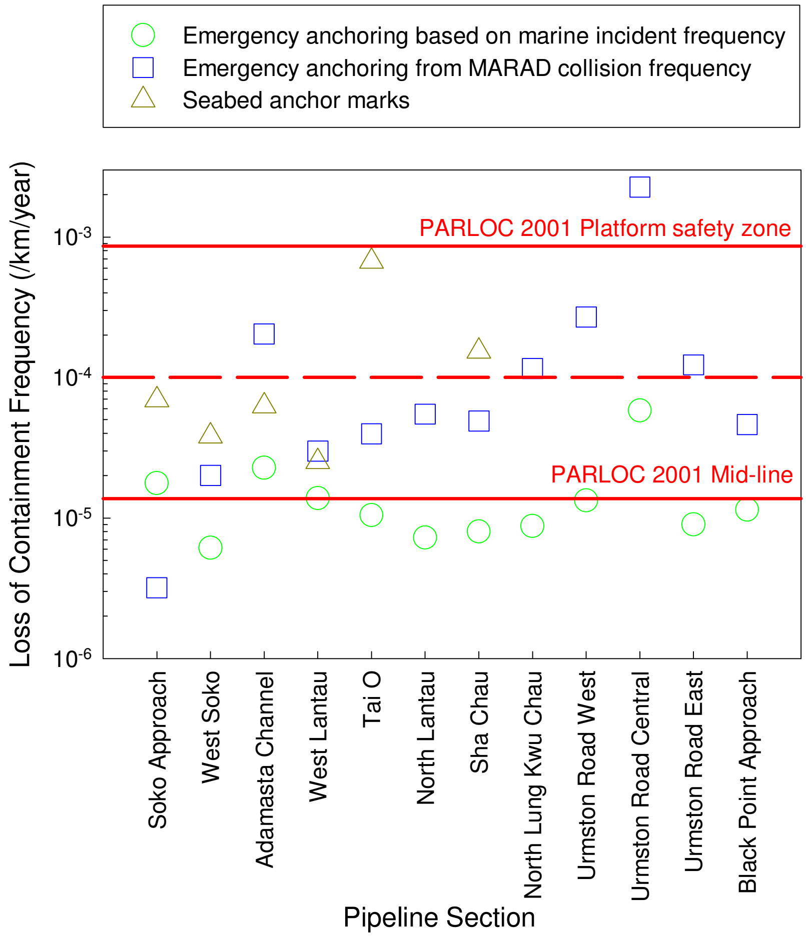
It was assumed that anchor marks persist for 2 years and so the frequency of anchoring damage for each km of pipeline was estimated as:

Routine anchoring damage freq =
number of anchor marks / 2 x (*anchor width* x 0.64 + 0.762)/500m *survey width* / *length of pipeline section*. (2)

Anchor dimensions were estimated from the Vyrhof anchor manual [20] for each class of ship. The factor of 0.64 arises because the anchor may fall at some random angle relative to the pipeline so the width of the anchor is effectively smaller by a factor equal to the mean of cosine of the angle = 0.64. It was assumed that the frequency of anchoring will decrease by 90% once the pipeline is installed and marked on navigation charts. Also, it was assumed that only 7% of impacts would result in loss of containment as before.

The results from this analysis are compared in *Figure 5.3*. Also shown are the loss of containment frequencies obtained from PARLOC 2001 for the platform safety zone and mid-line. These are assumed to be representative of areas of high and low marine activity respectively. It can be seen that there is some spread in the predictions. The platform safety zone and mid-line frequencies differ by almost two orders of magnitude but effectively bound most of the other predictions.

Figure 5.3 *Anchor Damage Frequency Based on Marine Incidents*



Predictions based on the MARAD collision rate are regarded as being a little high because they are simply proportional to vessel-km (and hence the traffic density) and do not take into account local conditions along the route. The marine activity in Urmston Road for example is about 19 times higher than Sha Chau, but according to *Figure 5.1*, the marine vessel incident rate is only about three times higher. On the other hand, calculations based on emergency incidents are likely low because they neglect indiscriminate anchoring or anchoring due to mistaken location.

The anchor marks on the seabed are the least reliable indicator of anchoring activity due to the low number of marks, the difficulty in distinguishing anchor marks from numerous trawling scars and the uncertainty over how long the marks will persist in the soft seabed. Nevertheless, anchor marks on the seabed do show two areas of high activity: Tai O and Sha Chau. The Y3 anchorage area near Tai O accounts for one of these high activity areas. The second occurs near Sha Chau. This is most likely activity from smaller vessels since the water is shallow in this region.

The calculations are broadly consistent with failure frequencies from PARLOC 2001. The frequency obtained from PARLOC 2001 for the mid-line is appropriate for regions of low marine vessel volume and low anchoring activity. The platform safety zone frequency is regarded as a more appropriate choice for the failure frequency in locations of high marine traffic or near anchorage areas. Some sections have intermediate levels of marine activity and so a frequency of 10^{-4} per km-year is adopted for these sections.

Based on the above considerations, the failure frequencies due to anchor impact used in this study are as summarized in *Table 5.6*. South Soko Approach and West Soko show some anchor marks but these are few in number and are from the anchoring of small vessels in the shallow water. The marine vessel activity is low n the area so these sections were assigned a low anchor damage frequency. The Adamasta Channel is borderline between a medium and high failure frequency and *Figure 5.1* suggests that the marine incident rate is actually low in this region, perhaps because of the traffic separation scheme. However, as a conservative measure, a high frequency is assigned to this section. Tai O has a fairly low volume of traffic but its position next to the Y3 anchorage and the numerous anchor marks observed on the seabed warranted a high anchor damage frequency assigned to this section.

Table 5.6 ***Anchor Damage Frequencies used in this Study***

Pipeline section	**Frequency (/km/year)**	**Comment**
South Soko Approach	1.37×10^{-5}	Low marine traffic
West Soko	1.37×10^{-5}	Low marine traffic
Adamasta Channel	8.6×10^{-4}	High marine traffic
West Lantau	1×10^{-4}	Medium marine traffic
Tai O	8.6×10^{-4}	Next to anchorage
North Lantau	1×10^{-4}	Medium marine traffic
Sha Chau	1×10^{-4}	Medium marine traffic + some anchoring
North Lung Kwu Chau	1×10^{-4}	Medium marine traffic
Urmston Road West	8.6×10^{-4}	High marine traffic
Urmston Road Central	8.6×10^{-4}	High marine traffic
Urmston Road East	1×10^{-4}	Medium marine traffic
Black Point Approach	1×10^{-4}	Medium marine traffic

5.4 *PIPELINE PROTECTION FACTORS*

Many pipelines are trenched to protect them from trawling damage. In the pipeline database in PARLOC 2001, 57% by length of all lines have some degree of protection, either trenching (lowering) or burial (covering) over part or all of their length. Considering large and small diameter lines, the proportion of lines with some degree of protection are 59% by length for lines

<16" diameter and 68% for larger diameter lines. It is, however, concluded in the PARLOC report that there have been insufficient incidents to determine a clear relationship between failure rate and the degree of protection.

The loss of containment frequencies given in *Table 5.6* assume minimal protection since they are based on the PARLOC data. The proposed CAPCO pipeline has rock armour protection specified for its whole length. To allow for this, protection factors were applied. Based on the classes of marine vessel found along the proposed route (*Table 3.2*), most classes of ship have anchors below 2 tonnes in weight. Only ocean-going vessels have anchors up to 15 tonnes. The rock armour protection along the route is designed to protect against either 2 tonne anchors (trench type 1 and 2A/B) or 20 tonne anchors (trench type 3A/B). Rock armour protection factors were therefore applied based on whether a ship's anchor is smaller than or larger than 2 tonnes.

Trench types 1 and 2A/B (designed to protect against 2 tonne anchors) were assumed to provide 99%protection for anchors smaller than 2 tonnes. This trench type should also offer some protection against larger anchors. For ocean-going vessels, 60% of them have anchors below about 5 tonnes (*Table 3.8*) and so trench type 1 should offer reasonable protection against these vessels. 50% protection was assumed for ocean-going vessels.

Trench type 3A/B (deigned to protect against 20 tonne anchors) was assumed to provide 99% protection for anchors greater than 2 tonnes, and 99.9% protection for anchors below 2 tonnes.

5.5 *SUMMARY OF FAILURE FREQUENCIES FOR CAPCO PIPELINE*

Based on the above discussions, the failure frequencies used in this study are as summarized in *Table 5.7*.

Table 5.7 Summary of Failure Frequencies used in this Study

Pipeline section	Trench type	Corrosion /defects (/km/year)	Anchor/Impact			Others /km/year	Total /km/year
			Frequency (/km/year)	Protection factor (%) anchor<2	Anchor>2		
South Soko Approach	2A	1.18×10^{-6}	1.37×10^{-5}	99	50	1.34×10^{-6}	2.66×10^{-6}
West Soko	1	1.18×10^{-6}	1.37×10^{-5}	99	50	1.34×10^{-6}	2.66×10^{-6}
Adamasta Channel	3B/3A	1.18×10^{-6}	8.6×10^{-4}	99.9	99	1.34×10^{-6}	3.49×10^{-6}
West Lantau	3A	1.18×10^{-6}	1×10^{-4}	99.9	99	1.34×10^{-6}	2.70×10^{-6}
Tai O	3B	1.18×10^{-6}	8.6×10^{-4}	99.9	99	1.34×10^{-6}	3.82×10^{-6}
North Lantau	1	1.18×10^{-6}	1×10^{-4}	99	50	1.34×10^{-6}	3.52×10^{-6}
Sha Chau	1	1.18×10^{-6}	1×10^{-4}	99	50	1.34×10^{-6}	3.52×10^{-6}
North Lung Kwu Chau	1	1.18×10^{-6}	1×10^{-4}	99	50	1.34×10^{-6}	3.52×10^{-6}
Urmston Road West	3B/3A	1.18×10^{-6}	8.6×10^{-4}	99.9	99	1.34×10^{-6}	3.93×10^{-6}
Urmston Road Central	3A/3B	1.18×10^{-6}	8.6×10^{-4}	99.9	99	1.34×10^{-6}	4.58×10^{-6}
Urmston Road East	1	1.18×10^{-6}	1×10^{-4}	99	50	1.34×10^{-6}	3.52×10^{-6}
Black Point Approach	2B	1.18×10^{-6}	1×10^{-4}	99	50	1.34×10^{-6}	3.52×10^{-6}

5.6 SCENARIO DEVELOPMENT

The outcome of a hazard can be predicted using event tree analysis to investigate the way initiating events could develop. This stage of the analysis involves development of the release cases into discrete hazardous outcomes. The following factors are considered:

- Failure cause;
- Hole size;
- Vessel position and type; and
- Ignition probability.

The probabilities used in the event trees are discussed below.

5.6.1 *Failure Cause*

Failures due to corrosion and other events are considered separately from failures caused by anchor impact. This is because the hole size distribution is different in both cases, as described below. Also, in the event of failure due to anchor impact, the probability of vessel presence is assumed to be higher, as discussed later.

5.6.2 *Hole Size Distribution*

The data on hole size distribution in PARLOC 2001 is summarised in *Table 5.8*.

Table 5.8 Hole Size Distribution from PARLOC 2001

Pipeline size	Location	Hole size (mm) 0 to 20mm	20 to 80mm	>80mm
2 to 9"	Safety zone	6	3 (1 rupture)	2
	Mid line	14	4 (2 ruptures)	1 (1 rupture)
10 to 16"	Safety zone	1	1	4 (3 ruptures)
	Mid line	1		3
>16"	Safety zone	1		
	Mid line	2		2 (2 ruptures)
Total		25 (55%)	8 (18%)	12 (27%)

This data on hole size distribution is clearly limited, particularly for large diameter pipelines. One approach is to compare this distribution with that for onshore pipelines, which include a much larger database of operating data and failure data. For example, the US Gas database [16] is based on 5 million pipeline km-years of operating data as compared to 300,000 km-years in the PARLOC study.

An analysis of hole size distribution for onshore pipelines as given in the

US Gas database [16] and European Gas Pipelines database [21] provides a hole size distribution as given in *Table 5.9.*

Table 5.9 Hole Size Distribution Adopted for Corrosion and Other Failures

Category	Hole Size	Proportion
Rupture (Half Bore)	15" or 381mm	5%
Puncture	4" or 100mm	15%
Hole	2" or 50mm	30%
Leak	<25mm	50%

The above distribution is largely similar to the distribution derived in the PARLOC report [7]. The only difference is the consideration of a small percentage of ruptures. It is a matter of debate whether ruptures could indeed occur although ruptures extending over several metres are reported in the various failure databases.

In this study, it is proposed that the hole size distribution given in *Table 5.9* be adopted for failures caused by corrosion and other failures (including material/weld defect). In the case of failures caused by anchor damage, the hole sizes are expected to be larger. The distribution given in *Table 5.10* is adopted.

Table 5.10 Hole Size Distribution for Anchor Impact

Category	Hole Size	Proportion
Rupture (Full Bore)	Full bore	10%
Major	15" or 381mm (half bore)	20%
Minor	4" or 100mm	70%

5.6.3 Vessel Position

In the case of failures due to corrosion/other events, the probability of a vessel being affected by the leak is calculated based on the traffic volume and the size of the flammable cloud. Dispersion modelling using PHAST [22] is used to obtain the size of the flammable cloud for each hole size scenario and four weather scenarios covering atmospheric stability classes B, D and F. Once the cloud size is known, the probability that a passing marine vessel will travel through this area within a given time can be calculated. A time period of 30 minutes is used since it is assumed that if a leak occurs, warnings will be issued to all shipping within 30 minutes. Further details on the dispersion modelling are given in *Section 6*.

In the case of failures due to anchor impact, the following two scenarios are considered:

- "Vessels in vicinity" - the vessel that caused damage to the pipeline (due to anchoring) is still in the vicinity of the incident zone. The probability of this is assumed to be 0.3; and

- "Passing vessels" - ships approach or pass the scene of the incident following a failure. In this case, the probability of a vessel passing through the plume is calculated using the same method as for a corrosion failure; i.e. based on cloud size and traffic volume.

Event trees showing these scenarios are given in *Figures 5.4* and *5.5*. If a vessel passes through the flammable gas cloud, a distinction is further made between vessels passing directly over the release area and vessels passing through other parts of the cloud. This is discussed further in the following section.

Figure 5.4 Event Tree for External Damage from Anchors

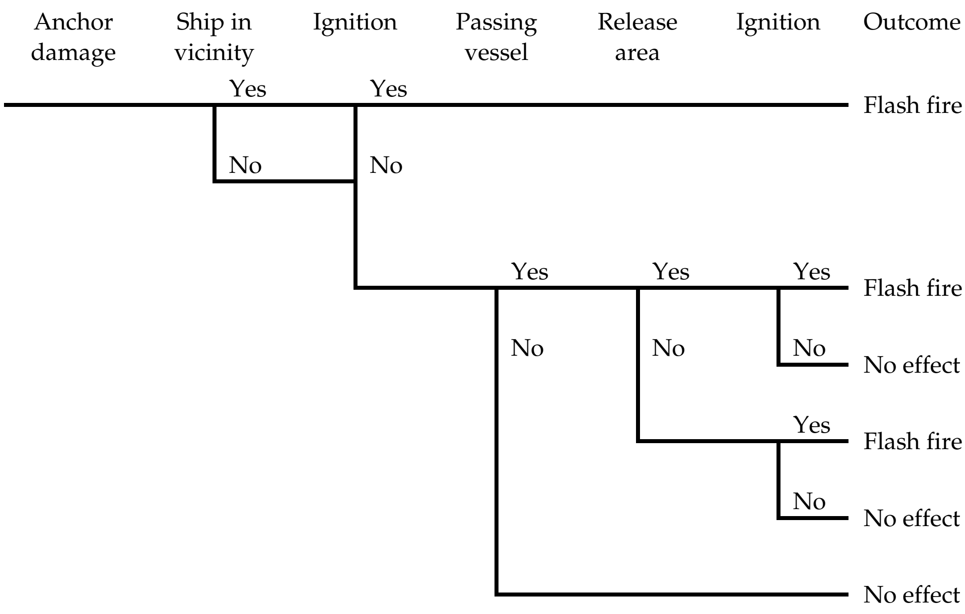
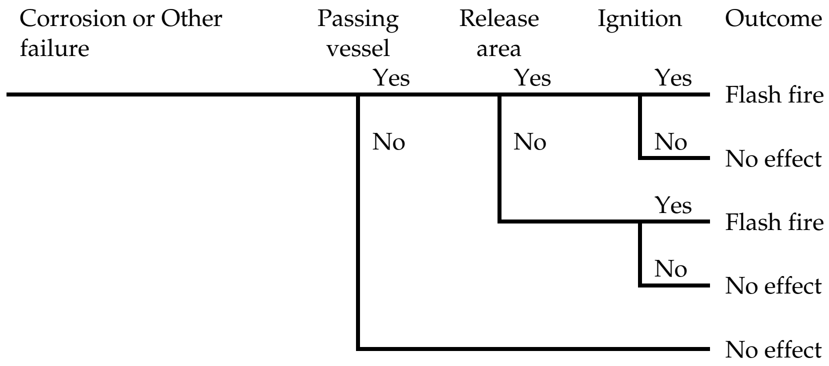


Figure 5.5 Event Tree for Spontaneous Failures



It is assumed that at most, only one vessel will be affected by a pipeline failure. Once the flammable plume is ignited, the resulting fire will be visible and other ships will naturally avoid the area. Given the likely size of plume and separation of shipping, the likelihood that two ships will be affected is deemed negligible. As an example, the highest density of marine vessels occurs along Urmston Road. Assuming an average speed of just 5m/s gives a marine vessel density of 0.7 ships/km^2. The hazard distances for the flammable cloud from a pipeline leak are typically of the order of 30-60m, with the largest being 130m. It is unlikely that two vessels will be within such close proximity, particularly for ocean-going vessels and fast ferries which are the more important categories for the risk analysis.

5.6.4 Vessel Type

The categorisation of vessel types follows those identified from the radar tracks (*Table 3.2*), namely:

- Fishing vessels and small crafts;
- Rivertrade coastal vessels;
- Ocean-going vessels;
- Fast Launches;
- Fast ferries;
- 'Others' (assumed to be small vessels)

The relative proportion of the different vessel types will vary along the pipeline route, as indicated in *Table 3.4*.

5.6.5 Ignition Probability

Ignition of the release is expected only from passing ships or ships in the vicinity. Ignition probabilities derived for offshore pipeline releases in the vicinity of an offshore platform is given in *Table 5.11* [23]. Similar values are adopted in this study, as given in *Table 5.12*.

Table 5.11 Pipeline Hydrocarbon Release Ignition Probability in Platform Vicinity [23]

	Typical Ignition Probability (integrated platform)		
Location of release	**Massive gas release (>20 kg/s)**	**Major gas release (2-20 kg/s)**	**Minor gas release(<2 kg/s)**
Riser above sea (1)	0.168	0.026	0.005
Subsea	0.443	0.13	0.043
	Typical Ignition Probability (bridge linked platform)		
Location of release	**Massive gas release (>20 kg/s)**	**Major gas release (2-20 kg/s)**	**Minor gas release (<2 kg/s)**
Riser above sea (1)	0.078	0.013	0.002
Subsea	0.14	0.051	0.002

1. 'Riser above sea' refers to pipeline riser portion that is above sea level.

Table 5.12 Ignition Probability Assumed

Release Case	**Ignition Probability**	
	Passing Vessels (1)	**Vessels in Vicinity (2)**
<25mm	0.01	n/a
50mm	0.05	n/a
100mm	0.1	0.15
Half bore	0.2	0.3
Full bore	0.3	0.4

1. Values applied to passing vessels for all types of incidents, i.e. corrosion, others and anchor impact.
2. Values applied only to scenarios where the vessel causing pipeline damage due to anchor impact is still in the vicinity.

6 CONSEQUENCE ANALYSIS

6.1 OVERVIEW

In the event of loss of containment, the gas will bubble to the surface of the sea and then disperse. If it comes in contact with an ignition source, most likely from a passing marine vessel, it could lead to a flash fire which will propagate through the cloud to the point of release and result in a gas fire above the water surface.

If a marine vessel passes into a plume of gas and ignites it, then there is the possibility of fatalities on that ship due to the flash fire. If a vessel passes through the 'release area' of the release, the vessel will likely be affected also by the ensuing fire and the consequences will be more severe. If the release gets ignited, it is presumed that no further ships will be involved because the fire will be visible and other ships will naturally avoid the area. In other words, it is assumed that at most, only one ship will be affected.

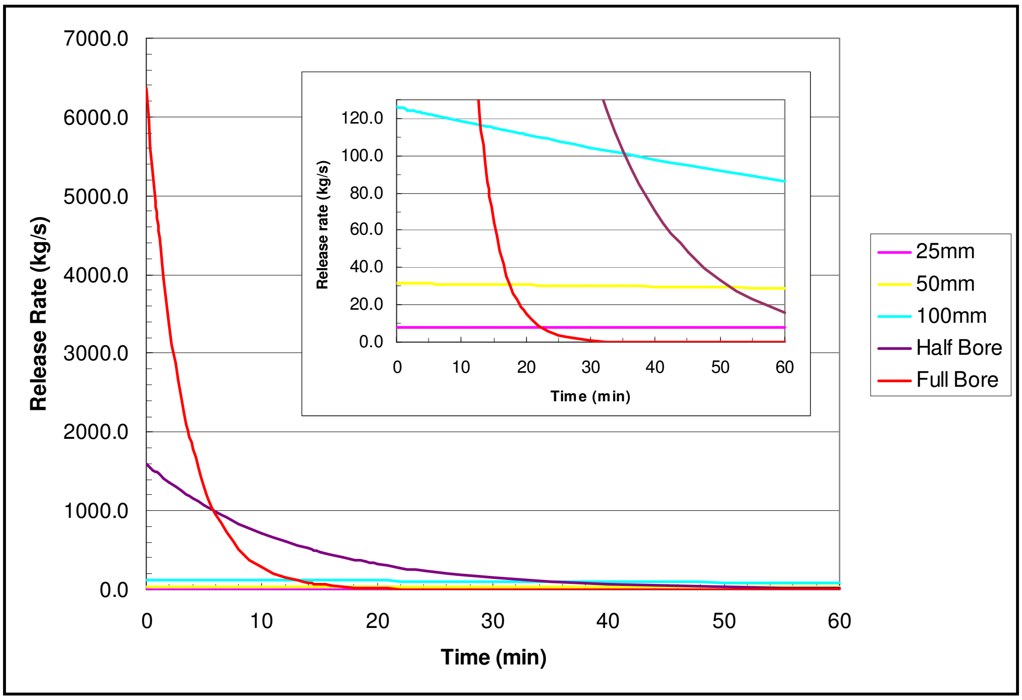
Further details are described in the following paragraphs.

6.2 SOURCE TERM MODELLING

The release rate is estimated based on standard equations for discharge through an orifice. The empirical correlation developed by Bell and modified by Wilson [24] is adopted. A maximum operating pressure of 101barg is assumed.

The results are presented in *Figure 6.1*. For holes with equivalent diameter smaller than about 100mm, the discharge rate diminishes rather slowly because of the large inventory in the pipeline (about 1,200 tonnes). For half and full bore failures, the discharge rate diminishes more quickly over a period of about 30-60 minutes.

