11 HAZARD TO LIFE

11.1 Introduction

Background

11.1.1 In accordance with Clause 3.4.11.2 to 3.4.11.5 of the EIA Study Brief for the Kai Tak Development (ESB-152/2006), hazard assessments are required for the hazardous sources as listed in **Table 11.1.1**. The locations of the hazardous sources are presented in **Figure 11.1.1**.

Table 11.1.1 Hazardous Sources within / near the Study Area of EIA Study for the Kai Tak Development

Relevant Clause in EIA Study Brief	Hazardous Sources	Location	Remarks
3.4.11.2	Ma Tau Kok Gas Works (North Plant and its associated facilities	To Kwa Wan Road, Ma Tau Kok	A designated PHI due to storage of more than 15 tonnes of Town Gas, with a Consultation Zone (CZ) of 300m radius from the mid point between the two gas holders of the North Works. Associated facilities include the gas pigging station, naphtha unloading jetty, pressure regulating station, landing point for the two 400mm diameter submarine gas pipelines and other operational related facilities situated at the seafront site just next to the Kowloon City Ferry Pier.
3.4.11.3	Chlorine Dock	Cheung Yip Street, Kowloon Bay	A chlorine dock for the unloading of chlorine drums and cylinders used by Water Supplies Department (WSD) at various water treatment works and chlorination station and other Government Departments.
3.4.11.4	DGV Ferry Pier	Kwun Tong	A ferry pier for DG ferries carrying dangerous goods vehicles.
3.4.11.4	Kerry DG Warehouse (Kowloon Bay)	7 Kai Hing Road, Kowloon Bay	A DG warehouse for storage of dangerous goods.

Relevant Clause in EIA Study Brief	Hazardous Sources	Location	Remarks
3.4.11.4	Petrol cum LPG Filling Stations and Dedicated LPG Filling Stations	Within KTD Area or in vicinity to the KTD Area	Address of the Petrol cum LPG Filling Stations are: • Wang Chin Street, Kowloon Bay • 4 Kai Fuk Road, Kowloon Bay (West Bound) • 8 Kai Fuk Road, Kowloon Bay (West Bound) • 7 Kai Fuk Road, Kowloon Bay (East Bound) • 5 Kai Fuk Road, Kowloon Bay (East Bound) Address of the Dedicated LPG Filling Stations area: • Wai Lok Street, Kwun Tong • Cheung Yip Street, Kowloon Bay
3.4.11.5	Explosives Storage and Blasting Operations	Within KTD Area	It is confirmed that no explosives would be used for the construction activities.

11.1.2 As required in Clauses 3.4.11.3 and 3.4.11.5 of the EIA Study Brief, it is confirmed that there is plan to decommission and relocate the existing chlorine dock outside the project boundary of Kai Tak Development prior to the future land uses of the Project in 2012 and that no explosives would be used for the construction activities in KTD, hazard assessments of these two hazardous sources are therefore not required.

11.1.3 As stated in Clause 3.2.2 (ix) of the EIA Study Brief, implication of any one or combination(s) of the above hazardous sites on early stages of the Project development such as the Tourism and Leisure Hub at Runway South is required. Combined risk of the above hazardous sites would be assessed.

11.1.4 The hazard assessment approach would follow the requirements as per the EIAO-TM, the EIA Study Brief and the Court of Final Appeal (CFA) ruling. Hazardous scenarios and frequency adopted in the hazard assessment are confirmed independently using review of historical incidents. All scenarios identified are assessed in the frequency analysis.

<u>Risk Guidelines</u>

11.1.5 The estimated risk levels of the hazardous sources shall be compared with the risk guidelines stipulated in the EIAO-TM Annex 4 to determine the acceptability.

11.1.6 As set out in Annex 4 of the EIAO-TM, the risk guidelines comprise two components as follows:

- *Individual Risk Guideline*: the maximum level of off-site individual risk should not exceed 1 in 100,000 per year, i.e. 1×10^{-5} / year
- *Societal Risk Guidelines*: it can be presented graphically as in **Figure 11.1.2**. The Societal Risk Guideline is expressed in terms of lines plotting the frequency (F) of N or more deaths in the population from accidents at the facility of concern. There are three areas shown:

- *Acceptable* where risks are so low that no action is necessary;
- *Unacceptable* where risks are so high that they should usually be reduced regardless of the cost or else the hazardous activity should not proceed;
- *ALARP* (As Low As Reasonably Practicable) where the risks associated with the hazardous activity should be reduced to a level "as low as reasonably practicable", in which the priority of measures is established on the basis of practicability and cost to implement versus risk reduction achieved.