Figure 6.1 Variation of Release Rate with Time

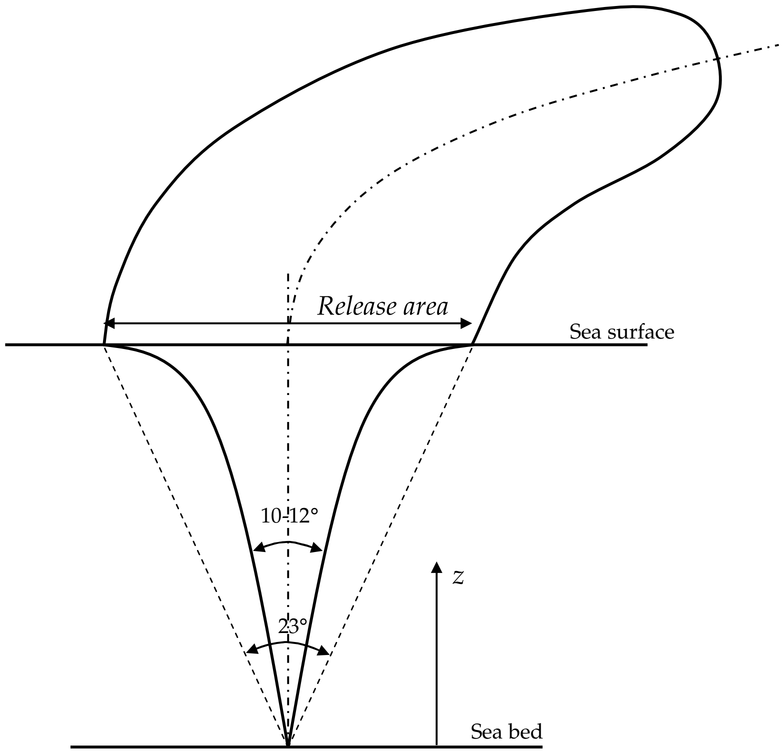


6.3 *DISPERSION MODELLING FOR SUBSEA RELEASES*

In the event of a release from the subsea pipeline, the gas jet is expected to lose momentum and bubble to the surface. The simplest form of modelling applied to subsea releases is to assume that the dispersing bubble plume (driven by gas buoyancy) can be represented by a cone of fixed angle (*Figure 6.2*) [24]. The typical cone angle is between 10 to 12°. However, Billeter and Fannelop [24] suggested that the 'release area' (where bubbles break through the surface) is about twice the diameter of the bubble plume. Hence, an angle of 23° was recommended and is used in this study.

Based on the EGS Survey [8], the water depth is between 5-8m for much of the proposed pipeline route, increasing to 20m in Urmston Road and 25m in the Adamasta Channel. The shallowest water occurs on the South Soko approach and is about 1.6m deep. For this range of water depths, the cone model predicts the 'release area' to be in the range of 0.6 to 10m diameter.

Figure 6.2 Simple Cone Model for Subsea Dispersion



6.4 DISPERSION ABOVE SEA LEVEL

The gas will begin to disperse into the atmosphere upon reaching the sea surface. The distance to which the flammable envelope of gas extends will depend on ambient conditions such as wind speed and atmospheric stability as well as source conditions. The extent of the flammable region is taken as the distance to 0.85 LFL (Lower Flammable Limit).

Conditions at the source such as momentum and buoyancy are important. At lower depths and high release rates, the gas will have a large momentum at the sea surface resulting in a plume extending rapidly upwards into the atmosphere. For smaller releases, the gas will lose all momentum by the time it reaches the sea surface resulting in a plume of greater horizontal extent. Dimensional analysis using the Froude number [24] suggests that momentum and buoyancy are both important over most release scenarios considered in the current study. Only full bore ruptures in shallow water result in a momentum dominated jet release.

The above sea dispersion was modelled using PHAST [22]. Based on the above discussion, to achieve realistic simulations it is important to give due consideration to the momentum and buoyancy of the source. The gas was assumed to gain heat from the sea water, during transport and following a release. The gas was therefore assumed to be released at 20°C and 101barg. Being lighter than air, natural gas lifts away from the sea surface under all atmospheric conditions.

The cone model is believed to be a reasonable approach for estimating the 'release area' for small to moderate releases. The worst scenario is deep water, which produces a large 'release area' and hence low efflux momentum for a given mass release rate. The deepest water case of 25m was therefore chosen for analysis. A low momentum gives a lower plume rise and hence a larger hazardous area near the sea surface. The cone model, however, has not been validated for massive releases such as would occur in a half bore or full bore rupture. To err on the cautious side, a larger 'release area' was assumed for massive releases. The diameter of the release area was increased by 50% for half bore rupture and by 100% for full bore rupture scenarios. This lowers the source momentum and gives conservative results.

PHAST was used to model the plume dispersion as an area source on the surface of the ocean. The mass release rate, the release velocity and temperature were specified and the release was assumed to be vertical. The surface roughness parameter was assumed to be 0.043, a value appropriate for dispersion over water. Even though the release is a transient, particularly for the large release scenarios, the time constant for the release is still longer than the dispersion time scale. The modelling therefore assumed a steady release of gas at the maximum release rate. Again, this is conservative. Simulations were performed for atmospheric stability classes of B, D and F to cover the range of meteorological conditions expected. Given that the plume in all cases lifted away from the surface due to buoyancy, the length of the plume was taken to be the maximum extent of the plume in the windward direction up to the ship height which is assumed to be a maximum of 50m.

The relative occurrence of weather conditions 2F, 3D, 7D and 2.5B were taken to be 0.1654, 0.1023, 0.6333 and 0.099 respectively to match conditions measured at the Sha Chau meteorology station.

6.5 IMPACT ASSESSMENT

6.5.1 *Impact on Population on Marine Vessels*

The hazardous distance was taken to be the distance to 0.85 LFL as discussed above. It was assumed that ships would be at risk for 30 minutes before warnings could be issued to advice vessels to avoid the area. Knowing the marine vessel traffic (in ships per day per km of pipeline), the probability that a passing ship will cross through the flammable plume during this 30 minutes is calculated as:

Prob. = *traffic* (/km/day) x *length of plume* (km) x 0.5 (hour) / 24 (hour/day) (3)

If a marine vessel comes in contact with the flammable plume and causes ignition, the resulting flash fire may lead to fatalities depending on the type of ship. Small open vessels such as fishing boats are expected to provide less protection to its occupants. Large ocean-going vessels will provide better protection. Fatality factors are therefore applied to each class of vessel to take into account the protection offered by the vessel. These take into consideration:

- The proportion of the passengers likely to be on deck or in interior compartments.
- The materials of construction of the vessel and the likelihood of secondary fires.
- The size of the vessel and hence the likelihood that it can be completely engulfed in a flammable gas cloud.
- The speed of the vessel and hence its exposure time to the gas cloud.
- The ability of gas to penetrate into the vessel and achieve a flammable mixture.

Considering fast ferries; they are air conditioned and travel at high speeds in excess of 30 knots (15m/s). If the occupants are to be affected by a flash fire, gas must penetrate into the interior of the vessel, achieve a flammable mixture and ignite. The time to transit the largest gas cloud of 130m is of the order of 10 seconds. Assuming typical air ventilation rates of 6 to 10 volume changes per hour, a time constant for changes in gas concentration within a ferry can be derived as 6 to 10 minutes. This implies that it would take several minutes for the gas concentration within a ferry to respond to changes in concentration in the ambient air. Given that the exposure time is mere seconds, it becomes apparent that it is very difficult to achieve a flammable mixture of gas within a ferry. Based on these considerations, the fatalities assumed in the current study for fast ferries and other vessels are as given in *Table 6.1*.

If a ship enters the 'release area' and ignites the gas cloud, the vessel is more likely to be caught in the ensuing fire. This is assumed to result in more severe consequences with potential for 100% fatality of occupants. The probability of this is calculated using a similar equation as above (*Equation 3*) but replacing the cloud size with the release area diameter.

Table 6.1 Fatality Probabilities

Class	Fatality	
	'Release area'	'Cloud area'
Fishing vessels	1	0.9
Rivertrade coastal vessels	1	0.3
Ocean-going vessels	1	0.1
Fast launches	1	0.9
Fast ferries	1	0.3
Others	1	0.9

If the failure is caused by corrosion, a passing ship may pass through the flammable plume or release area with a probability given by *Equation 3*. If the failure is caused by third party damage, then two scenarios are considered as mentioned in *Section 5*. The vessel that caused the incident may still be in the area and may ignite the plume, or if this vessel is no longer present, a passing ship may pass through the plume. The probability that the vessel causing the incident is still present is assumed to be 0.3 and this is assumed to result in 100% fatality.

The analysis limits the number of ships involved to one. It is assumed that once the plume is ignited, other ships will avoid the area.

6.5.2 *Impact on Population on Hong Kong Zhuhai Macau Bridge*

The proposed Hong Kong to Zhuhai Macau (HKZM) bridge will straddle the CAPCO pipeline within the Tai O section (*Figure 3.1*), although the precise alignment and construction schedule of the bridge has yet to be finalised. It is assumed that the pipeline can be laid between bridge support columns or that bridge construction procedures will take the necessary precautions to avoid damage to the pipeline. It is noted also that the Tai O section of the pipeline will be provided with 3m of rock armour protection. The bridge, therefore, is not expected to have any effect on pipeline failure frequencies during construction or operation.

If a pipeline failure does occur for other reasons, such as external corrosion or anchor impact, the transient road traffic population on the bridge may be affected. This scenario was considered in the consequence analysis for the Tai O section of the pipeline.

There are no official estimates available for the vehicle traffic expected on the bridge; it was therefore assumed that 20,000 vehicles per day will traverse the bridge. This is equivalent to 50% of the vehicles crossing all land borders currently [25]. The same vehicle mix was assumed as currently crossing the land borders, namely: 24% cars, 9% coaches/shuttle buses and 67% goods/container vehicles. It was further assumed that cars and goods vehicles have a population of 2, while buses have a population of 50.

Considering the vehicle traffic volume, the size of gas clouds expected from various release scenarios as predicted by PHAST, and assuming an average vehicle speed of 80 km/h, it was calculated that between 1 to 2 vehicles may be affected by the flash fire following ignition of the gas cloud. The ignition probability is assumed to be one due to the high traffic on the bridge. The possibility of both vehicles being buses was also considered, with an associated probability of 0.0081. 50% fatality was assumed for the vehicle occupants.

Hazard Zones for Gas Cloud dispersion – HZMB Bridge and BCF (Also refer to sections 6.2, 6.3, 6.4)

Table 6.2 *Down wind "Hazard distance" at 50 metres above sea level*

Hole Size (mm)	End Point Criteria	HZMB and BCF Hazard downwind distance (m) at 50 metres above sea level Weather Conditions			
		2F	**3D**	**7D**	**2.5B**
Full Bore	LFL	61	62	108	69
	0.85 LFL	65	68	115	75
Half Bore	LFL	54	55	121	54
	0.85 LFL	60	62	131	60
100	LFL	54	51	74	41
	0.85 LFL	60	59	84	47
50	LFL	35	36	48	32
	0.85 LFL	38	40	55	34
25	LFL	21	24	33	24
	0.85 LFL	25	29	36	26

These events have been modelled as a flash fire within the pipeline QRA (hazard distances are given in *Table 6.2*), however a flash fire is unlikely to damage the bridge. Also, the frequency of such events is very low; large releases require anchor damage, and the pipeline has 3 metres of rock protection so this is unlikely. Corrosion gives small releases with limited ability to impact the bridge.

6.5.3 Impact on Aircraft Approaching Chep Lap Kok

The North Lantau section of the pipeline passes within about 3.7km of the threshold for runways 07L and 4.5km from runway 07R at Chep Lap Kok International Airport. Commercial aircraft have an approach angle of about 3° which puts their altitude above the pipeline at about 200m. Large gas releases from the pipeline, such as those that occur from a full bore or half bore rupture, have the potential to produce a gas cloud that extends higher than 200m. It is therefore possible that aircraft on the approach to landing may pass through a gas cloud within the flammability limits. This scenario was considered in the analysis. Aircraft taking off from runways 25L and 25R are not a concern because modern commercial jets gain altitude very quickly.

If a commercial airliner does pass through a flammable gas cloud, it could be impacted in several ways. The jet engines would very likely ignite the cloud but since the flame speed in natural gas is about 10 m/s and the aircraft speed on approach is typically 160 knots (80 m/s), the plane is unlikely to be caught in the flash fire. The difference in density of natural gas compared to air would impact the aircraft in a manner similar to turbulence. The flow of natural gas through the engines may also upset the combustion process although the concentration of natural gas at aircraft altitudes will be low. There is uncertainty in these issues so for the purpose of analysis, a conservative approach is adopted and the gas cloud is assumed to cause sufficient upset to result in an aircraft crash with 100% fatality.

The hazardous distance is taken as the maximum size of the gas cloud above 200m from the sea surface. The probability that the gas cloud will cross the approach flight path is calculated from this hazard distance. If a gas cloud is present on the approach path, the probability that an aircraft will fly through the cloud is taken to be 1, since aircraft are landing every few minutes at Chep Lap Kok. In a similar manner as before, it is assumed that at most one aircraft will be affected.

A distribution of population is assumed in the analysis to take into account the varying size of aircraft using the airport. According to the Civil Aviation Department Annual Report [26], there are 263,506 take-off and landings per year and 39,799,602 passengers. This gives an average population of 151 passengers, plus crew, on each flight. It is further stated that 16% of flights are cargo flights. The distribution assumed is given in *Table 6.3*. This distribution gives an average population per flight as 165 which is close to the 151+crew published by the Civil Aviation Department.

Table 6.3 Aircraft Population Distribution

Population	% of flights	Comment
400	15	Fully loaded Boeing 747 or 777 or equivalent
300	15	Fully loaded Airbus A340 or A330 or equivalent
200	15	Fully loaded A320 or equivalent
100	20	Fully loaded Boeing 737 or equivalent
50	19	Partially loaded aircraft
5	16	Cargo flight

6.5.4 Impact on Macau Helicopters

Helicopters shuttling to and from Macau pass over the Adamasta Channel section of the pipeline at about 500 feet (150m) altitude. In the same way that accidental gas releases may affect aircraft on the approach to the airport, a release from the Adamasta Channel section may impact on helicopters. The hazard distance is taken to be the maximum width of the gas cloud above 150m altitude. Although there is only one flight every 30 minutes and the return flights pass further south missing the pipeline route, it is again assumed that one helicopter is certain to be affected if the gas cloud lies across the flight path. The methodology is the same as that used for aircraft (*Section 6.5.3*). It is further assumed that all helicopters are filled to capacity with 12 passengers and crew.

This is a conservative treatment for helicopters but given that they are not expected to make a significant contribution to the risk results, this simple approach is sufficient.

6.6 CONSEQUENCE RESULTS

Hazard distances are determined from the dispersion modelling for both marine vessels and aircraft (*Figure 6.3*). The hazard distance for marine vessels is defined as the maximum width of the gas cloud below a height of 50m above sea level. Similarly, the hazard distance for commercial airliners is defined above 200m and helicopters above 150m from sea level since this is the expected altitude of these aircraft. Based on this, the hazard distances obtained from dispersion modelling are summarised in *Table 6.4*.

Figure 6.3 Hazard Distance Definitions

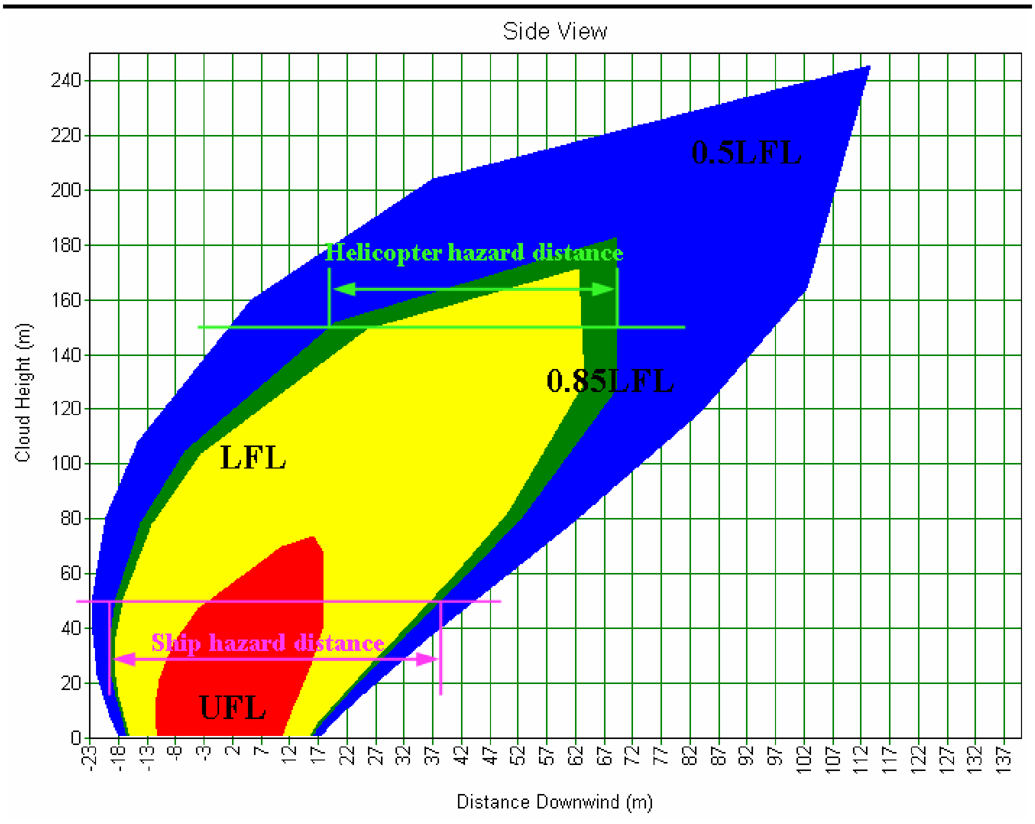


Table 6.4 Hazard Distances for Gas Cloud Dispersion

Hole Size mm	End Point Criteria	Marine Vessel Hazard Distance (m)				Helicopter Hazard Distance (m)*				Airliner Hazard Distance (m)*				Cloud Maximum Height (m)			
		Weather conditions				Weather conditions				Weather conditions				Weather conditions			
		2F	3D	7D	2.5B	2F	3D	7D	2.5B	2F	3D	7D	2.5B	2F	3D	7D	2.5B
Full bore	LFL	61	62	108	69	216	154	158	125	180	138	0	113	260	350	185	360
	0.85LFL	65	68	115	75	261	187	194	140	220	173	84	130	290	380	210	390
Half bore	LFL	54	55	121	54	0	45	0	38	0	0	0	0	147	165	95	170
	0.85LFL	60	62	131	60	67	72	0	51	0	0	0	0	155	185	102	185

Hole Size mm	End Point Criteria	Marine Vessel Hazard Distance (m)				Helicopter Hazard Distance (m)*				Airliner Hazard Distance (m)*				Cloud Maximum Height (m)			
100	LFL	54	51	74	41	0	0	0	0	0	0	0	0	52	42	24	43
	0.85LFL	60	59	84	47	0	0	0	0	0	0	0	0	55	48	27	47
50	LFL	35	36	48	32	0	0	0	0	0	0	0	0	29	20	12	20
	0.85LFL	38	40	55	34	0	0	0	0	0	0	0	0	31	24	13	22
25	LFL	21	24	33	24	0	0	0	0	0	0	0	0	16	11	5	10
	0.85LFL	25	29	36	26	0	0	0	0	0	0	0	0	18	11	6	11

* Values of zero for aircraft hazard distances mean that the gas cloud does not reach sufficient height to affect aircraft

7 *RISK SUMMATION*

The frequencies and consequences of the various outcomes of the numerous accident scenarios are integrated at this stage, to give measures of the societal risk (FN curves and Potential Loss of Life) and individual risk.

Risk results are compared with the criteria for acceptability as laid down in the Hong Kong Planning Standards and Guidelines, chapter 12 [27] and also in Annex 4 of the Technical Memorandum of EIAO. However, these risk guidelines cannot be applied directly for transport operations (such as pipeline transport). Since transport operations extend over several kilometres and communities, they cannot be equated with risks from fixed installations (such as an LPG plant, refinery or a petrochemical plant) which have a defined impact zone. As a result, a pipeline of 1km length is considered as equivalent to a fixed installation for the application of risk criteria. This approach is adopted internationally [28] and was adopted by the consultant in similar studies for onshore and offshore high pressure gas pipelines. Based on this approach, the results are presented on a per-kilometre basis for each section of the pipeline.

The individual risk (IR) criterion for a potentially hazardous installation specifies that the risk of fatality to an offshore individual should not exceed 1×10^{-5} per year. It is generally accepted that the same IR criteria should also apply for transport operations.

Risk results are given in the main text of this report (*Part 2, section 13.11*).

REFERENCES

[1] Kvaerner Petrominco Sdn Bhd, LNG Receiving Terminal Project Offshore Pipeline from South Soko Island to BBPS, Basis of Design Report, 2005.

[2] Kvaerner Petrominco Sdn Bhd, Drawing 8028-PLD-008, revision 3, 2006.

[3] Kvaerner Petrominco Sdn Bhd, LNG Receiving Terminal Project Offshore Pipeline from South Soko island to BPPS, Input to EIA Study, 17th Feb 2006.

[4] BMT Asia Pacific Ltd, Marine Impact Assessment for Black Point & Sokos islands LNG Receiving Terminal & Associated Facilities, Pipeline Issues, Working Paper #3, Issue 6, Sep 2006.

[5] Marine Department Port Statistics, 2004 http://www.info.gov.hk/mardep.index.htm

[6] Marine Department, Marine Traffic Risk Assessment for Hong Kong Waters (MARA Study), March 2004.

[7] Health & Safety Executive, PARLOC 2001 The Update of Loss of Containment Data for Offshore Pipelines, 5th Edition, 2003.

[8] EGS Earth Sciences & Surveying, Hydrographic and geophysical Survey for Proposed LNG Terminal, Final Survey Report, 2005.

[9] DnV, Rules for Submarine Pipeline Systems, 1981.

[10] Personal communication with BMT.

[11] Marine Department, Hong Kong Government, Passenger Arrivals/Departures and Passenger Load Factors at Cross-Boundary Ferry Terminals, January – December 2005. www.mardep.gov.hk

[12] UKAEA, Major Hazard Incident Database (MHIDAS) Silver Platter.

[13] Institution of Chemical Engineers UK, The Accident Database, Version 2.01.

[14] National Transportation Safety Board, Natural gas Pipeline Rupture and Fire During Dredging of Tiger Pass, Lousiana, October 23, 1998.

[15] National Research Council, Improving Safety of Marine Pipelines, 1994.

[16] PRC International American Gas Association, Analysis of DOT Reportable Incidents for Gas Transmission and Gathering Pipelines –

January 1, 1985 Through December 31, 1994 Keifner & Associate Inc., 1996.

[17] Marine Department, Hong Kong Government, Statistics on Marine Accidents, 1990-2004, www.mardep.gov.hk.

[18] Health and Safety Executive UK, PARLOC 96: The Update of Loss of Containment Data for Offshore Pipelines,

[19] Marine Department, The MARAD Strategy Report Comprehensive Study on Marine Activities Associated Risk Assessment and Development of a Future Strategy for the Optimum Usage of Hong Kong Waters, 1997.

[20] Vryhof, Vryhof Anchor Manual, www.vryhof.com, 2005.

[21] European Gas Pipeline Incident Data Group 3rd EGIG-Report 1970-1997.

[22] DnV Technica, PHAST Release Notes, DnV Technica Inc., Temecula, CA., 1993.

[23] Centre of Chemical Process Safety, Guidelines for Use of Vapour Cloud Dispersion Models, 1996.

[24] P J Rew, P Gallagher, D M Deaves, Dispersion of Subsea Releases: Review of Prediction Methodologies, Health and Safety Executive, 1995.

[25] Transport Department, Monthly Traffic and Transport Digest, March 2006, 2006.

[26] CAD Annual Report 2004/5, www.cad.gov.hk

[27] Planning Department, Hong Kong Planning Standards & Guidelines Chapter 12, Hong Kong Risk Guidelines for Potential Hazardous Installation, 1992.

[28] M J Pikaar, M A Seaman, A Review of Risk Control, Ministerie VROM (1995/27A), 1995.

Annex 13C

Quantitative Risk Assessment: Gas Receiving Station

CONTENTS

1 INTRODUCTION

This annex covers the details of the Quantitative Risk Assessment (QRA) for the Gas Receiving Station (GRS) at the Black Point Power Station (BPPS) which will receive gas through the subsea pipeline from the South Soko LNG Terminal . Detailed information of the study is presented here whilst the results and conclusions are given in the main report, *Section 13*.

2 *DESIGN DETAILS*

The pipeline from the South Soko Terminal to the BPPS will terminate at a GRS. For the detailed layout of the GRS, see *Figure 3.10* of *Section 3* of the main report.

The GRS will be located on a plot of 100m by 50m and comprise the following facilities:

- 2 emergency shutdown (ESD) valves
- 1 pig receiver, with associated service piping;
- Station inlet header;
- 2 inlet filter-separators (plus 1 standby);
- 2 metering runs (plus 1 standby);
- 4 water bath gas heaters (plus 1 standby);
- 2 pressure control runs (plus 1 standby);
- Station export header and check valves.

Piping and equipment will be skid-mounted and placed on prepared concrete footings. Larger piping and equipment assemblies will be delivered to site as discreet subassemblies and assembled on-site. Sensitive instrumentation will be housed in air-conditioned instrument enclosures that are commonly prefabricated portable buildings.

Gas will be received via the offshore pipeline and the first major piece of equipment in the station will be an Emergency Shutdown (ESD) valve, which can be closed by means of the station ESD system in the event of an emergency, isolating the station from the source of gas.

Downstream of the ESD valve will be the station inlet header that will distribute the gas to inlet filter units. Parallel to the inlet filters oriented in-line with the incoming pipeline will be a pig receiver, enabling the running of cleaning and inspection pigs in the pipeline.

3 POPULATION DATA

Both land and marine populations are considered in the analysis. Two cases are considered; years 2011 and 2021.

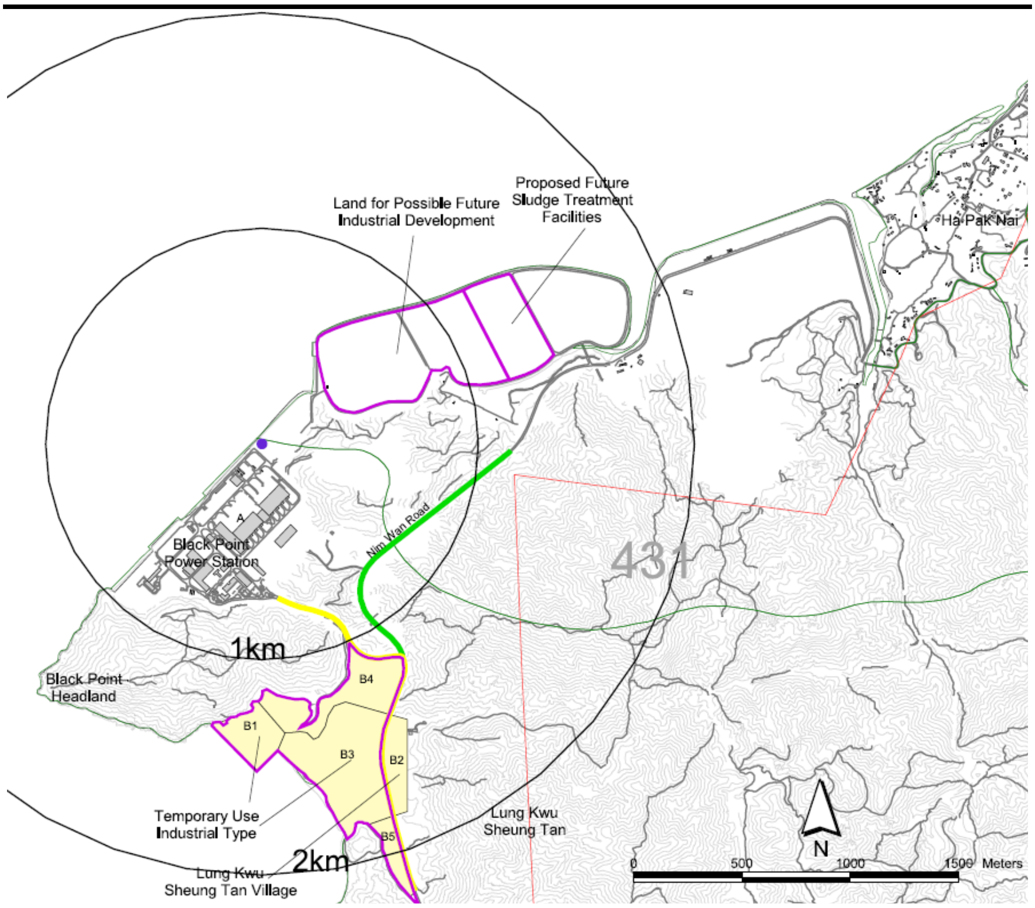
3.1 LAND POPULATION ESTIMATION

The following information sources were referred to for population estimation:

- Site Survey Data [1]
- Population Survey Report [2]
- Census Data [3]
- Land Records from Lands Department
- Road Traffic Data [4]
- Data on Key Individual Developments
- Marine Traffic Data [5-7]

As a conservative assumption, a radius of 2km from the boundary of the proposed GRS has been considered for population estimation (*Figure 3.1*). The land population is assumed to be the same for years 2011 and 2021.

Figure 3.1 Population in the Vicinity of Black Point



3.1.1 *Industrial Population*

According to data provided by Planning Department, Lung Kwu Sheung Tan and the government land allocated for temporary use (part of TPU 432) are the only areas assumed to hold population within 2km radius of the GRS [9]. The village of Lung Kwu Sheung Tan has just one house and so this population was combined with the industrial population in this area to give the "Black Point Site Surrounding" population. The main industry in this area comprises of construction material storage areas and a cement plant. The population was estimated at 76 [1]. As a conservative estimate the population in 2021 is assumed to increase by 30% and, for simplicity, the population in 2011 is taken to be the same. The data presented in *Table 3.1* [1].

Table 3.1 ***Industrial Facility Population***

Location	Approx. Distance from GRS	2011 Population	2021 Population
Black Point Site Surrounding	1km	100	100

3.1.2 *Road Traffic Population*

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

The population estimation for Lung Kwu Tan Road is based on the 2005 Annual Traffic Census [4]. The AADT value is 4,380 vehicles per day for station number 5481 from Lung Fai St. to Tsang Kok. Assuming an average speed of 50km/hr and an average of 3 persons per vehicle, the number of persons on the road is:

No. of persons = (AADT x Vehicle Occupancy / 24 / Speed)
= 4,380 x 3 / 24 / 50 = 11 persons/km

The traffic along this section of road has increased at an average rate of 4.3% in recent years. Assuming this trend continues, the traffic will increase by 30% by the year 2011, and by 100% by the year 2021. The future population for both 2011 and 2021 is therefore conservatively estimated as 11 x 2 = 22 persons/km.

3.1.3 *Occupancy and Indoor/Outdoor Fractions*

The land population is categorised further into 4 time periods: night time, weekday, peak hours and weekend day. These are defined in *Table 3.2*.

Table 3.2 Population Time Periods

Time Period	Description
Night time	7:00pm to 7:00am
Weekday	9:00am to 5:00pm Monday through Friday, and 9:00am to 1:00pm Saturday
Peak hours	7:00am to 9:00am and 5:00pm to 7:00pm, Monday to Friday
	7:00am to 9:00am and 1:00pm to 3:00pm, Saturdays
Weekend day	3:00pm to 7:00pm Saturdays, and 7:00am to 7:00pm Sundays

The occupancy assumed [2] during these time periods is given in *Table 3.3*. Different occupancy figures are assumed for industrial, residential and road types of population. The proportion of the population outdoors is also assumed to vary according to type of population and time period (*Table 3.3*).

The hazards that can potentially affect offsite population are flash fires and thermal radiation from pool fires. Buildings are assumed to offer protection to its occupants for these events. The protection factor used is 90%, or equivalently the exposure factor is 10%. Scenarios are therefore assumed to affect 100% of the outdoor population and 10% of the indoor population.

Road vehicles are also assumed to offer some protection, although less than a building. An exposure factor of 50% is used for vehicles.

Table 3.3 Land Population Occupancy and Indoor/Outdoor Fractions

Population Type	Occupancy				% Outdoors			
	Night	Peak	Weekday	Weekend day	Night	Peak	Weekday	Weekend day
Industrial	10 %	10 %	100 %	10 %	5 %	10 %	10 %	10 %
Residential	100 %	50 %	20 %	80 %	0 %	30 %	10 %	20 %
Road	10 %	100 %	50 %	20 %	0 %	0 %	0 %	0 %

3.2 MARINE POPULATION ESTIMATION

Black Point is situated near Deep Bay. The marine traffic in the vicinity of Deep Bay includes passenger ferries, container ships and rivertrade 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.

3.2.1 *Vessel Population*

The vessel population used in this study are as given in *Table 3.4*. The figures are based on BMT's Marine Impact Assessment report [6] 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 Urmston Road. However, the average load factors for fast ferries to Macau and Pearl River ports are 52% and 37% respectively while the overall average load factor considering all ferries is about 50% [7]. Hence, a distribution in ferry population was assumed as indicated in *Table 3.4*. This distribution gives an overall load factor of about 58% which is conservative and covers any future increase in vessel population.

Table 3.4 *Vessel Population*

Type of 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)	22.5
	175 (typical ferry at 50% capacity)	52.5
	105 (typical ferry at 30% capacity)	12.5
	35 (typical ferry at 10% capacity)	5.00
Tug and Tow	5	
Others	5	

3.2.2 *Marine Vessel Protection Factors*

The population on marine vessels is assumed to have some protection from the vessel structure, in a similar way that buildings offer protection to their occupants. 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
- The ability of gas to penetrate into the interior of the vessel and achieve a flammable mixture.

Small vessels such as fishing boats will provide little protection but larger vessels such as ocean-going vessels will 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 vessel are as given in *Table 3.5*.

Table 3.5 *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
	35	0.3	11
Tug and Tow	5	0.9	5
Others	5	0.9	5

3.2.3 *Methodology*

In this study, the marine traffic population in the vicinity of Black Point has been considered as both point receptors and average density values. The population of all vessels are 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 12.67km^2 grid cells, each grid being approximately 3.6km x 3.6km. The transit time for a vessel to traverse a grid is calculated based on the travel distance divided by the vessel's average speed. The average speed [5] and transit time for different vessel types are presented in *Table 3.6.*

Table 3.6 Average Speed and Transit Time of Different Vessel Type [5]

Type of Vessel	Assumed Speed (m/s)	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 vessels traversing each grid daily was provided by the marine consultant [5]. These are given in *Table 3.7*, where the grid cell reference numbers are defined according to *Figure 3.2*. The number of marine vessels present within each grid cell at any instant in time is then calculated from:

$$\textit{Number of vessels} = \textit{No. of vessels per day} \times \textit{grid length} / 86400 / \textit{Speed} \quad (1)$$

This was calculated for each type of vessel, for each grid and for years 2011 and 2021. The values obtained represent the number of 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.

Figure 3.2 Grid Cell Numbering Scheme

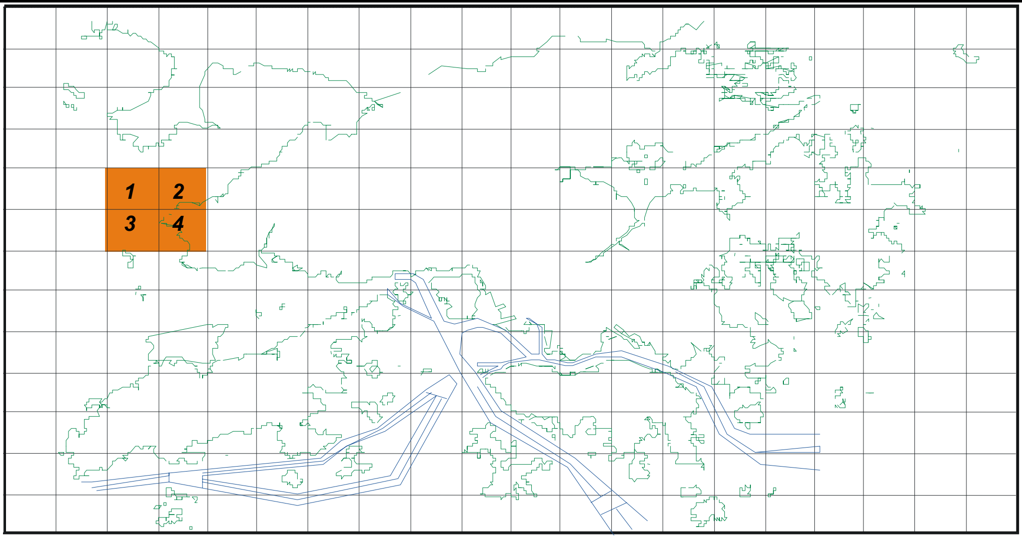


Table 3.7 Number of Marine Vessels Per Day

Grid No.	Average Number of Vessels 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 vessels
RT = Rivertrade coastal vessels
TT = Tug & tow vessels
FF = Fast ferries
OTH = others

Average Density Approach

The average marine population for each grid is calculated by combining the number of vessels in each grid (from *Equation 1*) with the population at risk for each vessel (*Table 3.5*). The results are shown in *Figures 3.3* and *3.4*. This grid population is assumed to apply to all time periods. Note 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:

$$\textit{Number of fatalities} = \textit{grid population} \times \textit{impact area} \,/\, \textit{grid area} \qquad (2)$$

Figure 3.3 Marine Population at Risk by Grid, Year 2011

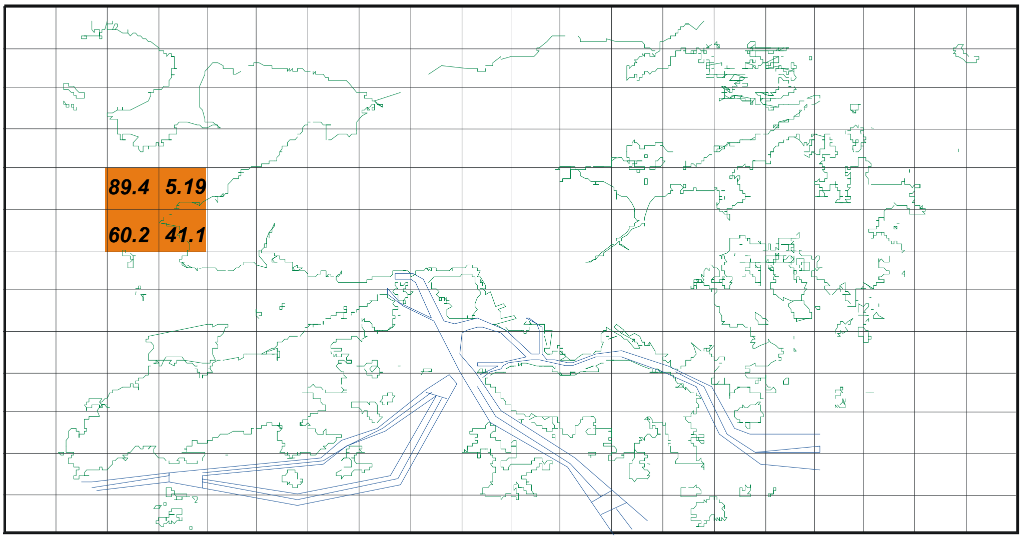
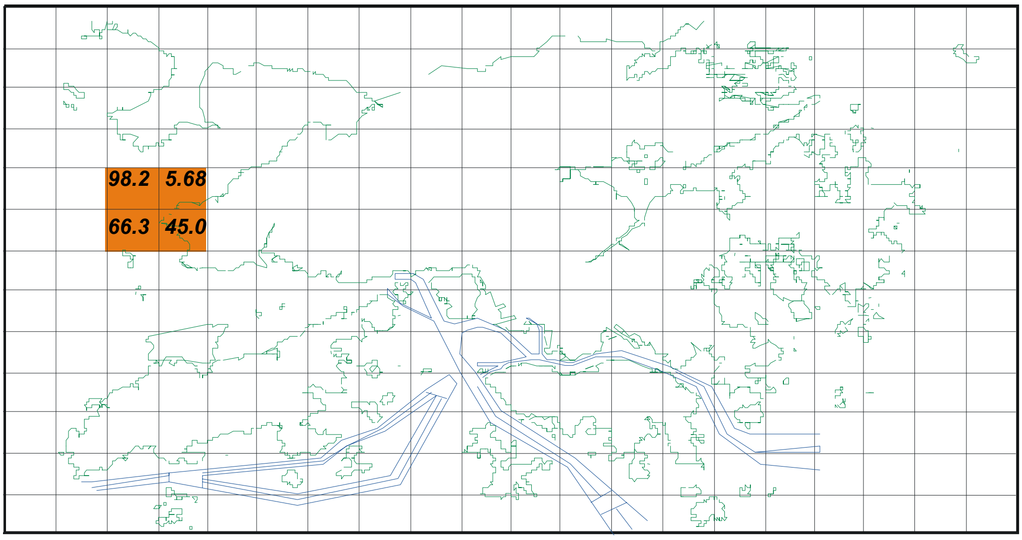


Figure 3.4 Marine Population at Risk by Grid, Year 2021



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 a little differently in the analysis.

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 equivalently 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:

$$\textit{Prob. that ferry is affected} = \textit{presence factor} \times \textit{impact area} \,/\, \textit{grid area} \qquad (3)$$

The fast ferry population distribution adopted was described in *Table 1.5*. Information from the main ferry operators suggests that 25% of ferry trips take place at night time, while 75% occur during daytime. Day and night ferries are therefore assessed separately in the analysis. The distribution assumed is given in *Table 3.8*.

Table 3.8 Fast Ferry Population Distribution for Day and Night Time Periods

Population	Population at Risk	% of Day Trips	% of Night Trips	% of All Trips (= 0.75 x day + 0.25 x night)
450	135	5	-	3.75
350	105	5	-	3.75
280	84	30	-	22.5
175	53	60	30	52.5
105	32	-	50	12.5
35	11	-	20	5.0

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.

3.2.4 Stationary Marine Population

Stationary marine population in the vicinity of the GRS was also considered. Contributions to these populations come from the Urmston Road Anchorage [5]. The population on each type of vessel (*Table 3.4*) was treated the same as mobile vessels and the same fatality factors (*Table 3.5*) were used to calculate the population at risk for each grid cell. The results are given in *Figures 3.5* and *3.6*. This population is assumed to be present during all time periods.

Figure 3.5 Stationary Marine Population at Risk (2011)

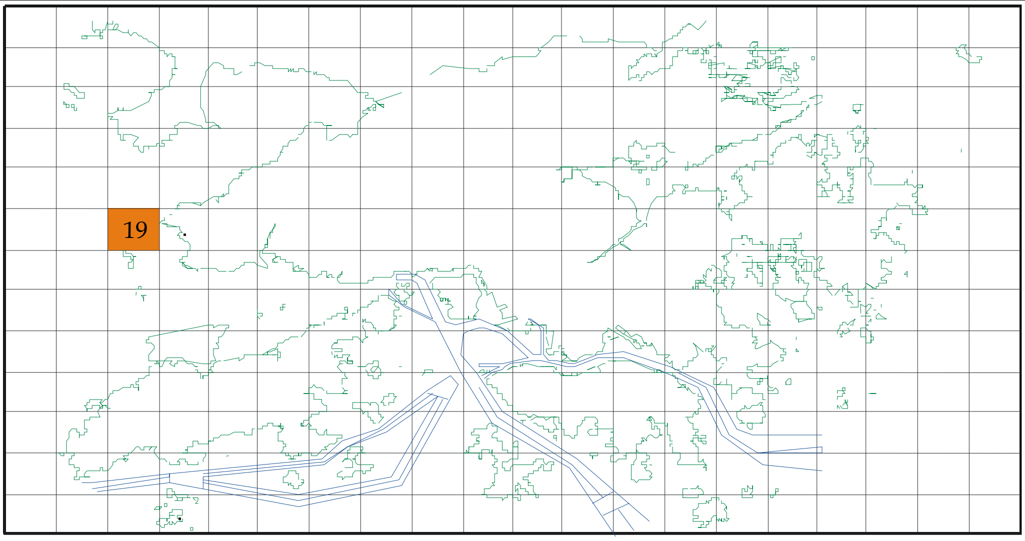
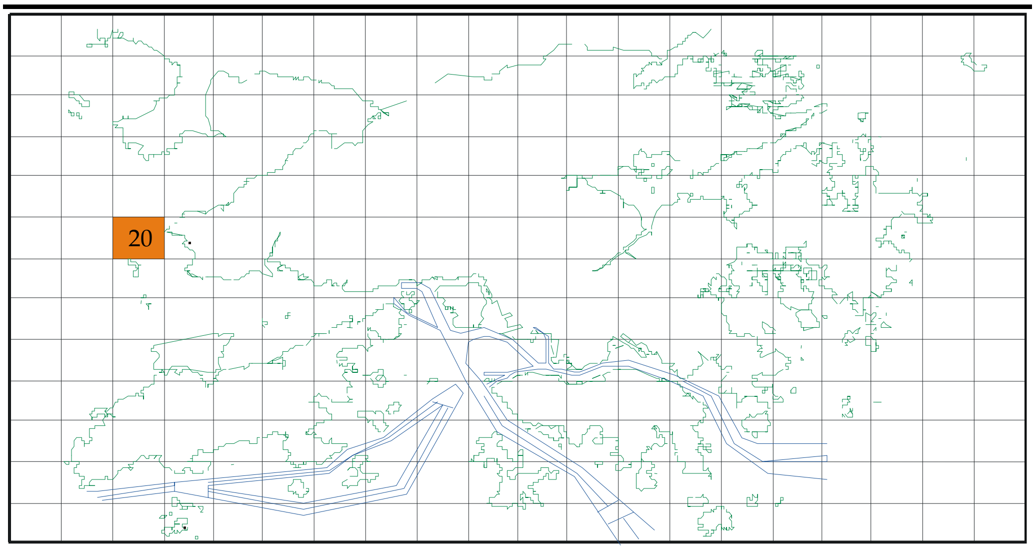


Figure 3.6 Stationary Marine Population at Risk (2021)

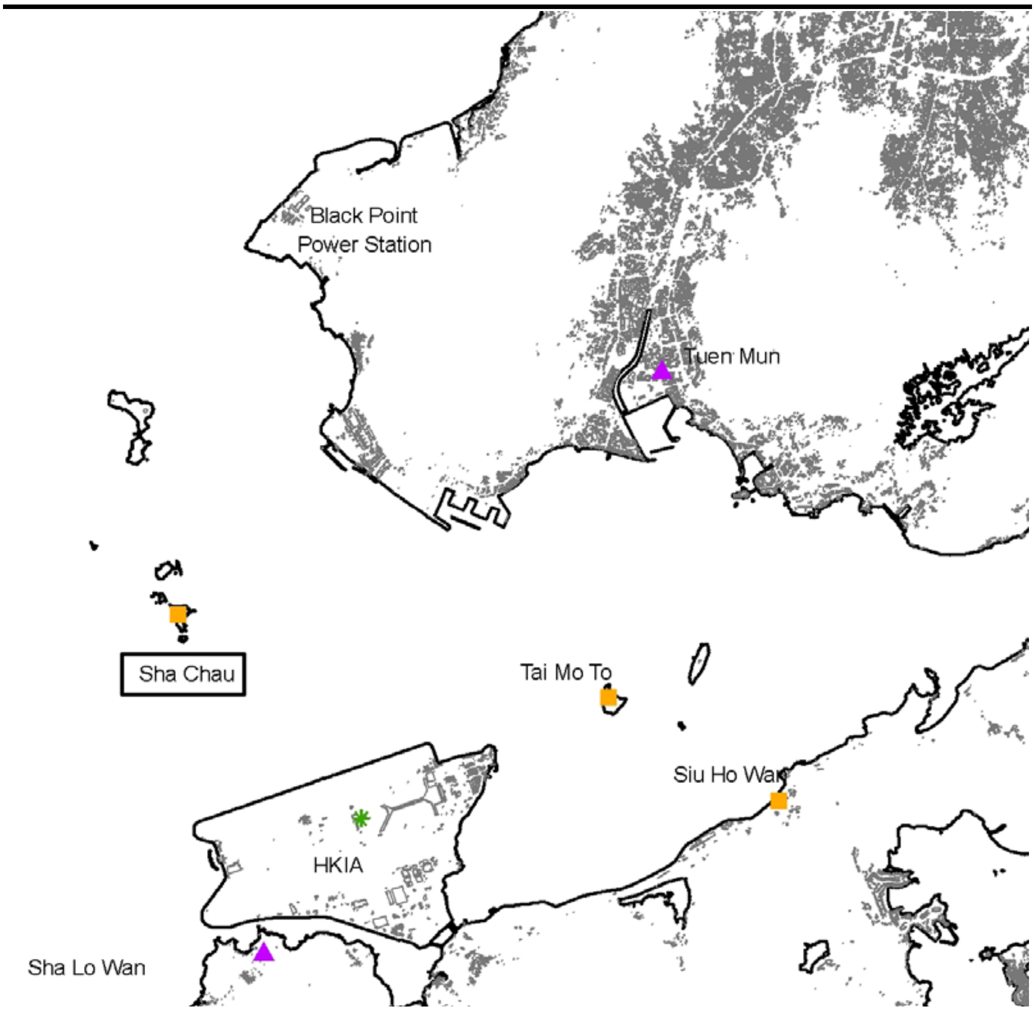


4 METEOROLOGICAL DATA

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

The location of weather stations in the vicinity of the GRS is shown in *Figure 4.1*. Data from the Sha Chau weather station was adopted for the GRS study as it is closest to the site and also the most relevant based on the topography. The meteorological data used in this study is based on the data recorded by the stations over a five year period.

Figure 4.1 Weather Stations in Vicinity of Black Point



The raw data from the Observatory is a series of readings taken every hour for a period of one year. This data has been rationalized into different combinations of wind direction, speed and atmospheric stability class, as per the following:

- Each data record is rated with a stability class A through F. For simplicity, this study has used three stability classes, B, D and F. Accordingly, the data records have been assigned to these three classes;

- Each data record has an associated wind speed. For simplicity, this study has used five wind speed classes. Accordingly, the data records have been assigned to these five classes;

- Each data record has an associated wind direction. For simplicity, this study has used 12 wind directions. Accordingly, the data records have been assigned to these twelve classes;

- The data has been split into night and day times encompassing day time from 7am to 7pm and night time from 7pm to 7am.

The annual average temperature for Black Point is 23.9 °C. Temperature data was not available from the Sha Chau station and so temperature readings were taken from the Hong Kong Airport instead. The average relative humidity is 78%. *Table 4.1* below tabulates temperature statistics.

Table 4.1 Temperature Statistics for Black Point

		Min.	Max.	Average
Ambient air (T°C)[1]	*BP*	6.7	35.1	23.9
Surface (T°C)[1]		20.9	25.7	23
Seawater (T°C)[2]	*BP*	16.2	27.8	23.9
Humidity (%)[1]		65	82	77

Source: 1. Hong Kong Observatory, "The Year's Weather – 2003"
2. HK EPD, "Summary water quality statistics of the Junk Bay and Deep Bay WCZs in 2002"

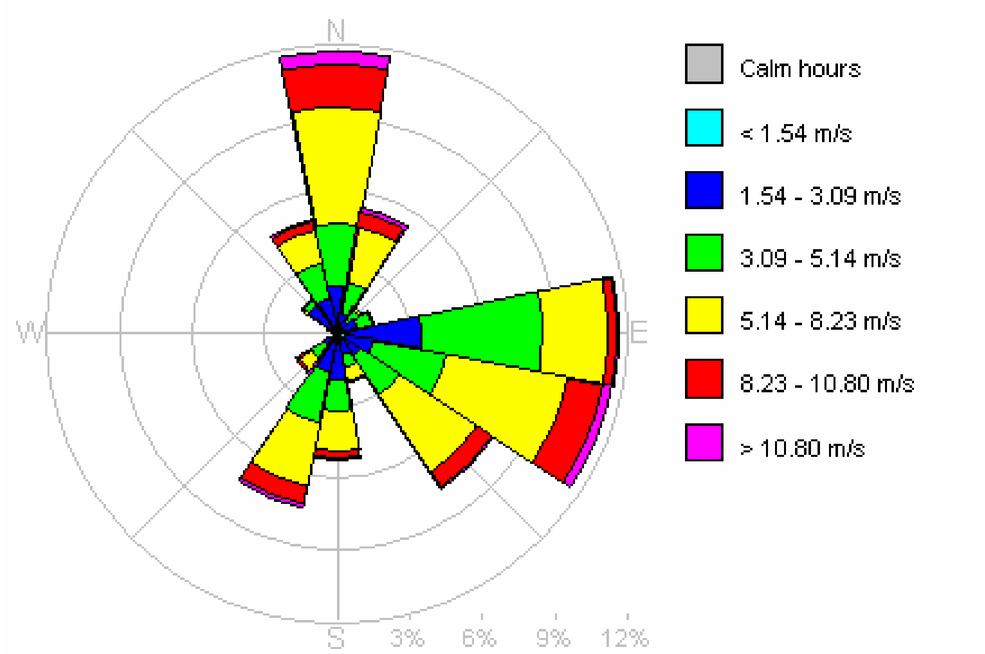
The percentage of occurrence for each combination of wind direction, speed and atmospheric stability during day and night are presented in *Table 4.2*. In addition, the percentages frequencies are plotted in the form of wind roses for Sha Chau in *Figure 4.2*.

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

Table 4.2 Data for Sha Chau Weather Station

	Day				Night			
Wind Speed (m/s)	2.5	2	3	7	2.5	2	3	7
Atmospheric Stability	B	F	D	D	B	F	D	D
Wind Direction	Percentage of Occurrence							
0°	2.48	0.92	1.37	13.75	0.00	2.08	0.89	9.93
30°	0.72	0.61	0.76	4.38	0.00	1.78	0.84	7.12
60°	0.55	0.61	0.59	0.55	0.00	1.89	0.76	0.95
90°	2.00	1.57	2.43	6.07	0.00	6.69	2.97	9.53
120°	1.68	0.90	1.32	15.98	0.00	3.82	1.84	20.08
150°	1.06	0.61	0.36	3.12	0.00	2.28	0.60	3.83
180°	2.43	0.71	0.65	3.64	0.00	1.81	0.74	3.88
210°	3.35	0.86	1.39	9.04	0.00	2.06	1.01	6.91
240°	0.07	0.16	0.05	0.02	0.00	0.23	0.02	0.04
270°	0.08	0.09	0.01	0.01	0.00	0.11	0.00	0.01
300°	1.58	0.35	0.21	0.07	0.00	0.62	0.04	0.05
330°	3.78	0.74	1.09	5.22	0.00	1.59	0.53	2.45

Figure 4.2 Wind Rose for Sha Chau Weather Station (1999-2004)



Note on Atmospheric Stability

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. Category D is neutral and neither enhances nor suppresses atmospheric turbulence. Class F on the other hand represents moderately stable conditions, which typically arise on clear nights with little wind.

5 FREQUENCY ANALYSIS

Failure Frequencies

Table 5.1 lists all the failure frequencies adopted for the various release scenarios used in the GRS study. Codes are assigned for various source terms; these are defined in *Section 6, Table 6.1*.

Table 5.1 Gas Release Event Frequencies

Code	No. of Items	Length of Section (m)	Hole Size (mm)	Initiating Event Frequency	Unit	Reference
G1	1	25.5	10	1.00E-07	per meter per year	Hawksley [5]
			25	1.00E-07		
			50	7.00E-08		
			100	7.00E-08		
			FB	3.00E-08		
G2	4	4.5	10	3.00E-07	per year	Hawksley
			25	3.00E-07		
			50	1.00E-07		
			100	1.00E-07		
			FB	5.00E-08		
G3	2	3.9	10	3.00E-07	per meter per year	Hawksley
			25	3.00E-07		
			50	1.00E-07		
			100	1.00E-07		
			FB	5.00E-08		

Ignition Probabilities

Table 5.2 gives a summary of the ignition probabilities assumed for the study. 10 and 25mm holes are considered "small leaks", while 50 and 100mm holes are considered "large leaks".

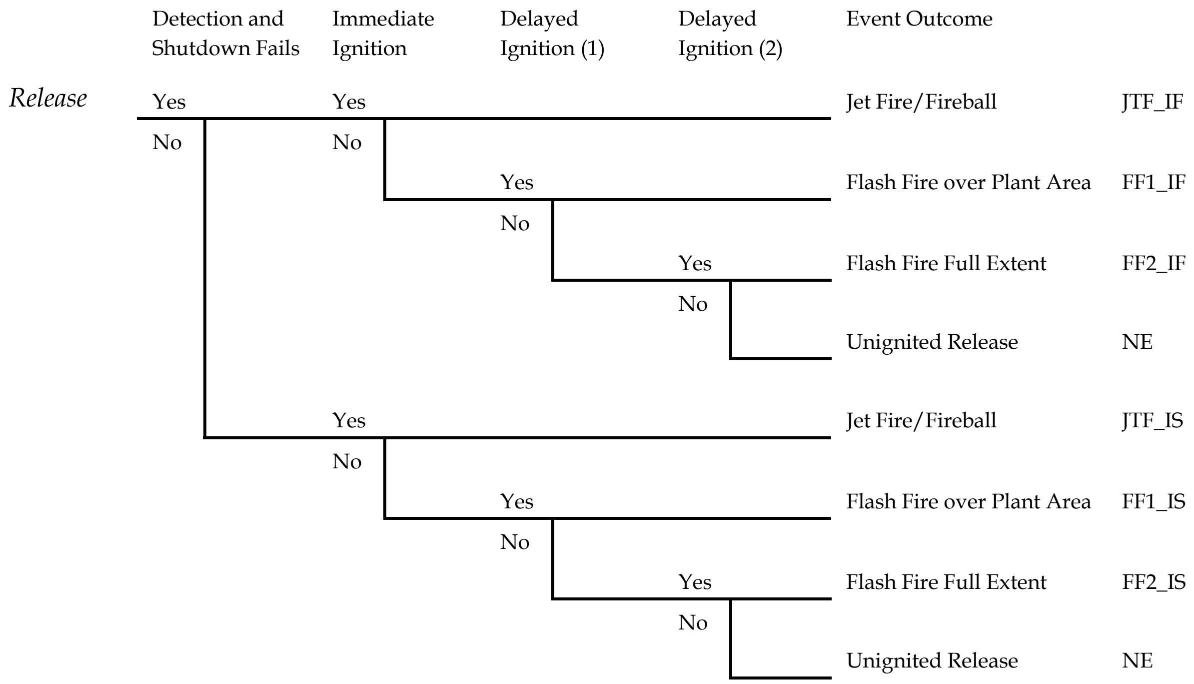
Table 5.2 Ignition Probabilities Assumed

	Immediate Ignition	Delayed Ignition 1	Delayed Ignition 2	Delayed Ignition Probability	Total Ignition Probability
Gas small leak	0.02	0.045	0.005	0.05	0.07
Gas large leak/rupture	0.1	0.2	0.02	0.22	0.32

Outcome Frequencies

A Generic Event Trees is shown in *Figure 5.1*. Based on the initiating event frequencies listed in *Table 5.1* and ignition probabilities in *Table 5.2*, specific event trees can be generated for different release scenarios.

Figure 5.1 Generic Event Tree



A summary of outcome frequencies for all the events considered in the GRS study is listed in *Table 5.3*.

Detail of the nomenclature is as follows:

IS = Isolation Success
IF = Isolation Failure
FF1 = Flash Fire over the Plant Area
FF2 = Flash Fire, Full Extent
PLF = Pool Fire
JTF = Jet Fire
FBL = Fire Ball
FB = Full Bore
NE = No Effect

Table 5.3 Outcome Frequencies Summary

Release Event	Release Scenario					
	10mm	**25mm**	**50mm**	**100mm**	**IS_FB**	**IF_FB**
G01_FF2	4.68E-11	4.68E-11	1.01E-10	1.01E-10	3.89E-10	4.32E-11
G01_FF1	4.41E-10	4.41E-10	1.26E-09	6.93E-09	4.86E-09	5.40E-10
G01_JTF	2.00E-10	2.00E-10	7.00E-10	7.00E-09		3.00E-10
G01_FBL					2.70E-09	
G02_FF2	1.40E-10	1.40E-10	1.44E-10	1.44E-10	6.48E-10	7.20E-11
G02_FF1	1.32E-09	1.32E-09	1.80E-09	9.90E-09	8.10E-09	9.00E-10
G02_JTF	6.00E-10	6.00E-10	1.00E-09	1.00E-08		5.00E-10
G02_FBL					4.50E-09	
G03_FF2	1.40E-10	1.40E-10	1.44E-10	1.44E-10	6.48E-10	7.20E-11
G03_FF1	1.32E-09	1.32E-09	1.80E-09	9.90E-09	8.10E-09	9.00E-10
G03_JTF	6.00E-10	6.00E-10	1.00E-09	1.00E-08		5.00E-10
G03_FBL					4.50E-09	

6 CONSEQUENCE ANALYSIS

6.1 SOURCE TERM MODELLING

The process facility was divided into 3 isolatable sections. *Table 6.1* lists the process details adopted for each process section.

Table 6.1 Release Source Term Information

Code	Scenario Name	Fluid Phase	Nature of Section	No. of Items	Length of Section (m)	Pipe Diameter (mm)	Pressure (bara)	Temperature (°C)	Density (kg/m³)	Inventory (kg)	Normal Flow Rate (kg/s)
G01	Gas piping from shutdown valve through gas filter to control valve	Gas	Piping	1	25.5	750	91.18	11.93	92.73	1044	356.40
G02	Gas Heater Piping	Gas	Piping	3	4.5	250	90.68	43.39	73.9	16	54.84
G03	Pressure Control Assembly	Gas	Piping	2	3.9	450	88.68	77.49	61.84	38	135.31

6.2 CONSEQUENCE MODELLING

Table 6.2 shows the list of release scenarios along with the corresponding consequence model used in *PHAST*.

Table 6.2 Release Scenarios and Consequence Models Applied

Release Scenario	Release Type	Model Applied in PHAST
10mm leak	Leak	Leak
25mm leak	Leak	Leak
50mm leak	Leak	Leak
100mm leak	Leak	Leak
Full bore rupture	Rupture	Catastrophic Rupture

The consequence modelling parameters for PHAST are listed in *Table 6.3*.

Table 6.3 Consequence Modelling Parameters

BLEVE Parameters		
Maximum SEP for a BLEVE	400.00	kW/m2
Fireball radiation intensity level 1	7.00	kW/m2
Fireball radiation intensity level 2	14.00	kW/m2
Fireball radiation intensity level 3	21.00	kW/m2
Mass Modification Factor	3.00	
Fireball Maximum Exposure Duration	30.00	s
Ground Reflection	Ground Burst	
Ideal Gas Modeling	Model as real gas	
Discharge Parameters		
Continuous Critical Weber number	12.50	
Instantaneous Critical Weber number	12.50	
Venting equation constant	24.82	
Relief valve safety factor	1.20	
Minimum RV diameter ratio	1.00	
Critical pressure greater than flow phase	0.34	bar
Maximum release velocity	500.00	m/s
Minimum drop size allowed	0.00	mm
Maximum drop size allowed	10.00	mm
Default Liquid Fraction	1.00	fraction
Continuous Drop Slip factor	1.00	
Instantaneous Drop Slip factor	1.00	
Pipe-Fluid Thermal Coupling	0.00	
Number of Time Steps	100.00	
Maximum Number of Data Points	1,000.00	
Non-Return Valve velocity head losses	0.00	
Pipe roughness	0.046	mm
Shut-Off Valve velocity head losses	0.00	
Excess Flow Valve velocity head losses	0.00	
Default volume changes	3.00	/hr
Line length	10.00	m
Elevation	1.00	m
Atmospheric Expansion Method	Closest to Initial Conditions	
Tank Roof Failure Model Effects	Instantaneous Effects	
Outdoor Release Direction	Horizontal	

Dispersion Parameters

Dense cloud parameter gamma (continuous)	0.00	
Dense cloud parameter gamma (instant)	0.30	
Dense cloud parameter k (continuous)	1.15	
Dense cloud parameter k (instantaneous)	1.15	
Jet entrainment coefficient alpha1	0.17	
Jet entrainment coefficient alpha2	0.35	
Ratio instantaneous/continuous sigma-y	1.00	
Ratio instantaneous/continuous sigma-z	1.00	
Distance multiple for full passive entrainment	2.00	
Quasi-instantaneous transition parameter	0.80	
Impact parameter - plume/ground	0.80	
Expansion zone length/source diameter ratio	0.01	
Drop/expansion velocity for inst. release	0.80	
Drag coefficient between plume and ground	1.50	
Drag coefficient between plume and air	0.00	
Default bund height	0.00	m
Maximum temperature allowed	626.85	degC
Minimum temperature allowed	-263.15	degC
Minimum release velocity for cont. release	0.10	m/s
Minimum integration step size (Instantaneous)	0.10	s
Maximum integration step size (Instantaneous)	1,000.00	s
Minimum integration step size (Continuous)	0.10	m
Maximum integration step size (Continuous)	100.00	m
Maximum distance for dispersion	50,000.00	m
Maximum height for dispersion	1,000.00	m
Minimum cloud depth	0.02	m
Expansion energy cutoff for droplet angle	0.69	kJ/kg
Droplet evaporation thermodynamics model	Rainout, Non-equilibrium	
Flag for mixing height	Constrained	
Accuracy for integration of dispersion	0.00	
Accuracy for droplet integration	0.00	
Richardson number criterion for cloud lift-off	-20.00	
Flag to reset rainout position	Do not reset rainout position	
Surface over which the dispersion occurs	Water	
Minimum Vapor Fraction for Convection	0.00	fraction
Coefficient of Initial Rainout	0.00	
Minimum Continuous Release Height	0.00	m
Flag for finite duration correction	Finite Duration Correction	
Near Field Passive Entrainment Parameter	1.00	
Jet Model	Morton et.al.	
Maximum Cloud/Ambient Velocity Difference	0.10	
Maximum Cloud/Ambient Density Difference	0.02	
Maximum Non-passive entrainment fraction	0.30	
Maximum Richardson number	15.00	
Core Averaging Time	18.75	s
Ground Drag Model	New (Recommended)	
Flag for Heat/Water vapor transfer	Heat and Water	
Richardson Number for passive transition above pool	0.02	
Pool Vaporization entrainment parameter	1.50	
Modeling of instantaneous expansion	Standard Method	
Minimum concentration of interest	0.00	fraction

Maximum distance of interest	10,000.00	m
Model In Use	Best Estimate	
Maximum Initial Step Size	10.00	m
Minimum Number of Steps per Zone	5.00	
Factor for Step Increase	1.20	
Maximum Number of Output Steps	1,000.00	
Flammables Parameters		
Height for calculation of flammable effects	0.00	m
Flammable result grid step in X-direction	10.00	m
LFL fraction to finish	0.85	
Flammable angle of inclination	0.00	deg
Flammable inclination	Variable	
Flammable mass calculation method	Mass between LFL and UFL	
Flammable Base averaging time	18.75	s
Cut Off Time for Short Continuous Releases	20.00	s
Observer type radiation modelling flag	Planar	
Probit A Value	-36.38	
Probit B Value	2.56	
Probit N Value	1.33	
Height for reports	Centreline Height	
Angle of orientation	0.00	deg
Relative tolerance for radiation calculations	0.02	fraction
General Parameters		
Maximum release duration	3,600.00	s
Height for concentration output	0.00	m
Jet Fire Parameters		
Maximum SEP for a Jet Fire	400.00	kW/m2
Jet Fire Averaging Time	20.00	s
Jet fire radiation intensity level 1	7.00	kW/m2
Jet fire radiation intensity level 2	14.00	kW/m2
Jet fire radiation intensity level 3	21.00	kW/m2
Rate Modification Factor	3.00	
Jet Fire Maximum Exposure Duration	30.00	s
Model Correlation Type	Shell	
Weather Parameters		
Atmospheric pressure	1.01	bar
Atmospheric molecular weight	28.97	
Atmospheric specific heat at constant pressure	1.00	kJ/kg.degK
Wind speed reference height (m)	10.00	m
Temperature reference height (m)	0.00	m
Cut-off height for wind speed profile (m)	1.00	m
Wind speed profile	Power Law	
Atmospheric Temperature and Pressure Profile	Temp.Logarithmic; Pres.Linear	
Atmospheric temperature	23.00	degC
Relative humidity	0.77	fraction
Surface Roughness Parameter	0.043	
Surface Roughness Length	0.912	mm
Roughness or Parameter	Parameter	
Dispersing surface temperature	23.00	degC
Default surface temperature of bund	23.00	degC

Solar radiation flux	0.50	kW/m2
Building Exchange Rate	4.00	/hr
Tail Time	1,800.00	s

6.3 *CONSEQUENCE RESULTS*

The end-point criteria used to define the impact level at which a fatality could result are the same as those used in the terminal study (*Annex13A7*). A complete list of hazard distances obtained from the consequence modelling is provided in *Table 6.4*.

Table 6.4 Consequence Results

Section		Phase L/G	Leak size (mm)	Hazard effects	End point criteria	Hazard extent (m) Weather conditions			
						F, 2 m/s	D, 3 m/s	D, 7 m/s	B, 2.5 m/s
G1	Gas piping from shutdown valve through gas filter to control valve	G	10	Jet fire	35.5 kW/m2	19	17	14	18
					20.9 kW/m2	17	16	15	16
					14.4 kW/m2	19	18	16	18
					7.3 kW/m2	22	21	19	21
				Flash fire	0.85 LFL	12	12	11	12
			25	Jet fire	35.5 kW/m2	42	38	31	40
					20.9 kW/m2	42	40	36	41
					14.4 kW/m2	45	43	39	44
					7.3 kW/m2	52	49	41	50
				Flash fire	0.85 LFL	35	35	36	34
			50	Jet fire	35.5 kW/m2	78	70	56	73
					20.9 kW/m2	81	75	68	78
					14.4 kW/m2	85	81	73	83
					7.3 kW/m2	98	92	85	95
				Flash fire	0.85 LFL	78	79	83	77
			100	Jet fire	35.5 kW/m2	142	128	103	134
					20.9 kW/m2	151	141	127	146
					14.4 kW/m2	161	151	137	156
					7.3 kW/m2	182	172	159	177
				Flash fire	0.85 LFL	169	171	184	167
			Full bore (isoln. succ.)	Fireball	35.5 kW/m2	29	29	29	29
					20.9 kW/m2	102	102	102	102
					14.4 kW/m2	124	124	124	124
					7.3 kW/m2	174	174	174	174
				Flash fire	0.85 LFL	19	20	27	19
			Full bore (isoln. fail.)	Jet fire	35.5 kW/m2	218	195	158	206
					20.9 kW/m2	235	220	197	227

					14.4 kW/m2	251	235	213	242
					7.3 kW/m2	283	268	248	275
				Flash fire	0.85 LFL	288	293	317	287
G2	Gas Heater Piping	G	10	Jet fire	35.5 kW/m2	19	17	14	18
					20.9 kW/m2	17	16	15	16
					14.4 kW/m2	19	18	16	18
					7.3 kW/m2	22	21	19	21
				Flash fire	0.85 LFL	12	12	11	12
			25	Jet fire	35.5 kW/m2	42	38	31	40
					20.9 kW/m2	42	40	35	41
					14.4 kW/m2	45	43	38	44
					7.3 kW/m2	51	49	45	50
				Flash fire	0.85 LFL	35	35	36	34
			50	Jet fire	35.5 kW/m2	78	70	56	73
					20.9 kW/m2	80	75	67	78
					14.4 kW/m2	85	81	73	83
					7.3 kW/m2	97	92	85	94
				Flash fire	0.85 LFL	78	79	83	77
			100	Jet fire	35.5 kW/m2	142	127	103	134
					20.9 kW/m2	151	141	126	145
					14.4 kW/m2	161	151	136	155
					7.3 kW/m2	182	172	159	176
				Flash fire	0.85 LFL	169	171	184	167
			Full bore (isoln. succ.)	Fireball	35.5 kW/m2	25	25	25	25
					20.9 kW/m2	86	86	86	86
					14.4 kW/m2	106	106	106	106
					7.3 kW/m2	148	148	148	148
				Flash fire	0.85 LFL	16	17	23	16
			Full bore (isoln. fail.)	Jet fire	35.5 kW/m2	218	195	158	205
					20.9 kW/m2	234	219	197	226
					14.4 kW/m2	250	235	213	241
					7.3 kW/m2	283	268	247	274

				Flash fire	0.85 LFL	287	292	316	287
G3	Pressure Control Assembly	G	10	Jet fire	35.5 kW/m2	17	15	12	16
					20.9 kW/m2	15	14	13	15
					14.4 kW/m2	17	16	14	16
					7.3 kW/m2	20	19	17	19
				Flash fire	0.85 LFL	11	10	9	10
			25	Jet fire	35.5 kW/m2	38	34	28	36
					20.9 kW/m2	38	36	32	37
					14.4 kW/m2	41	38	35	40
					7.3 kW/m2	46	44	41	45
				Flash fire	0.85 LFL	31	31	31	30
			50	Jet fire	35.5 kW/m2	71	63	51	66
					20.9 kW/m2	73	68	61	70
					14.4 kW/m2	78	73	66	75
					7.3 kW/m2	88	83	77	85
				Flash fire	0.85 LFL	63	68	70	66
			100	Jet fire	35.5 kW/m2	129	115	93	122
					20.9 kW/m2	136	128	114	132
					14.4 kW/m2	145	136	123	140
					7.3 kW/m2	164	156	143	160
				Flash fire	0.85 LFL	141	143	151	138
			Full bore (isoln. succ.)	Fireball	35.5 kW/m2	10	10	10	10
					20.9 kW/m2	36	36	36	36
					14.4 kW/m2	44	44	44	44
					7.3 kW/m2	62	62	62	62
				Flash fire	0.85 LFL	6	6	8	6
			Full bore (isoln. fail.)	Jet fire	35.5 kW/m2	143	128	104	135
					20.9 kW/m2	152	142	128	147
					14.4 kW/m2	162	152	138	157
					7.3 kW/m2	184	174	160	178
				Flash fire	0.85 LFL	163	163	170	156

REFERENCES

[1] ERM, Environmental and Risk Assessment Study for a Liquefied natural gas (LNG) Terminal in the Hong Kong SAR – Population Update Report, Dec 2004.

[2] ERM, Liquefied Natural Gas (LNG) Terminal and Associated Facilities – Marine Quantitative Risk Assessment, Population Survey Report, Jun 2006.

[3] www.censtatd.gov.hk

[4] The Annual Traffic Census 2005, Transport Department, Hong Kong SAR, Jun 2006.

[5] BMT Asia Pacific Ltd., personal communication, 2006

[6] BMT Asia Pacific Ltd, Marine Impact Assessment for Black Point & Sokos islands LNG Receiving Terminal & Associated Facilities, Pipeline Issues, Working Paper #3, Issue 6, May 2006

[7] Passenger Arrivals/Departures and Passenger Load Factors at Cross-Boundary Ferry Terminals, January to December 2005, Marine Department, Hong Kong SAR.

[8] Hong Kong 2030, Planning Vision and Strategy, Planning Department, Hong Kong SAR.

[9] Projected Hong Kong Resident Population by TPU, Planning Department, Hong Kong SAR, 2004

[10] Hawksley, J.L., Some Social, Technical and Economic Aspects of the Risks of Large Plants, CHEMRAWN III, 1984.

Annex 13D

Safety Management System

Liquefied Natural Gas Receiving Terminal Safety Management System

Castle Peak Power Company Limited (CAPCO) plans to incorporate the proposed Liquefied Natural Gas (LNG) Receiving Terminal into its current Safety Management System. An excerpt of the existing Safety Management System from the CAPCO Safety Case is included in Appendix 1. In addition to the practices and procedures identified in the Safety Management System, the following measures will be taken to prevent or control accidents:

1. Safety Feature Installations

A centralized spill, fire and combustible gas alarm and control system will provide input to an information management system. The primary purpose is to provide plant operators with a central facility for monitoring the conditions of accidental spill, fire and the release of combustible gas. It will also provide the operators with the information and the means of responding to emergencies involving these conditions.

The main distributed control system, DCS console, is the physical operator/alarm and control system interface and will be located in the central control room, which is manned 24 hours a day. Various lighted push buttons, digital read outs and annunciates provide the operator with complete monitoring and control capabilities. The information management in the main DCS console will display combustible gas concentrations, alarm locations, etc.

In the event of total power failure, the LNG terminal will be shut down, the unloading operation will be stopped and the boil-off gas will be routed to the LP and HP vent system.

Color TV monitors will be installed to allow a visual picture of the entire facility at the central control room and gatehouse area.

Automatic detection devices, manual alarms and audible and visual signaling devices will be strategically located throughout the terminal. Hazard detection and alarm signaling devices will report to the central control room and tie-in to the DCS.

Automatic detection devices will include flame, fire and heat, smoke, low temperature and combustible gas detectors. The hazard detection system will be designed to minimize the time a spill, leak or fire might go undetected by installing multiple and redundant different detectors within the terminal to detect gas, fire, low temperatures and low and/or high operating pressures outside normal operating levels. The detectors are located to provide warning as quickly as possible. The detector signals are continuously monitored by an online computer in the control room that identifies a hazardous condition within the terminal to alarm and locate the situation for operating personnel.

The operators will be trained so that they are familiar with the fire prevention, fire protection and fire fighting methods.

The following safety and fire fighting features will be installed:

i. Deluge systems will be installed on the tank roof.

ii. Spill-collection system designed and located to deflect and prevent a pressurized LNG spill. The LNG leak detection system is typically designed to detect spills and to shutdown the plant less than two minutes after a spill, and the LNG spill is able to be contained in the drainage basin area. LNG spill sump will be designed for removing water and keeping debris free.
iii. Install fixed dry chemical fire suppression systems on the tank roof.
iv. Portable dry chemical extinguishers will be installed on the tank roof platform.
v. Fixed high expansion foam protect will be provided. Foam generators will be blower type, with hydraulic turbine-driven fans, producing a nominal 500:1 foam at an application rate of 120 m^3/hour of expanded foam per m^2 of contained LNG spill surface area.
vi. Hydrants approximate 90 meters apart and firewater monitors approximate 60 meters apart to be installed on the firewater main. Isolation valves in the fire water main will be provided.
vii. Automatic actuation for the firefight system will be automatic actuated by combustible gas detectors and low temperature detectors installed near the entrance to the LNG spill sump, and by means of voting UV/IR optical flame detectors.

The LP and HP vent system is designed to consider the following:

- LNG tank rollover and BOG from sudden drop in barometric pressure.
- The inner tank-overfilling scenario is eliminated by safety instrumentation system by tripping the unloading system.

The LNG terminal is designed for safe handling of vapor discharges from the system, such as relief valves. During normal operation, there is no vent and relief. Venting will be a rare event during normal and unloading operations.

2. Emergency Shutdown (ESD) and Depressurization (EDP) System

The isolation systems are located in different areas along with equipment with fire, explosion and toxicity potential risks. An Emergency Shut Down (ESD) and Emergency Depressurization (EDP) systems will be provided to protect plant personnel, plant equipment and the environment in case of an emergency such as fire, potential dangerous process upset or hydrocarbon leak. The ESD system will isolate the unit/system where an incident is occurring from the adjacent units/system. The EDP system will reduce the hydrocarbon inventory of the system and will decrease its pressure. Equipment and piping are divided into sections called ESD zones, considering the plot plan and the process flow.

An emergency shutdown system (ESD) will be incorporated in the design of the Terminal and provide the operators with the capability of remotely shutting down the entire or selective portions of the Terminal.

There will be three major ESD modes for the Terminal:

i. LNG unloading Isolation – The LNG unloading dock to the LNG storage tanks.

The ESD system will be installed on the LNG unloading lines to block in the unloading lines in the case of an LNG leak, a sudden unplanned disconnect of the LNG carrier, an external fire or any other emergency during unloading. It consists of quick shut-off valves at the unloading dock. These valves are triggered automatically by ship separation or high pressure or manually by an operator. The closure times of the valves are set to prevent a liquid surge in the lines.

ii. Send-out Shutdown – The LNG tanks through the pipeline shutoff valves. Shut down the Primary LNG pumps, send-out pumps and BOG compressors; Isolation of the Terminal from the pipeline by closure ESD valves; Isolation of the high pressure part of the Terminal by closure ESD valves at send-out pump suction, primary pump discharge, compressor discharge, and depressurization of the vaporizers.

iii. Overall Shutdown – From the ship-unloading area through the pipeline shutoff valves, with activation of modes 1 and 2 above

The following Shutdown functions will be provided:

- Block in of the LNG loading arms
- Block in of the LNG vapor return arm
- Block in at shore line all unloading lines
- Block in of LNG lines to LNG storage tanks
- Shut down return gas
- Shut down LP LNG send-out pumps in the LNG tanks
- Block in send-out valves to BOG condenser
- Shut down BOG compressors
- Shut down HP LNG booster pumps
- Block in LNG to vaporizers
- Block in the outlet of the vaporizers
- Emergency depressurizing the vaporizer units

Detector types will include:

- Fire/Flame detectors
- Gas detectors
- Low temperature detectors
- High-level shutdowns on the LNG storage tanks' High-pressure shutdowns
- Low flow shutdowns
- Smoke detectors (for Buildings)
- Heat detectors
- Camera surveillance of the facility
- Manual ESD activation stations

3. Instrumentation, Control and Tank Level Measurement

The control system of the plant is performed by a Distributed Control System (DCS).

The major process control loops described below are shown in the Process Flow Diagrams.

The control system for the Terminal will be designed for fail-safe operation. The control valves will be designed to move to a "fail safe" position, fully opened or closed, depending on the service.

The LNG flow unloaded from the ship is measured by flow recorders in both unloading lines.

The LNG flow from the in-tank LNG send-out pumps is controlled by kickback into the LNG storage tank. The LNG level in the BOG condenser is used to control the LNG feed flow rate to the BOG condenser. The send-out flow to each LNG vaporizer uses a flow controller that is reset by the vaporizer outlet gas temperature.

Each LNG vaporizer has an independent control system. The seawater flow is adjusted by a butterfly valve. The gas outlet temperature of each vaporizer is also controlled. The LNG flow is controlled by a flow control valve, which is overridden by low-low flow of seawater or low temperature at the vaporizer outlet.

The proper pressure control of the LNG storage tanks is of utmost importance both in terms of safeguarding the mechanical integrity of the LNG storage tanks and the overall safety of the terminal. The tank pressure is primarily controlled by using the gage pressure in the boil-off vapor header to load or unload the reciprocating boil-off gas compressor. If the LNG storage tank pressure falls to below the minimum allowable operating limit, natural gas would then be fed from the vacuum breaker header to increase the pressure. The final level of protection against low or vacuum pressure levels is provided by vacuum breaker relief valves, which would allow ambient air into the LNG storage tanks to prevent collapse if the pressure were to drop below -5 mbarg vacuum (the typical negative design pressure).

A pressure controller that relieves excess vapor to the low-pressure vent at high tank vapor header pressures provides the primary tank overpressure protection. A secondary level of tank overpressure protection is provided by the tank relief valves which discharge directly to the atmosphere.

For LNG tank level measurement, an automatic, multi-sensor probe assembly, a tank top entry electronic control module, continuous level and density measurement with temperature and pressure monitoring will be provided. These measurements are achieved by means of a control unit and an electro-mechanical drive mechanism, which operates as a unit to position a multi-sensor probe assembly suspended within the LNG storage tank. The probe is moved vertically by the drive mechanism in response to commands generated by the control unit. Both automatic and manual control of the probe assembly is incorporated into the system design. All system components, which are located inside the tank, can be completely removed from the tank for inspection and/or maintenance at any time. The system has a probe enclosure assembly with viewing glass, which allows for probe to be removed from tank for maintenance. Solid-state level sensors detect liquid and vapor interface. This system will also effectively detect any LNG layering so that preventative measures can be taken. Enraf and Scientific Instruments (SII), for example, manufacture such instrument packages for the LNG tanks.

An additional microprocess-based Servo Tank Gauge is provided to measure the level with accuracies to +/-0.04" and a solid-state based temperature gauging system is provided with accuracies up to 0.1 °C.

The volume of LNG delivered for any given shipment will be able to be checked by calculation based on measurement of level, temperature and pressure in the LNG tanks.

4. LNG Spill / Storm Water Containment

The LNG Terminal shall be curbed for containment of LNG spills and storm water. Catch basins shall be located strategically on the LNG Terminal to collect LNG spills and storm water and shall gravity flow to a Storm water / LNG Spill Sump via a collection header. Open collection pan shall be provided under equipment where there is a possibility of a large LNG leak, and will be routed to the collection header.

LNG leak detection will be provided by:

a. Gas detectors
b. Low temperature detectors

The detection system will be designed to detect spills and to shut down the plant within two minutes after a spill occurs.

All the detection systems are connected to ESD and activate alarms on the operators' console placed in the Main Control Room, Field Control Room, and Jetty Control Room.

High expansion foam system will be provided to control LNG fires and vapor dispersion of LNG spills. Foam will be discharged to cover the impoundment area to a depth of 0.6 meter within 2 minutes.

The LNG spill sump will serve the following purposes:

a. Vaporization reduction
b. Thermal radiation reduction
c. Efficient application area for high expansion foam

In the event of a large LNG spill, it will be collected in the sump. Low temperature alarm will activate high expansion foam.

Appendix 1

CAPCO

SAFETY MANAGEMENT SYSTEM

(except from the CAPCO Safety Case)

7. SAFETY MANAGEMENT SYSTEM

7.0 SAFETY MANAGEMENT SYSTEM

7.1 Company Health and Safety Policy

Statement Of CAPCO's General Policy With Respect To Health And Safety

CAPCO recognises its responsibility to ensure that its Operators manage their operations in a manner that protects the health and safety of their employees, customers, contractors and members of the public, as well as the environment.

The maintenance of a healthy and safe working environment is regarded as a major objective for management and employees in all positions.

It is CAPCO's policy to conduct its business in a manner that protects the safety of employees and others directly involved in its operations, as well as customers and the public. CAPCO will strive to prevent all accidents, injuries and occupational illnesses through the active participation of every employee.

CAPCO, and its Operators, are committed to continuous efforts to identify and to eliminate or minimise recognised safety, health and environmental risks associated with their operations.

CAPCO's policy on Occupational Health is to require its Operators to:-

- identify and evaluate potential health hazards related to its activities;
- plan, implement and evaluate programs to eliminate or control any such hazards;
- communicate, in a timely fashion, about potential health hazards which are identified by the occupational health program, or other recognised professional source, to individuals or groups that are potentially affected,
- determine, at the time of employment and thereafter, as appropriate, the medical fitness of employees to do their work without undue hazard to themselves or others;
- provide or arrange for medical services necessary for the treatment of occupational illnesses or injuries, and for the handling of medical emergencies.

CAPCO's policy on safety is to require its Operators to:-

- design and manage operations in a manner which safeguards employees, property and the community in which it operates.
- respond quickly and effectively to emergencies or accidents resulting from its operations, co-operating with industry organisations and authorised government agencies.
- comply with all applicable, territorial or local laws and regulations

governing safety, health and environmental protection, and diligently apply responsible standards of its own where laws and regulations do not exist.

- work with government agencies and others to develop reasonable regulations and standards pertaining to safety, health and environmental protection.
- stress to all employees their responsibility and accountability for safety performance
- undertake appropriate reviews and evaluations of its operations to measure progress and to ensure compliance with this safety policy.

The Operators have statements of policy on health and safety related subjects, which are similar in content to and in compliance with the CAPCO Board of Directors policy on Health and Safety, and are contained in their respective policy documents.

<u>Statement Of CAPCO'S General Policy With Respect To Health And Safety Of The Public</u>

It is CAPCO'S policy to conduct its operations through the Operators in a manner that protects contractors' employees, others involved in its operations, customers and the public from recognised and unacceptable risks.

The health and safety of contractors, customers and the general public are of primary importance to CAPCO in discharging its responsibilities to provide a secure and adequate supply of electricity.

CAPCO requires that those who do work on its behalf share this goal and adopt measures to ensure compliance with this policy.

<u>Statement of CLP Group Safety, Health and Environmental Policy</u>

Being a responsible corporation, the CLP group is committed to providing a safe, healthy and clean business environment for the employees, customers and the public. A policy on Safety, Health and Environment (SHE) is endorsed and the principles are :

- Recognise responsibility to protect employees, customers, public and environment;
- Meet legal requirements;
- Provide a safe workplace and adopt a balanced approach in operation;
- Achieve high standards of operational integrity, make continuous improvement, minimise SHE risks and impact on environment;
- Encourage and train employees for SHE concern and responsibility;

- Encourage / require partners, suppliers and contractors to comply with the policy;
- Monitor the group's compliance and disclose relevant information.

Statement of CLP Power Safety, Health, Environmental and Quality Policy Statement

CLP Power is committed to providing quality power supply and services to the customers in a manner that ensures a safe, healthy and clean business environment for the employees, customers and the public. The goals are "Zero Accident", "Zero Non-compliance" and "World Class Products and Services". The principles are to :

- Exceed the service requirements and expectations of the customers, to ensure CLP Power are their preferred energy service supplier;
- Operate to the highest standards in safety and health;
- Conduct the business in a manner that strives to balance the sustainable environmental, social and economic needs of the community;
- Develop a competent, innovative, responsible and motivated work force;
- Encourage and require, wherever appropriate, the business partners, suppliers and contractors to adopt equivalent principles.

CLP Power will continue to systematically identify, monitor, review and control our safety and health risks, environmental impact and quality issues to ensure ongoing improvement.

Safety, Health, Environmental Protection and Quality is everybody's responsibility.

7.2 Safety Goals and Standards

CLP Power has adopted the 5-Star health and safety system, which is Independent, internationally recognised and enables CLP Power to benchmark its safety performance against other companies internationally. The 5-Star system is an audit of each site against a detailed list of factors which contribute to the overall level of safety. It also includes a criterion of injury statistics. The result is a rating for each site on a scale of up to five Stars, and an indication of where efforts are succeeding and where more effort is required.

The target is to achieve 5-Star rating on all sites and at the present time, Castle Peak power Station and Black Point Power Station has the 5-Star rating.

GBG will continue to implement the total safety approach and behavioural based safety in managing our safety performance. GBG would further entrench our SHEQ culture with quality drive in attaining performance excellence

BPCEPC has adopted the Process Safety Management Standard (American Petroleum Institute Recommended Practice #750 and US-OSHA) for establishing and maintaining its standard for operations on a world-wide basis. The Process Management Standard focuses on communications of process information to employees and contract personnel, hazards analysis and communications, incident investigation and reporting; permitting system for hot work and confined space activities; and auditing.

7.3 Site Organisation and Manning Levels

The management structure and levels in BPPS, CPPS and BPCEPC is shown in fig. 7.3.1

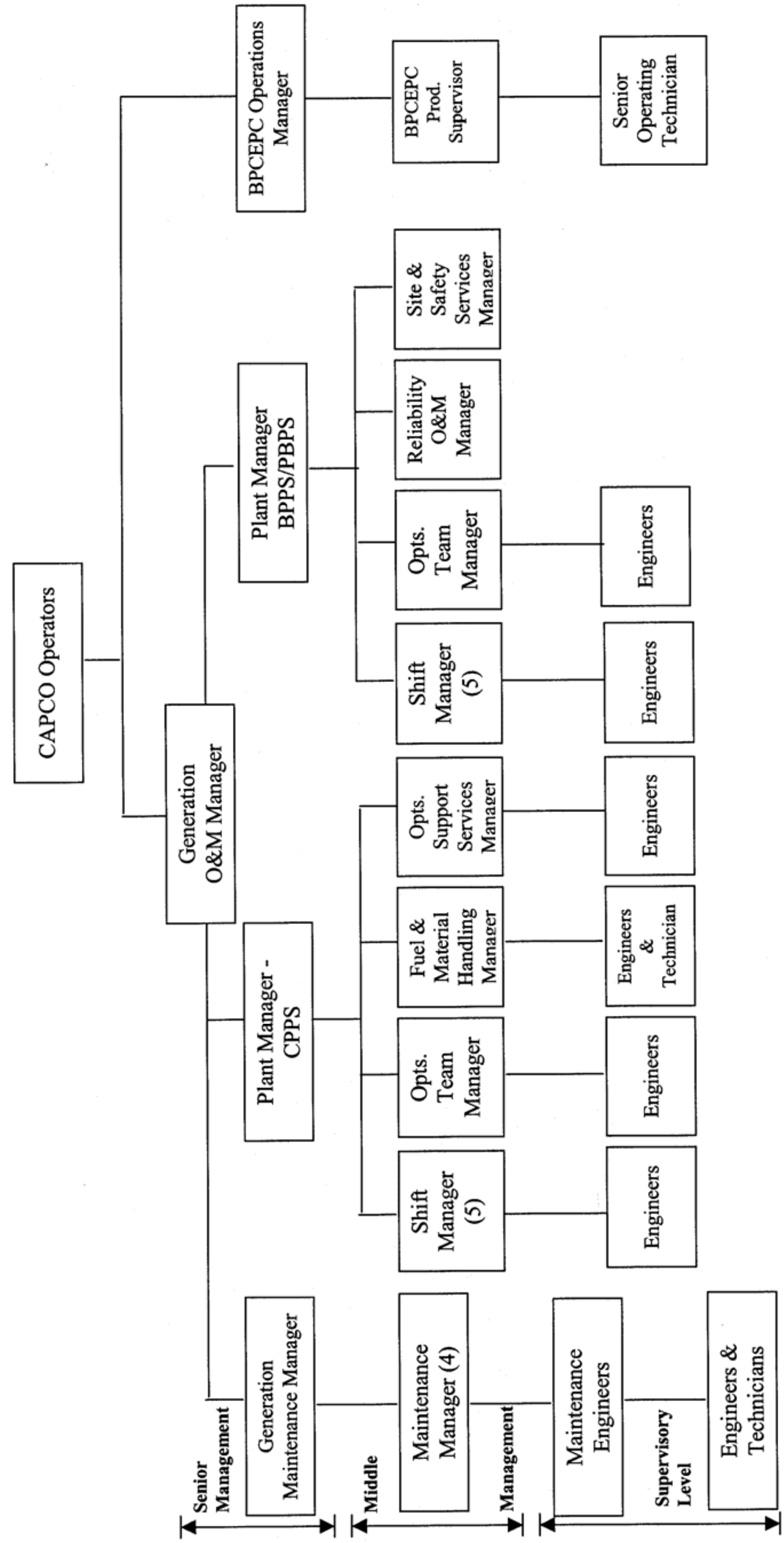

CAPCO Operators
BPCEPC Operations Manager
BPCEPC Prod. Supervisor
Senior Operating Technician
Generation O&M Manager
Plant Manager BPPS/PBPS
Site & Safety Services Manager
Reliability O&M Manager
Opts. Team Manager
Shift Manager (5)
Engineers
Engineers
Plant Manager - CPPS
Opts. Support Services Manager
Fuel & Material Handling Manager
Opts. Team Manager
Shift Manager (5)
Engineers
Engineers & Technician
Engineers
Engineers
Generation Maintenance Manager
Maintenance Manager (4)
Maintenance Engineers
Engineers & Technicians
Senior Management
Middle Management
Supervisory Level

Figure 7.3.1

Figure 7.3.1

7.4 Responsibilities of Key Operating Positions

CAPCO and its Operators recognise the benefit and importance of a broad range of qualifications for key operational positions. These include a mix of experience, maturity and corporate and professional qualifications. In addition CAPCO and its Operators appreciate that technical competence and expertise further enhances the quality of its key operational positions.

CLP Power engaged several experienced practitioners in the natural gas operating field during the initial natural gas operations stage between 1995 and 1998. Most of the natural gas operation policy and procedures were developed during this period. After CLP Power had gained sufficient experience and knowledge to continue to operate safely and effectively, Gas Engineering Team (later called Fuel Technology Team) with members from internal natural gas experts were formed to continue to enforce the safe operations of natural gas facilities.

The acceptable mix of qualifications will depend on the job classification and reflects the level of responsibility and accountability. Examples of established standards include:

Senior Management must have at least 10 years experience in appropriate, managerial and/or engineering posts in a relevant industry with minimum qualification of a recognised college/university degree, or membership/registration in a recognised professional body or extensive relevant experience.

Senior Management are responsible for setting policy and goals and ensuring safe, effective and efficient operation and maintenance of the facility and personnel.

Middle Management must have at least 5 years working experience in appropriate managerial and/or engineering posts in a relevant industry with similar qualifications to senior management. The incumbents in these positions possess expertise and experience to effectively support Senior Management in the operation and maintenance of the facility.

Middle Management is directly accountable to Senior Management and responsible for operations in a designated facility or area. They provide direction to subordinates to accomplish all necessary task within the limits of policy, procedures and engineering and safety standards.

Supervisory Level personnel are responsible for execution of tasks under the direction of their supervision/management. The qualifications for the third and fourth level positions (together forming the Supervisory Level) vary according to the nature of the position. The positions may include engineer, technician and foreman. A recognised college/university qualification, or membership/registration in a recognised professional body or appropriate relevant experience is required for the engineer and technical level positions.

7.5 Safety Management Practices

7.5.1 Occupational Safety & Health Management System

The objective of the Occupational Safety & Health Management System (OSHMS) is to support GBG's goal of providing an injury free and healthy working environment, through the application of a structured approach for safety and health management that complies with external and internal safety and health requirements and conforms to CLP Power Safety, Health, Environment and Quality Policy Statement.

In line with this objective, the OSHMS is to provide a comprehensive management framework for establishing appropriate safety and health standards, programs and training for implementation in GBG for the purpose of:

- Achieving objective/goal of the CLP Power Safety, Health, Environment and Quality (SHEQ) Policy Statement and CLP Power SHEQ Policy on Contractors & Supplier
- Achieving full compliance with statutory and company's safety and health requirements
- Identifying the safety and health issues of GBG facilities, activities, products and services
- Establishing short and long-term safety and health objectives and targets
- Developing Safety, Health and Environment Plan and safety management plans and programs to meet objectives and targets
- Establishing responsibilities and provide resources for the implementation, maintenance and improvement of this OSHMS, to ensure proper management of GBG's safety and health issues
- Verifying compliance with regulatory requirements and company policy, evaluate safety and health performance against GBG's objectives and targets, and communicate outcome of the evaluation
- Minimizing risk and preventing losses due to occupational safety and health incident
- Ensuring systems are in place for the anticipation, identification, evaluation, monitoring, control and management of occupational hygiene stresses.
- Enhancing the safety and health standards of all GBG operations through continuous improvements.

CLP Power Operations Integrity Management System

CLP Power operates within a well established Operation Integrity Management System (OIMS) which is adopted for both Black Point and Castle Peak Power Station.

OIMS is adopted as a management framework specifically to assist the accomplishment of safety, health and environmental objectives. It is to be applied to all systems for managing process, plant, equipment and activities within GBG. It builds upon and will enhance existing programs to ensure operations integrity.

GBG will commit to implement OIMS in all operational activities with the management leadership and commitment as required under OIMS Element 1 - which requires that management establishes policy, provides the perspective, establishes the framework, sets the expectations, and provides the resources for successful operations.

There are eleven principle elements to OIMS which are used as a reference to ensure that systems and procedures are achieving expectations. The elements include management, risk, facilities, documentation, personnel, operation & maintenance, change, third party, incident, emergency, assessment. An additional "OIMS element 12 – Asset management" and the corresponding management principles have been drafted, which imposes the essential requirements for effective management of GBG assets.

BPCEPC Health, Safety and Environmental Procedure

BPCEPC have developed a Health, Safety and Environmental Procedure which are consistent practice by all their employees. The Health, Safety and Environmental Procedure includes the safety practise of offshore platform, Nanshan Shore Base, offshore gas pipeline, gas receiving station and also the main office building in Shekou.

The goals for BPCEPC are simply stated – no accidents, no harm to people and no damage to environment. BPCEPC will continue to drive down the environmental and health impact of their operations by reducing waste, emissions and discharges, and using energy efficiently. BPCEPC will produce quality products that can be used safely by their customers.

7.5.2 Safety assessment for new projects

Under the Operational Integrity Management System, CLP Power begins evaluating the potential risk at the conceptual stage of the project, and continues to do so throughout the life of the plant. This is done to help reduce risk to a minimum whilst still satisfying the commercial needs. The techniques used include preliminary hazard assessment , Quantitative risk assessment (QRA) for potentially hazardous installations, area classification and Hazard and Operability (HAZOP) studies.

CLP Power has a commitment to minimise the quantity of hazardous materials on any new sites. This is an important part of the safety assessment of new projects and expansions to existing projects.

BPCEPC has utilised both qualitative and quantitative process hazards analysis for the purpose of risk identification and analysis. Multiple Failure Effects Analysis (MFEA), Fault Tree Analysis (FTA) and HAZOP were used at various design stages of the project to ensure risks were minimised. BPCEPC has adopted the operational rule of "three failures to safe" as a guiding principle for its operations. In other words, for any particular process component or system, three separate failures could occur and operational conditions would remain safe. This principle ensures adequate redundancy and controls are applied to process design and operations.

As potential problems were realised during the process hazards analysis, a formal system for communicating these potential problems was used. These potential problem reports were reviewed by Engineering, Production, the Project Management Team and Safety, Health and Environmental Personnel. Appropriate solutions for correcting, addressing and/or managing these problem areas were documented on the report and implemented in the field.

In addition to the process hazards analysis, an independent safety, health and environmental protection audit was conducted during the final design. This audit focused on compliance with design basis, regulatory compliance, cause and effect charts, layout, operational controls, operational procedures and practices. The audit findings were presented to BPCEPC Management and the Project Management Team. A formal response to the audit findings, including an itemised response and action plan for addressing each audit finding, was presented to the audit team. The audit team periodically monitored responses, as well as updates to ensure appropriate measures were taken during the course of construction, installation, commissioning and start-up.

7.5.3 Inspection and maintenance

Black Point and Penny's Bay Power Station (BPPS/PBPS), Castle Peak Power Station (CPPS)and Generation Maintenance Department (GMD) have developed schedule, routine procedures and instructions for regular inspection and maintenance of the gas system. These included the liaison with other departments, third parties and those responsible for gas transmission process and control, i.e. System Operation of CLP Power and Gas Receiving Station of BPCEPC. Fuel Technology / TSD is normally the representative from CLP Power responsible to liaison with BPCEPC on maintenance activities.

In view of this organisation structure and limited manpower of the Station, a Computerised Maintenance Management System (CMMS) provides the station staff at all levels with adequate information for the management of operation and maintenance of the station assets and plant equipment and maintenance process installed.

This CMMS provides sufficient information for the Station Management to exercise Management Control and for Maintenance Engineers to make Engineering Decision. It also smoothes work order flow, inventory control and cost analysis.

Maximo Series 5 is selected as the basic modules for CMMS in BPPS. Maximo system is made up of 12 interconnected modules tied to an Oracle database on a HP UNIX server.

BPCEPC utilises a computer based preventive maintenance system, MAXIMO, for generating work orders for inspection and maintenance of equipment, controls and systems at each operating location. Inspection and maintenance frequencies are established in the system based on regulatory requirements or internationally accepted maintenance standards, such as outlined by the American Petroleum Institute. In addition to generating work orders, each inspection and/or maintenance performed is documented into the system, providing a documented performance and maintenance history on each piece of equipment or system on site.

Performance and Regulatory Compliance, as pertaining to the preventive maintenance conducted on site, are monitored and evaluated on a quarterly basis during the safety, health and environmental audits conducted at each operating location. Any deficiencies are noted in the audit report and must be addressed by facility supervision.

7.5.4 Procedures for altering design/equipment

Management of Change

The Management of Change System (MOC) applies to any addition, revision, deletion, modification, or replacement (except replacement in kind) that has impact on safety, health & environment, regulatory compliance and plant integrity & reliability.

The Objectives of the System are to ensure:

- Changes are identified
- Changes are evaluated and control measures are in place to address SHE risks introduced, impact on regulatory compliance or relate to plant integrity & reliability that would lead to major loss in operation
- SHE Risks associated with the change are assessed and managed as appropriate
- Changes are documented and communicated to affected parties
- Training on the change if required
- Evaluation is performed on the outcome / result of the change in meeting the original intent / purpose
- Temporary changes and their need, scope, time frame and control measures are reviewed regularly

BPCEPC follows its Management of Change procedure as outlined in the BP HSE manual. All temporary and permanent changes to organization, personnel, systems, procedures, equipment, products, materials or substances will be evaluated and managed to ensure that health, safety and environmental risks arising from these changes remain at an acceptable level.

7.5.5 Procedures for updating procedures

All CLP Power procedures are being incorporated into the OIMS system which ensures all documents are numbered and have a revision date on. The controlled copies are the most up to date version, and any changes to the procedures have to be approved by the responsible manager for the particular group of procedures.

As noted in Section 7.5.4, BPCEPC utilises the Management of Change Standard outlined in its Safety and Health Manual as a means for reviewing any operating procedural changes, particularly those which affect design, safety or control system intent. The same procedures would apply as noted previously. As required, HAZOP analysis are conducted for procedural changes. BPCEPC's practice concerning Operating, Emergency, Safety, Health and Environmental Procedures is to review each procedure periodically (at least annually) to ensure they reflect actual operations, comply with regulatory requirements and incorporate regulatory requirements. Any changes to these procedures are communicated to all personnel.

7.5.6 Permit-to-work system

The Power System Safety Rules states that no repairs, maintenance, cleaning or alternation can be carried out on any system in the power station without a valid safety document in force except those specified in the Safety Rules such as floating of safety valves and hydraulic test. The safety document required may be a Permit-to-Work, Permit-to-Work with restoration of Motive Power, Limited Work Certificate or Sanction For Test depending on the nature of the work to be undertaken, and these safety documents will only be issued in strict accordance with the current Power System Safety Rules.

For BPCEPC, before conducting work that involves confined space entry, work on energy systems, ground disturbance in locations where buried hazards may exist, or hot work in potentially explosive environments, a permit must be obtained that :

- Defines scope of work
- Identifies hazards and assesses risk establishes control measures to eliminate or mitigrate hazards
- Links the work to other associated work permits or simultaneous operations
- Is authorized by the responsible person
- Communicates above information to all involved in the work
- Ensures adequate control over the return to normal operations

7.5.7 Arrangements with contractors on safety matters

A contractor management system was set up to provide an incident-free working environment by establishing a safety awareness culture through effective and efficient third party service management practices, this includes:

- Ensure contractors perform in a manner consistent and compatible with the GBG's policies and business objectives, CLP corporate SHE policy, as well as in compliance with the legislation.
- Provide for the evaluation and selection of suppliers capable of performing work in a safe and environmentally sound manner.
- Provide guidance on Company requirements for effective third party services management.
- Provide regular feedback on supplier performance to encourage continual improvement in the service provided, and ensure that deficiencies are corrected.

The partnership approach with contractors has already yielded good results on SHE performance of contractors. The approach is to be further cultivated so that we could work closely with contractors' SHE personnel to enhance and motivate them to deliver the expected roles and results. Also, CLP Power needs to review the effectiveness of the regular SHE induction course and the monthly contractor briefing to further improve their effectiveness and quality to ensure these are organized and delivered in a quality and efficient manner.

BPCEPC provides its own induction course and appropriate orientation for its employees and contractors applicable to the inherent hazards of a gas production facility. Requirements have been developed for contractors and their subcontractors performing work on BP facilities/work site and exclusively for BP at contractor work sites. Contractors will ensure that any subcontractor whom they employ meets these same requirements. Contractors will take any additional precautions necessary to prevent harm to personnel or damage to property and the environment.

7.5.8 Personnel protection

Inside Natural gas control areas

- Smoking is totally forbidden.
- Use of naked light is not allowed. Where there is no alternative to using naked lights such as in the event of welding, then a Hot Work Permit is required.
- Use sparkproof hand tools wherever practicable and only intrinsically safe equipment. The use of portable electric equipment and tools which are capable of causing ignition are forbidden unless covered by a safety document.
- Always monitor the atmosphere before commencing work and during work.
- Always carry a personal gas monitor to protect people.

General

- Protective clothing, shoes, gloves etc should be worn as instructed.
- Special safety equipment such as breathing apparatus, fire retardant clothing etc should be made readily available and used as directed.
- Fire extinguishers should be placed readily available where work is being carried out.
- Always follow the safety procedures related to natural gas.
- Use only approved gas monitoring equipment.

7.5.9 Reporting and investigation of incidents

The Incident Investigation and Management System covers all safety, health and environmental reportable incidents/Near-misses which involve direct employees, contractors, property, location or activities hired, owned, controlled or supervised by Generation Business Group.

The System is specifically designed to report, investigate, and analyze on incidents associated with the following:

- Fatal accidents
- Serious injury & lost-time accidents
- Electrical accidents
- Employee or contractor occupational injury or illness
- Plant incidents
- All significant and/or high potential property damage
- Fire accidents
- Traffic accidents
- Environmental incidents
- Near-miss cases
- Emergency response situations
- Any events reportable to regulatory agencies according to the Dangerous Occurrence Regulation

The degree of investigation should be linked to the actual and potential severity of the incident.

For BPCEPC, incidents will be reported, investigated and analysed to prevent recurrence and improve our performance. The investigations will focus on root causes and /or system failures. Corrective actions and preventive measures will be utilized to reduce future injuries and losses.

7.6 Site Safety Committee

7.6.1 CAPCO Safety, Occupational Health and Environment Committee (SOHEC)

- Being the highest management committee for approval and endorsement of any SHE initiatives and set management goal and expectation of SHE matters in GBG
- Approve the annual CAPCO SHE plan
- Set high level direction and objectives for managing SHE matters in GBG
- Monitor the program progress and review performance

7.6.2 GBG OIMS Steering Committee

- Endorse the annual CAPCO SHE Plan
- Approve objectives for safety and health performance in consistent with overall policies and objectives

- Monitor performance and regulatory compliance through
  - on-going review of major incidents and performances
  - periodic review of training and operating practices
  - review of OIMS and other compliance assessments audits
  - committee inspections of facilities and operation

7.6.3 SHE Committee at each Operation Unit

- Review SHE performance of the operation unit
- Monitor the progress and status of the implementation of safety and health initiatives
- Feedback and communicate the safety and health programs

7.6.4 BPCEPC Safety Committee

During normal operations, the Gas Receiving Station does not have an ample number of personnel to support a site safety committee. However, site safety, health and environmental issues are discussed in weekly safety meetings. These issues are forwarded to the Production Manager and the Safety, Health and Environmental Protection Manager in Shekou for handling, as appropriate.

In addition, BPCEPC has established a Safety, Health and Environmental Council in Shekou, PRC, which includes Executive Management as Members. The Safety, Health and Environmental Protection Manager co-ordinates quarterly Council Meetings to discuss all safety, health and environmental protection issues, such as those addressed in the weekly safety meetings. The Production Managers, Drilling Manager, Materials Manager, Project Team Management and Human Resources Management are included in the quarterly meetings as sub-committee chairpersons, reporting and discussing relevant safety, health and environmental performance and relevant issues. Council Meeting Minutes are distributed to all participating member and sub-committee chairpersons to use as a communication tool to subordinate personnel within the organisation.

7.7 Review of Human Tasks and Possible Errors

CLP Power addresses the review of human tasks and possible errors in a number of ways and at each stage in the development of a project.

At the design stage, risk assessment and risk analysis are performed and areas of potential problem are identified and the problem eliminated or mitigated. Human Factor consideration is accessed during the HAZOP process of the system.

Moreover, there are operating and maintenance instructions for all tasks that will be performed on the stations. All the GBG staff will follow the instructions to carry out the works. Job safety analysis also carry out to reduce the risk.

For BPCEPC, the potential for human tasks or human errors are reviewed as a part of the Process Hazards Analysis. Any potential risk or errors are minimised or eliminated during the design and construction phase. During operation, the GRS supervisor is designated the responsibility for reviewing the performance of tasks by both BPCEPC personnel and its contractors for potential task of human errors.

7.8 Staff Recruitment and Training

CAPCO and its Operators recognise that personnel, whose work could affect the safety of the facilities, equipment and operations, must have and maintain the necessary knowledge and skills to execute their functions safely. Employees receive adequate training prior to being assigned to positions involved in the gas systems. The Operators also ensure that each employee receives the appropriate refresher training necessary to maintain the required knowledge and skill levels.

Key managerial, professional and technical operational positions receive specific training related to the safe performance of their jobs either locally or internationally. This training include safe facility design and layout; safe work, operational and maintenance practices; emergency response; hazards identification, control and management; incident investigation and mitigation techniques; and safety auditing techniques, as applicable.

Operators, technicians, foremen and tradesmen have structured on-the-job and classroom training programs regarding safe operations and maintenance practices for gas systems. These training programs are arranged internally or with a recognised institution.

Appropriate measures are in place to ensure training and appropriate authorisation of the various levels of personnel required to work on the gas system. Contractor's personnel training will be evaluated prior to work commencement and monitored during the duration of the contract.Training records are maintained and monitored for all employees of the Operators.

7.8.1 Training Plan

The training plan highlights key training areas identified as essential to ensure management and operational staff are fully trained to meet the demands of using natural gas as a fuel for power generation. The training of all staff is documented and recorded.

Topics on Authorisation Training

Same for Competent Person – Natural Gas & Senior Authorised Person – Natural Gas

Part 1 Natural Gas Safety Practices

- Natural Gas Production & Transmission
- Natural Gas Properties & Hazards
- Properties & Hazards of Other Flammable Gases
- Natural Gas Safety Policy

- Natural Gas Safe Working Practices
- Gas Leak Detection & Gas Test
- Emergency Response in Gas Incidents

Part 2 Protection of Electrical Equipment in Hazardous Areas

- Flammable Gases and Vapours
- Area Classification
- Ignition Sources
- Principles of Ex Protection
- Apparatus Group
- Temperature Class
- Ingress Protection
- Flameproof Concept Exd
- Increased Safety Concept Exe
- Intrinsic Safety Concept Exi
- Purged and Pressurised Concept Exp
- Non Incentive Concept ExN
- Combined and other Concepts
- Standards
- Marking

For Senior Authorised Person – Natural Gas

Part 3 SAP_NG Authorisation

- Safety on Handling & Operating of Natural Gas
- Analysing for Gas Work Hazards
- Fighting Gas Incidents
- Safety Procedures

For BPCEPC, the students are given practical experience training at other BPCEPC Operating locations, at Equipment Manufacturer's facilities or within BPCEPC operations within China, depending on developmental needs. This practical experience training will last for a period of approximately six months.

BPCEPC’s ex-patriate employee staff are selected from various BP operations world-wide. The selection process is based on applicable experience and education, past performance and suitability to the working environment in China/Hong Kong. BPCEPC's expatriate contractors are selected based on the same criteria as BPCEPC's ex-patriate employee staff. All ex-patriate staff are required to attend all required training under PRC and Hong Kong SAR regulations and ensure that training is current.

7.9 Internal Audit of Company Safety Management System

CLP Power operates the OIM system which has an internal audit plan and each section is audited at some point during a year. In addition, the companies Safety Management Systems are audited on annual basis.

Operation review:

The monitoring of compliance with operating procedures is conducted on a continuous and programmed audit/review basis.

All operations within CLP Power are under close supervision by qualified and trained shift managers on a continuous 24 hour basis. The supervision is also extended to cover front line maintenance and trouble shooting carried out by the shift maintenance personnel and contractors.

BPCEPC also provide continuous manning of gas receiving facilities

The Operators have procedures for control of operational systems to ensure safe operation, work permit procedures are in place and utilised at all the Operators' facilities.

Adherence to operational procedures is facilitated by periodic audits, manual and computerised logs, operational records, data sheets, trend charts and routine maintenance and testing.

Operations integrity assessment:

CAPCO and its Operators have adopted a process that measures performance relative to expectations which is essential to improve the operation and maintain accountability. A system has been established as an approach for measuring how well operations are meeting goals and objectives.

As noted in previous sections, BPCEPC has established a comprehensive safety, health and environmental protection auditing program for all its operating facilities. BPCEPC has commenced to conduct comprehensive safety, health and environmental audits of all its operating facilities and will continue each year. The objectives of this comprehensive internal audit effort are to: verify the compliance status of the facility with applicable regulations; verify the compliance status of the facility with respect to BPCEPC policies and design basis; confirm that applicable safety, health and environmental management controls are in place and functioning properly; and access current practices to identify areas or situations requiring corrective measures.

Annex 13E

Tables of Assumptions

CONTENTS

TABLES OF ASSUMPTIONS

This section summarizes the assumptions adopted in the QRA study. These are broadly categorised as population, meteorological, frequency, consequence and plant data assumptions.

1 TERMINAL

1.1 POPULATION

Table 1.1 Residential Population

Location	Approx. Distance from Terminal Site	2011 Population	2021 Population
Fan Lau	7km	52	52
Tai Long Wan Tseun	7km	293	293
Shek Pik Prison	7km	824	824
Tung Wan School	6km	152	152
Shui Hau	6km	375	375
Ma Po Ping Prison	6km	1,728	1,728
Tong Fuk	7km	1,133	1,133
Cheung Sha Villas	9km	665	665
Cheung Sha	9km	597	597
San Shek Wan	10km	156	156
Pui Wo	11km	2,628	2,628
Ham Tin	11km	859	859
Mong Tung Wan	11km	43	43
Sea Ranch	10km	313	313
Tai Long	11km	34	34
Shek Kwu Chau	8km	43	43
South Lantau Hospital	9km	90	90

Table 1.2 Road Population

Location	Approx. Distance from Terminal Site	2011 Population	2021 Population
South Lantau Road	7km	5/km	5/km

Table 1.3 Population Time Periods Definitions

Time Period	Description
Night time	7:00pm until 7:00am
Weekday	9:00am till 5:00pm, Monday through Friday
Peak hours	7:00am to 9:00am and 5:00pm to 7:00pm, Monday to Friday
	7:00am to 9:00am and 1:00pm to 3:00pm, Saturdays
Weekend day	3:00pm to 7:00pm Saturdays, and 7:00am to 7:00pm Sundays

Table 1.4 Land Population Occupancy and Indoor/Outdoor Fractions

Population Type	Occupancy				% Outdoors			
	Night	Peak	Weekday	Weekend day	Night	Peak	Weekday	Weekend day
Residential	100 %	50 %	20 %	80 %	0 %	30 %	10 %	20 %
Prison	100 %	110 %	100 %	110 %	5 %	100 %	50 %	50 %
Hospital	100 %	120 %	110 %	120 %	0 %	30 %	10 %	30 %
School	0 %	10 %	100 %	10 %	0 %	100 %	20 %	20 %
Road	10 %	100 %	50 %	20 %	0 %	0 %	0 %	0 %

Table 1.5 Marine Vessel Population

Type of 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)	22.5
	175 (typical ferry at 50% capacity)	52.5
	105 (typical ferry at 30% capacity)	12.5
	35 (typical ferry at 10% capacity)	5.00
Tug and Tow	5	
Others	5	

Figure 1.1 *Marine Population at Risk by Grid, Year 2011 (excluding fast ferries)*

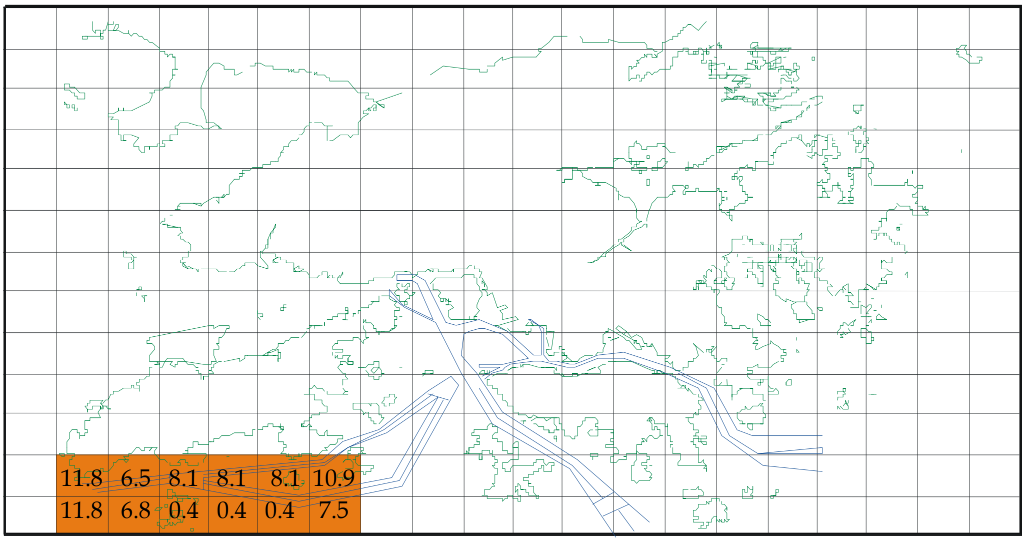


Figure 1.2 *Marine Population at Risk by Grid, Year 2021 (excluding fast ferries)*

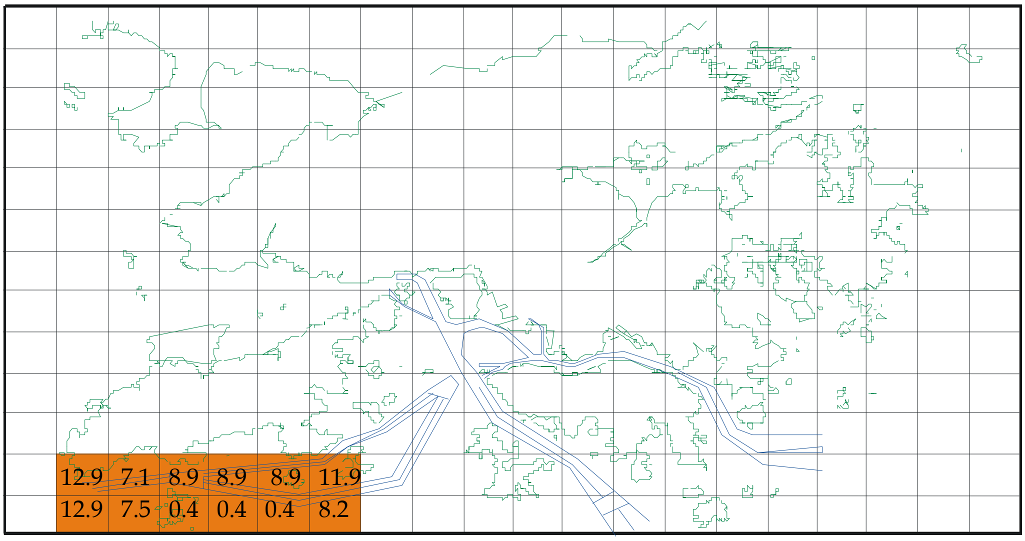
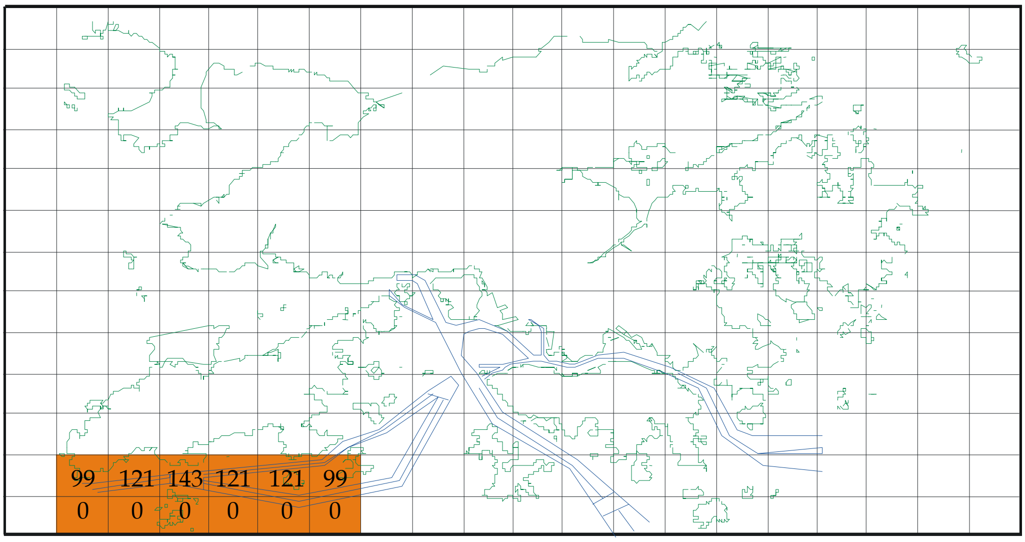
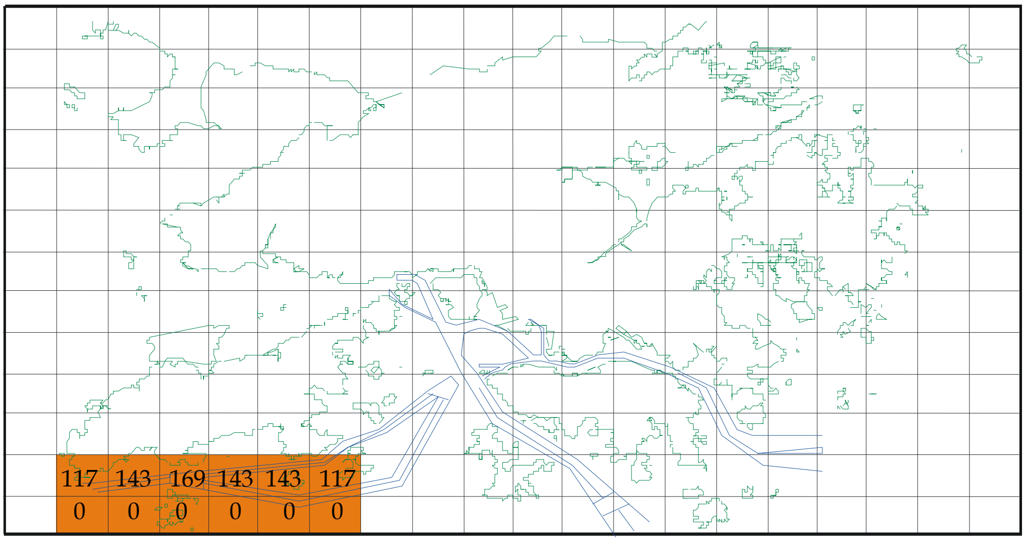


Figure 1.3 Number of Fast Ferries Per Day, 2011*



* 75% in daytime, 25% in night time

Figure 1.4 Number of Fast Ferries Per Day, 2021*



* 75% in daytime, 25% in night time

Table 1.6 Fast Ferry Population Distribution for Day and Night Time Periods

Population	Population at Risk	% of Day Trips	% of Night Trips	% of All Trips (= 0.75 x day + 0.25 x night)
450	135	5	-	3.75
350	105	5	-	3.75
280	84	30	-	22.5
175	53	60	30	52.5
105	32	-	50	12.5
35	11	-	20	5.0

Table 1.7 Helicopter Population

Population	Daytime Flights	Night time flights
12 per flight	2 return flights per hour	0

Table 1.8 Fatality Factors

Population Type	Fatality Probability
Land Population	
Indoor	0.1
Outdoor	1
Road vehicles	0.5
Marine Population	
Ocean-Going Vessel	0.1
Rivertrade Coastal Vessel	0.3
Fast Ferries	0.3
Tug and Tow	0.9
Others	0.9
Helicopters	1

1.2 METEOROLOGICAL DATA

Table 1.9 Weather Data Adopted from Cheung Chau Weather Station (2003)

	Day				Night			
Wind Speed (m/s)	2.5	2	3	7	2.5	2	3	7
Atmospheric Stability	B	F	D	D	B	F	D	D
Wind Direction	Percentage of Occurrence							
0°	1.57	1.92	1.31	11.42	0.00	6.05	1.31	13.14
30°	1.60	0.94	1.34	4.21	0.00	3.02	1.20	4.36
60°	0.81	0.68	0.92	3.05	0.00	3.26	1.56	5.02
90°	0.87	0.65	1.39	14.86	0.00	3.57	2.19	19.48
120°	3.18	0.62	1.38	18.32	0.00	2.02	0.75	9.32
150°	2.10	0.44	0.93	2.92	0.00	1.21	0.36	2.29
180°	2.41	0.35	0.72	2.77	0.00	1.35	0.53	3.47
210°	1.78	0.27	0.67	4.97	0.00	1.40	0.58	4.13
240°	0.89	0.23	0.44	2.10	0.00	1.20	0.54	1.80
270°	0.40	0.27	0.28	0.79	0.00	1.27	0.41	0.83
300°	0.22	0.17	0.09	0.30	0.00	0.61	0.10	0.25
330°	0.47	0.22	0.21	1.57	0.00	0.65	0.18	0.59

1.3 *FREQUENCY ANALYSIS*

Table 1.10 Ignition Probabilities

	Immediate Ignition	Delayed Ignition 1	Delayed Ignition 2	Delayed Ignition Probability	Total Ignition Probability
Liquid small leak	0.01	0.035	0.005	0.04	0.05
Liquid large leak/rupture	0.08	0.18	0.02	0.2	0.28
Gas small leak	0.02	0.045	0.005	0.05	0.07
Gas large leak/rupture	0.1	0.2	0.02	0.22	0.32

* Small leak = 10 and 25mm. Large leak = 50 and 100mm holes

Table 1.11 LNG Storage Tank Release Ignition Probabilities

	Ignition Probability
Immediate ignition	0.3
Delayed ignition 1	0.1
Delayed ignition 2	0.6

Release Size

For piping and equipment, a range of release sizes are considered, including 10mm, 25mm, 50mm, 100mm holes and full bore ruptures.

For LNG storage tanks, all failures are modelled at catastrophic failures.

1.4 CONSEQUENCE ANALYSIS/PLANT DATA

Table 1.12 Process Conditions used for Calculating Discharge Rate

Code	Scenario Name	Fluid Phase	Nature of Section	No. of Items	Length of Section (m)	Pipe Diameter (mm)	Pressure (bara)	Temperature (°C)	Density (kg/m³)	Inventory (kg)	Pumping Rate (kg/s)
L01	Liquid Piping from Tank to HP Pump	Liquid	Piping	1	450	500	7.50	-161.5	464	40,977	248
L02	Liquid Unloading Arm	Liquid	Unloading Arm	3	20	400	5.50	-161.5	464	1,166	601
L03	Liquid Transfer Pipe from Jetty to Shore End	Liquid	Piping	2	300	700	5.50	-161.5	464	53,543	601
L04	Liquid from HP Pump Discharge to Vaporisers (ORV/SCV)	Liquid	Piping	1	30	400	106	-155.2	464	1,748	251
L05	Liquid Transfer Pipe from Shore End to Tank	Liquid	Piping	2	900	700	5.50	-161.5	464	160,630	601
L06	Liquid in Recondenser	Liquid	Process Vessel	1	N/A	N/A	6.50	-160.5	463	46,300	100
G07	Gas from Metering Station to Battery Limit	Gas	Piping	1	390	750	102	5.0	79.4	13,680	251
G08	Gas from Vaporisers (ORV/SCV) Outlet to Metering Station	Gas	Piping	1	108	750	104	5.8	80.8	3,851	251
G09	Vapour Piping from Tank to Compressor	Gas	Piping	1	450	600	1.08	-110.0	1.43	182	2.93
G10	Gas Piping from Compressor to Recondenser	Gas	Piping	1	24	400	6.80	57.0	4.46	13	2.93

Code	Scenario Name	Fluid Phase	Nature of Section	No. of Items	Length of Section (m)	Pipe Diameter (mm)	Pressure (bara)	Temperature (°C)	Density (kg/m³)	Inventory (kg)	Pumping Rate (kg/s)
G11	Recycle Gas Piping from Compressor to Ship (till Shore End)	Gas	Piping	1	720	500	1.05	-120.2	1.49	211	4.74
G12	Recycle Gas Piping from Compressor to Ship (Shore End to Jetty)	Gas	Piping	1	300	500	1.05	-120.2	1.49	88	4.74
G13	Gas Piping from HP Compressor Discharge to Vaporiser Outlet	Gas	Piping	1	30	150	104	5.8	80.8	43	0.78
G14	Vapour Unloading Arm	Gas	Unloading Arm	1	20	400	1.05	-120.2	1.49	4	4.54
P15	Ship Compressor	Gas	Pump	1	1	450	23.0	35.0	16.2	51	3.00
P16	BOG Compressor	Gas	Pump	1	1	400	6.80	57.0	4.46	11	1.50
P17	SCV Inlet/Outlet Piping	Gas	Piping	5	10	400	106	5.8	82.3	103	25.0
P18	ORV Inlet/Outlet Piping	Gas	Piping	5	10	400	106	5.8	82.3	103	50.3
P19	HP Pump Suction/Discharge Piping	Liquid	Piping	10	10	400	106	-155.2	464	583	51.6
P20	In-Tank Pump Discharge Piping (on Tank Roof up to ESD Valve)	Liquid	Piping	1	150	400	7.30	-161.5	464	8,742	87.0
P21	Piping at Jetty between ESD Valves	Liquid	Piping	1	300	600	5.50	-161.5	464	39,338	601
P22	HPBOG Compressor	Gas	Pump	1	1	450	102	35.0	71.7	228	0.78
T23	LNG Storage Tank	Liquid	Tank	3	N/A	N/A	1.08	-161.5	464	83,520,000	N/A

2 PIPELINE

2.1 SEGMENTATION OF ROUTE

Figure 2.1 Segmentation of Route

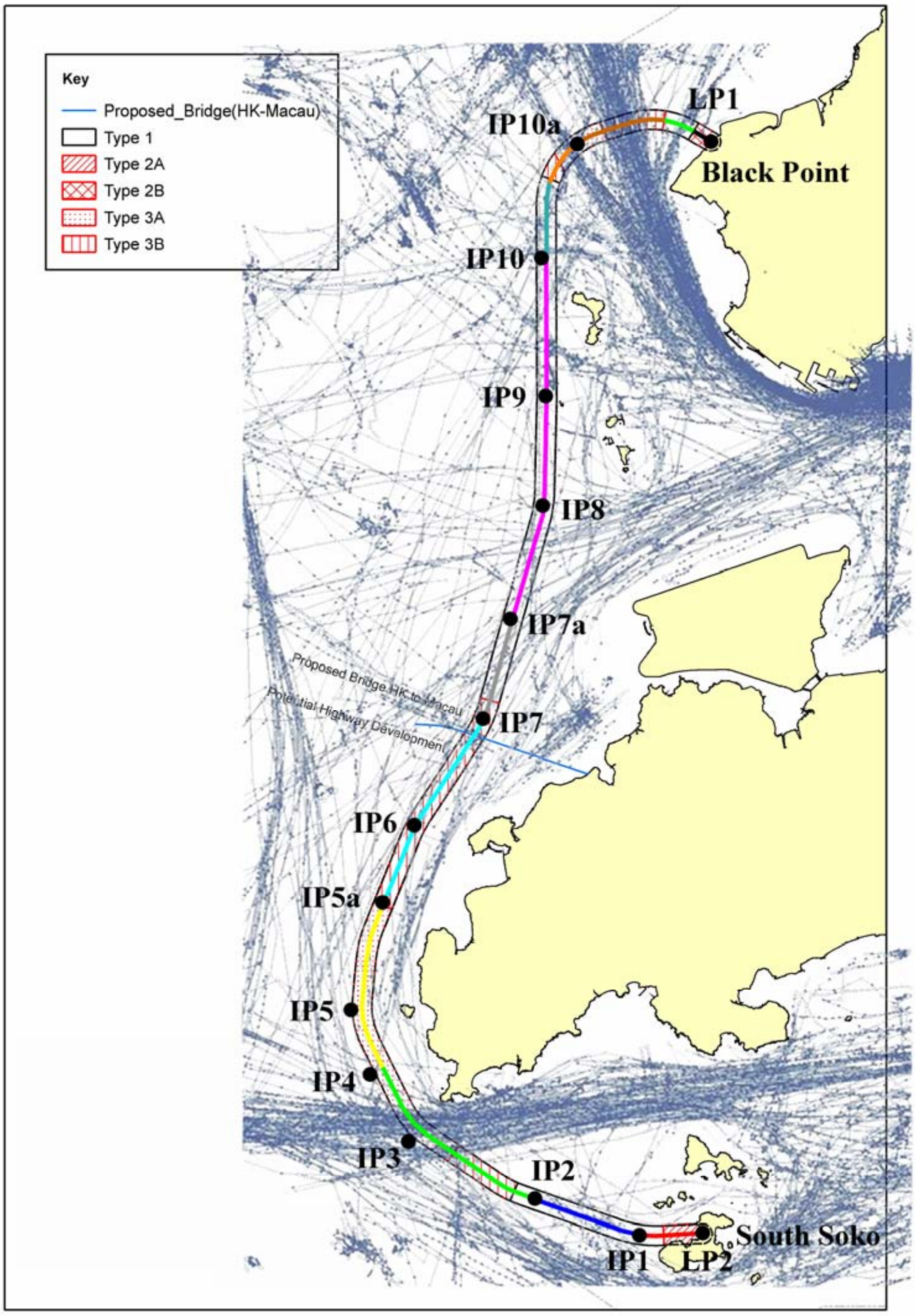


Table 2.1 Pipeline Segmentation

Section		Gate [2] From	To	Kilometre Post From	To	Length (km)	Typical water depth (m)	Trench type
1	South Soko Approach	LP2	IP1	0	1.6	1.6	5	2A
2	West Soko	IP1	IP2	1.6	4.5	2.9	8	1
3	Adamasta Channel	IP2	IP4	4.5	9.8	5.3	25	3B/3A
4	West Lantau	IP4	IP5a	9.8	14.2	4.4	20	3A
5	Tai O	IP5a	IP7	14.2	19.5	5.3	17	3B
6	North Lantau	IP7	IP7a	19.5	22.2	2.7	7	1
7	Sha Chau	IP7a	IP10	22.2	31.6	9.4	6	1
8	North Lung Kwu Chau	IP10		31.6	33.5	1.9	4	1
9	Urmston Road West		IP10a	33.5	34.7	1.2	20	3B/3A
10	Urmston Road central	IP10a		34.7	37.0	2.3	20	3A/3B
11	Urmston Road East			37.0	37.8	0.8	5	1
12	Black Point Approach		LP1	37.8	38.3	0.5	4	2B

2.2 MARINE VESSEL CLASSIFICATION

Table 2.2 Vessel Classes Adopted for Assessment

Class	Type	Typical Length (m)	Typical Beam (m)	Typical Draft (m)	Typical Displace -ment (tonnes)	Typical Anchor Size (tonnes)
"A1" - Fishing Vessels & Small craft		5 – 30	2 – 7.5	1 - 3	1 – 400	< 1
"B1" - Rivertrade coastal vessels		35 – 75	8 - 12	2.5 – 4.5	1,500	< 2
"C1" - Ocean-going Vessels		75 – 350	12 - 45	4 - 15	1,500 – 150,000	2 – 15
"A2" - Fast Launches and Fast Ferries		10 – 30	3 - 7.5	1 – 2.5	1 - 150	< 0.1
"B2" - Fast Ferries		30 - 50	7.5 - 12	1.5 - 2.5	100 – 150	< 0.5
"C2" - Fast Ferries & Ocean-going Vessel	*As above*					

2.3 *MARINE TRAFFIC*

Table 2.3 Traffic Volume Assumed for Base Case 2011

Section		Traffic volume (ships per day)						
		Fishing	River-trade	Ocean-going	Fast Launch	Fast ferry	Other	Total
1	Soko Approach	0	0	0	1	0	0	1
2	West Soko	21	0	0	2	6	4	33
3	Adamasta Channel	126	16	7	83	260	4	496
4	West Lantau	11	2	3	4	9	4	33
5	Tai O	42	1	4	7	12	4	70
6	North Lantau	37	12	0	5	11	6	71
7	Sha Chau	79	22	0	28	44	27	200
8	North Lung Kwu Chau	21	3	0	24	31	8	87
9	Urmston Road West	21	2	6	23	30	2	84
10	Urmston Road Central	250	265	144	117	150	5	931
11	Urmston Road East	11	13	0	5	7	2	38
12	Black Point Approach	2	3	0	2	0	0	7
	Total	621	339	164	301	560	66	2051

Table 2.4 Traffic Volume Assumed for 2021 "No Tonggu" Case

Section		Traffic volume (ships per day)						
		Fishing	River-trade	Ocean-going	Fast Launch	Fast ferry	Other	Total
1	Soko Approach	0	0	0	1	0	0	1
2	West Soko	22	0	0	2	7	5	36
3	Adamasta Channel	132	17	1	91	307	5	560
4	West Lantau	11	2	0	5	10	5	36
5	Tai O	44	1	0	8	14	4	76
6	North Lantau	39	13	0	6	13	7	78
7	Sha Chau	83	24	0	31	52	30	220
8	North Lung Kwu Chau	22	3	0	26	36	9	96
9	Urmston Road West	22	2	1	25	35	2	93
10	Urmston Road Central	262	290	197	128	177	6	1102
11	Urmston Road East	11	14	0	6	8	2	41
12	Black Point Approach	2	3	0	2	0	0	7
	Total	650	369	263	331	659	76	2346

Table 2.5 Traffic Volume Assumed for 2021 "With Tonggu" Case

Section		Traffic volume (ships per day)						
		Fishing	River-trade	Ocean-going	Fast Launch	Fast ferry	Other	Total
1	Soko Approach	0	0	0	1	0	0	1
2	West Soko	22	0	0	2	7	5	36
3	Adamasta Channel	132	17	162	91	307	5	714
4	West Lantau	11	2	3	5	10	5	36
5	Tai O	44	1	4	8	14	5	76
6	North Lantau	39	13	0	6	13	7	78
7	Sha Chau	83	24	0	31	52	30	220
8	North Lung Kwu Chau	22	3	0	26	36	9	96
9	Urmston Road West	22	2	7	25	35	2	93
10	Urmston Road Central	262	290	85	128	177	6	948
11	Urmston Road East	11	14	0	6	8	2	41
12	Black Point Approach	2	3	0	2	0	0	7
	Total	650	369	199	331	659	76	2346

2.4 *MARINE VESSEL POPULATION*

Table 2.6 Vessel Population and Population at Risk

Class	Population	% of trips	Fatality Probability	Population at Risk
Fishing vessels	5		0.9	5
Rivertrade coastal vessels	5		0.3	2
Ocean-going vessels	21		0.1	2
Fast launches	5		0.9	5
Fast ferries*	450 (largest ferry at 100% capacity)	3.75	0.3	135
	350 (typical ferry at 100% capacity)	3.75	0.3	105
	280 (typical ferry at 80% capacity)	22.5	0.3	84
	175 (typical ferry at 50% capacity)	52.5	0.3	53
	105 (typical ferry at 30% capacity)	12.5	0.3	32
	35 (typical ferry at 10% capacity)	5	0.3	11
Other	5		0.9	5

* A distribution was assumed for the fast ferry population to reflect the occupancy at different time periods so that on average, the population is similar to the average load factor published by the Marine Department.

2.5 FREQUENCY ANALYSIS

Table 2.7 Anchor Damage Frequencies used in this Study

Pipeline section	Frequency (/km/year)	Comment
South Soko Approach	1.37×10^{-5}	Low marine traffic
West Soko	1.37×10^{-5}	Low marine traffic
Adamasta Channel	8.6×10^{-4}	High marine traffic
West Lantau	1×10^{-4}	Medium marine traffic
Tai O	8.6×10^{-4}	Next to anchorage
North Lantau	1×10^{-4}	Medium marine traffic
Sha Chau	1×10^{-4}	Medium marine traffic + some anchoring
North Lung Kwu Chau	1×10^{-4}	Medium marine traffic
Urmston Road West	8.6×10^{-4}	High marine traffic
Urmston Road Central	8.6×10^{-4}	High marine traffic
Urmston Road East	1×10^{-4}	Medium marine traffic
Black Point Approach	1×10^{-4}	Medium marine traffic

Table 2.8 Failure Frequencies and Pipeline Protection Factors

Pipeline section	Trench type	Corrosion /defects (/km/year)	Anchor/Impact			Others /km/year	Total /km/year
			Frequency (/km/year)	Protection factor (%) anchor<2	Protection factor (%) Anchor>2		
South Soko Approach	2A	1.18×10^{-6}	1.37×10^{-5}	99	50	1.34×10^{-6}	2.66×10^{-6}
West Soko	1	1.18×10^{-6}	1.37×10^{-5}	99	50	1.34×10^{-6}	2.66×10^{-6}
Adamasta Channel	3B/3A	1.18×10^{-6}	8.6×10^{-4}	99.9	99	1.34×10^{-6}	3.49×10^{-6}
West Lantau	3A	1.18×10^{-6}	1×10^{-4}	99.9	99	1.34×10^{-6}	2.70×10^{-6}
Tai O	3B	1.18×10^{-6}	8.6×10^{-4}	99.9	99	1.34×10^{-6}	3.82×10^{-6}
North Lantau	1	1.18×10^{-6}	1×10^{-4}	99	50	1.34×10^{-6}	3.52×10^{-6}
Sha Chau	1	1.18×10^{-6}	1×10^{-4}	99	50	1.34×10^{-6}	3.52×10^{-6}
North Lung Kwu Chau	1	1.18×10^{-6}	1×10^{-4}	99	50	1.34×10^{-6}	3.52×10^{-6}
Urmston Road West	3B/3A	1.18×10^{-6}	8.6×10^{-4}	99.9	99	1.34×10^{-6}	3.93×10^{-6}
Urmston Road Central	3A/3B	1.18×10^{-6}	8.6×10^{-4}	99.9	99	1.34×10^{-6}	4.58×10^{-6}
Urmston Road East	1	1.18×10^{-6}	1×10^{-4}	99	50	1.34×10^{-6}	3.52×10^{-6}
Black Point Approach	2B	1.18×10^{-6}	1×10^{-4}	99	50	1.34×10^{-6}	3.52×10^{-6}

2.6 SCENARIO DEVELOPMENT

Table 2.9 Hole Size Distribution for Corrosion and Other Failures

Category	Hole Size	Proportion
Rupture (Half Bore)	15" or 381mm	5%
Puncture	4" or 100mm	15%
Hole	2" or 50mm	30%
Leak	<25mm	50%

Table 2.10 Hole Size Distribution for Anchor Impact

Category	Hole Size	Proportion
Rupture (Full Bore)	Full bore	10%
Major	15" or 381mm (half bore)	20%
Minor	4" or 100mm	70%

Table 2.11 Ignition Probability

Release Case	Ignition Probability	
	Passing Vessels (1)	Vessels in Vicinity (2)
<25mm	0.01	n/a
50mm	0.05	n/a
100mm	0.1	0.15
Half bore	0.2	0.3
Full bore	0.3	0.4

1. Values applied to passing vessels for all types of incidents, i.e. corrosion, others and anchor impact.
2. Values applied only to scenarios where the vessel causing pipeline damage due to anchor impact is still in the vicinity.

3 *GAS RECEIVING STATION*

3.1 POPULATION

3.1.1 *Land Population*

Table 3.1 Land Population

Location	Approx. Distance from GRS	2011 Population	2021 Population
Residential Population		-	-
Industrial Population			
Black Point Site Surrounding	1km	100	100
Road Population			
Lung Kwu Tan Road	1.3km	22/km	22/km

Table 3.2 Population Time Periods

Time Period	Description
Night time	7:00pm until 7:00am
Weekday	9:00am till 5:00pm, Monday through Friday
Peak hours	7:00am to 9:00am and 5:00pm to 7:00pm, Monday to Friday 7:00am to 9:00am and 1:00pm to 3:00pm, Saturdays
Weekend day	3:00pm to 7:00pm Saturdays, and 7:00am to 7:00pm Sundays

Table 3.3 Land Population Occupancy and Indoor/Outdoor Fractions

Population Type	Occupancy				% Outdoors			
	Night	Peak	Weekday	Weekend day	Night	Peak	Weekday	Weekend day
Industrial	10 %	10 %	100 %	10 %	5 %	10 %	10 %	10 %
Residential	100 %	50 %	20 %	80 %	0 %	30 %	10 %	20 %
Road	10 %	100 %	50 %	20 %	0 %	0 %	0 %	0 %

3.1.2 *Marine Population*

Table 3.4 Vessel Population and Population at Risk

Class	Population	% of trips	Fatality Probability	Population at Risk
Fishing vessels	5		0.9	5
Rivertrade coastal vessels	5		0.3	2
Ocean-going vessels	21		0.1	2
Fast launches	5		0.9	5
Fast ferries*	450 (largest ferry at 100% capacity)	3.75	0.3	135
	350 (typical ferry at 100% capacity)	3.75	0.3	105
	280 (typical ferry at 80% capacity)	22.5	0.3	84
	175 (typical ferry at 50% capacity)	52.5	0.3	53
	105 (typical ferry at 30% capacity)	12.5	0.3	32
	35 (typical ferry at 10% capacity)	5	0.3	11
Other	5		0.9	5

Figure 3.1 Marine Population at Risk by Grid, Year 2011 (excluding fast ferries)

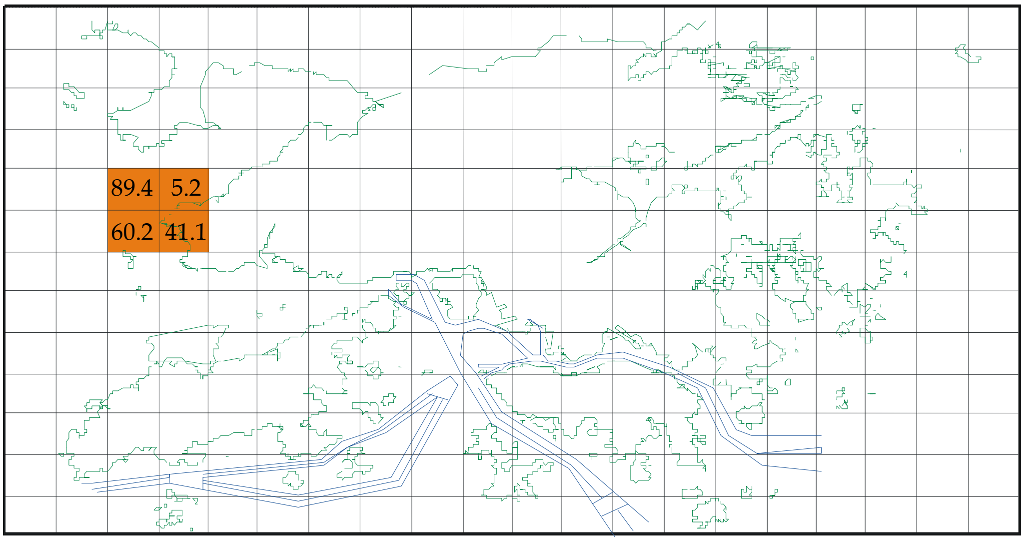


Figure 3.2 Marine Population at Risk by Grid, Year 2021 (excluding fast ferries)

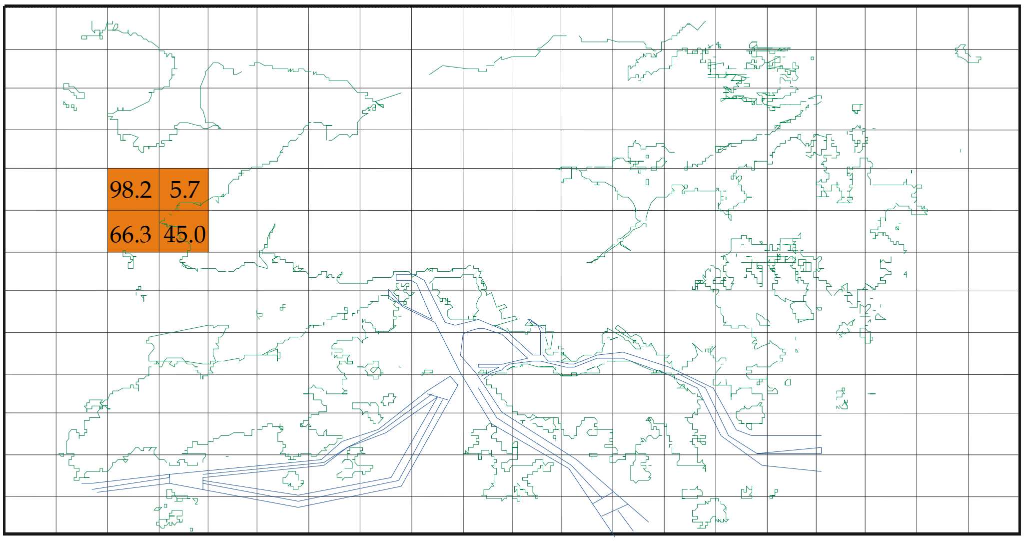


Figure 3.3 Number of Fast Ferries Per Day by Grid, Year 2011

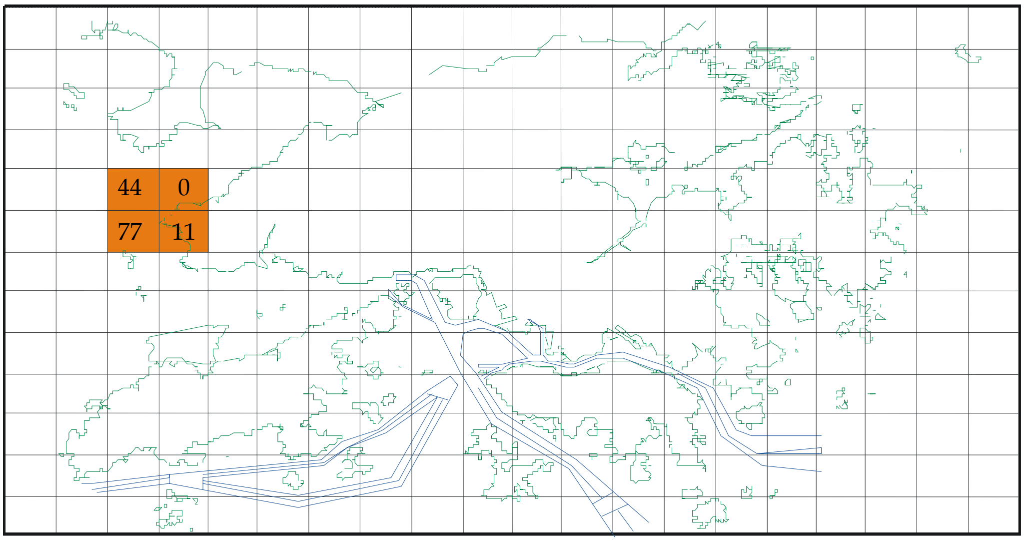


Figure 3.4 Number of Fast Ferries Per Day by Grid, Year 2021

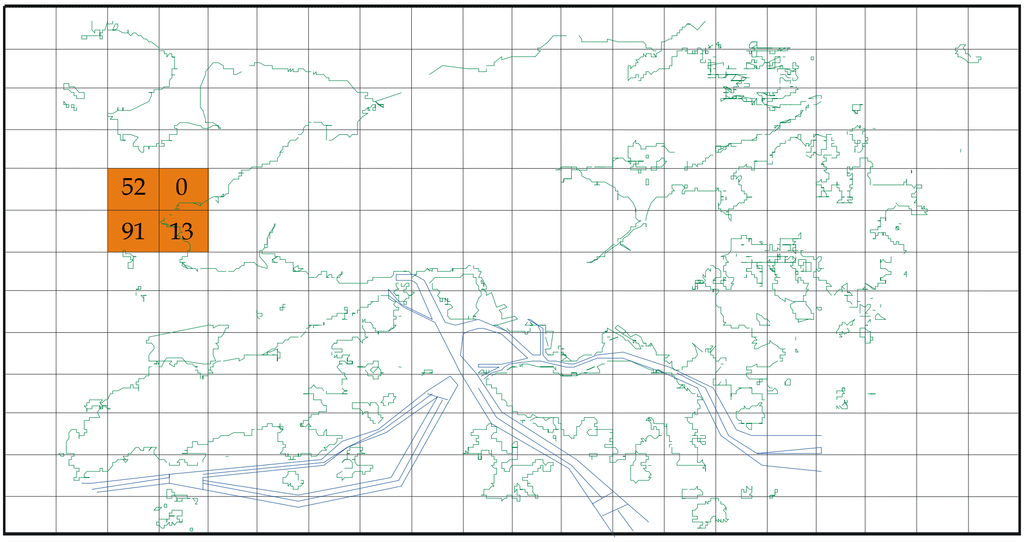


Table 3.5 Fast Ferry Population Distribution for Day and Night Time Periods

Population	Population at Risk	% of Day Trips	% of Night Trips	% of All Trips (= 0.75 x day + 0.25 x night)
450	135	5	-	3.75
350	105	5	-	3.75
280	84	30	-	22.5
175	53	60	30	52.5
105	32	-	50	12.5
35	11	-	20	5.0

Figure 3.5 *Stationary Marine Population at Risk (2011)*

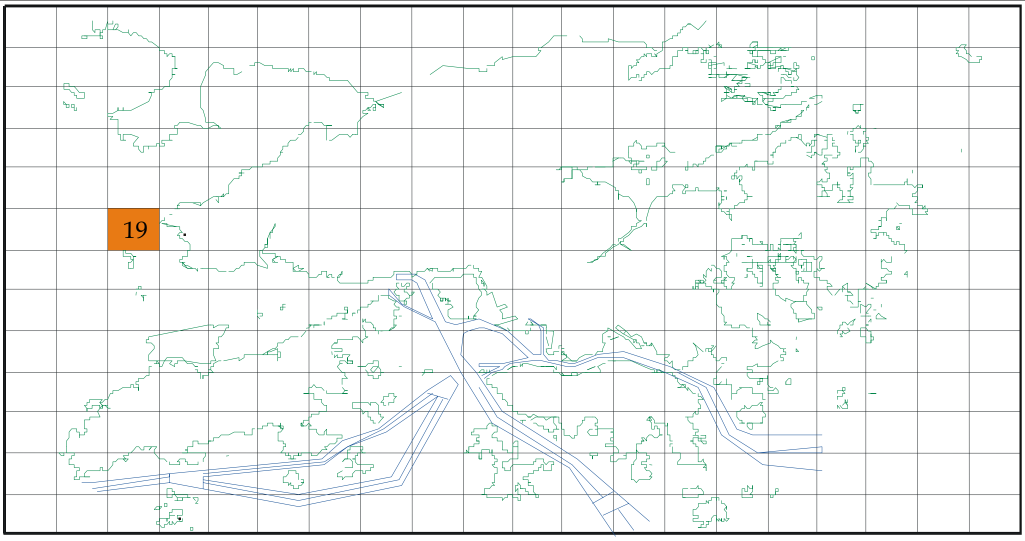
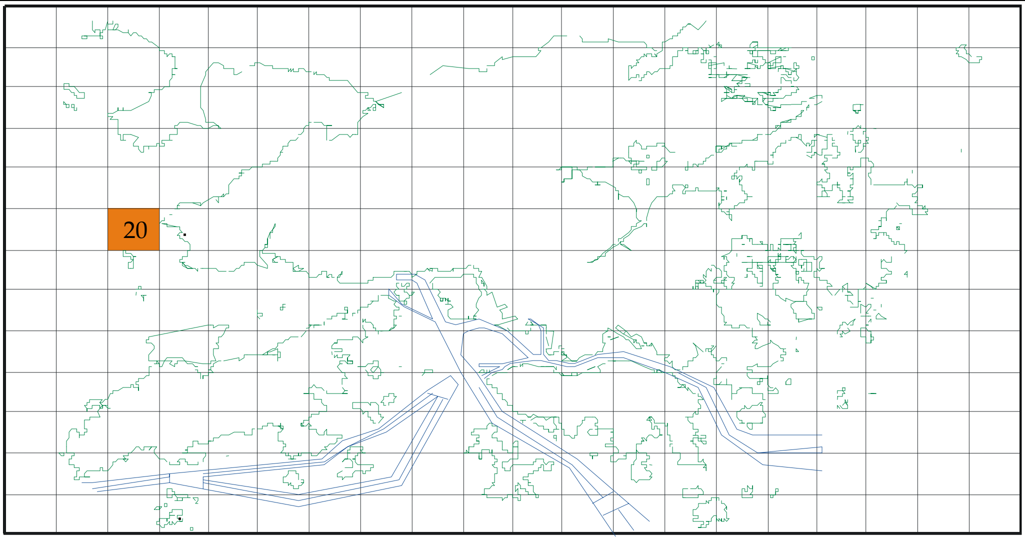


Figure 3.6 *Stationary Marine Population at Risk (2021)*



3.2 METEOROLOGICAL DATA

Table 3.6 Data for Sha Chau Weather Station

	Day				Night			
Wind Speed (m/s)	2.5	2	3	7	2.5	2	3	7
Atmospheric Stability	B	F	D	D	B	F	D	D
Wind Direction	Percentage of Occurrence							
0°	2.48	0.92	1.37	13.75	0.00	2.08	0.89	9.93
30°	0.72	0.61	0.76	4.38	0.00	1.78	0.84	7.12
60°	0.55	0.61	0.59	0.55	0.00	1.89	0.76	0.95
90°	2.00	1.57	2.43	6.07	0.00	6.69	2.97	9.53
120°	1.68	0.90	1.32	15.98	0.00	3.82	1.84	20.08
150°	1.06	0.61	0.36	3.12	0.00	2.28	0.60	3.83
180°	2.43	0.71	0.65	3.64	0.00	1.81	0.74	3.88
210°	3.35	0.86	1.39	9.04	0.00	2.06	1.01	6.91
240°	0.07	0.16	0.05	0.02	0.00	0.23	0.02	0.04
270°	0.08	0.09	0.01	0.01	0.00	0.11	0.00	0.01
300°	1.58	0.35	0.21	0.07	0.00	0.62	0.04	0.05
330°	3.78	0.74	1.09	5.22	0.00	1.59	0.53	2.45

3.3 *FREQUENCY ANALYSIS*

Table 3.7 Ignition Probabilities

	Immediate Ignition	**Delayed Ignition 1**	**Delayed Ignition 2**	**Delayed Ignition Probability**	**Total Ignition Probability**
Gas small* leak	0.02	0.045	0.005	0.05	0.07
Gas large* leak/rupture	0.1	0.2	0.02	0.22	0.32

* Small leak = 10 and 25mm. Large leak = 50 and 100mm holes

3.4 CONSEQUENCE ANALYSIS/PLANT DATA

Table 3.8 Process Conditions Used for Discharge Rate Calculations

Code	Scenario Name	Fluid Phase	Nature of Section	No. of Items	Length of Section (m)	Pipe Diameter (mm)	Pressure (bara)	Temperature (°C)	Density (kg/m³)	Inventory (kg)	Normal Flow Rate (kg/s)
G01	Gas piping from shutdown valve through gas filter to control valve	Gas	Piping	1	25.5	750	91.18	11.93	92.73	1044	356.40
G02	Gas Heater Piping	Gas	Piping	4	4.5	250	90.68	43.39	73.9	16	54.84
G03	Pressure Control Assembly	Gas	Piping	2	3.9	450	88.68	77.49	61.84	38	135.31