11.2 Hazard Assessment for the existing Ma Tau Kok Gas Works North Plant (MTKGWNP) and its facilities

Introduction

11.2.1 The MTKGWNP is one of the Towngas production plants in Hong Kong and it is classified as a Potentially Hazardous Installation (PHI) which is located adjacent to part of the planning area of the Kai Tak Development (KTD). The plant is located at To Kwa Wan Road with Ma Tau Kok Road and San Shan Road to the northeast and southwest of its boundary respectively.

11.2.2 In addition to the gas production plant, there are other associated gas facilities in Ma Tau Kok within the boundary of Kai Tak Development. These include the gas pigging station, naphtha-unloading jetty, pressure regulating station, landing point for the two 400mm diameter submarine gas pipelines and other operational related facilities situation at a seafront site just next to the Kowloon City Ferry Pier.

11.2.3 **Figure 11.2.1** shows the location of the MTKGWNP together with the associated gas facilities and its environs with respect to the Kai Tak Development.

11.2.4 The hazard related to the operation of the MTKGWNP and all associated gas facilities; in particular the implication that these facilities may have on early stages of the Project development such as the Tourism and Leisure Hub at Runway South; has been assessed in this study.

11.2.5 This section of the report detailed assessment of risk associated to construction and operation of the Project due to operations of the MTKGWNP and its associated facilities.

Assessment Approach

General

11.2.6 The hazard assessment consists of the following tasks:

1. ***Data / Information Collection***: collects relevant data / information which is necessary for the hazard assessment.
2. ***Hazard Identification***: identifies hazardous scenarios associated with the operation of the MTKGWNP and its associated facilities by review of historical accident database, such as MHIDAS [1], and relevant similar studies and then determine a set of relevant scenarios to be included in a QRA.
3. ***Frequency Assessment***: assess the likelihood of occurrence of the identified hazardous scenarios by reviewing historical accident data, previous studies or using Fault Tree Analysis. Event Tree Analysis, which is already built into the SAFETI package (v6.51), is adopted to determine the possible outcome from the identified hazardous events and to estimate the frequencies.

4. ***Consequence Assessment***: the consequences are established for every outcome developed from initial event by using internationally well recognised consequence model – PHAST in the SAFETI Package (v6.51), to assess the impacts from gas leaks, fires, explosions, toxicity and other process hazards.

5. ***Risk Assessment***: evaluates the risks level, in terms of individual risk and societal risk, associated with the identified hazardous scenarios. The overall risk level is compared with the criteria as stipulated in Annex 4 of the TM to determine their acceptability. Mitigation measures will be identified where the risk is considered in the ALARP (As Low As Reasonably Practicable) region. The reduction in risk achievable by these means will then be quantified. The cost-effectiveness and the practicable of these measures will also be assessed.

6. ***Alternative Measures Assessment***: cost-effectiveness and practicable measures or alternative measures will be identified and assessed for the construction stage and operational stage of the Project in case the alignment of the two existing 400mm submarine gas pipelines are required to be changed and the landing points at both pipe ends are required to be relocated.

11.2.7 The hazard assessment covers three (3) future scenarios listed below:

- Year 2012 scenario - The first berth of the Cruise Terminal is commissioned. It assesses risk impact to the planned population and peak construction workforce level in year 2012 due to the existing gas facilities.

- Year 2016 scenario – It assesses risk impact to the overall population including the second phase of KTD population intake in year 2016 due to the existing gas facilities.

- Year 2021 scenario – It assesses risk impact to the overall population including the third phase of population intake of KTD population in year 2021 (Ultimate Scenario) due to the existing gas facilities.

Data / Information Collection

General

11.2.8 Data / information presented in the approved EIA study of "Comprehensive Feasibility Study for the Revised Scheme of South East Kowloon Development" (Agreement No. CE32/99) (SEKD) has been reviewed and adopted as appropriate. The following relevant data / information has been collected:

- Details of gas facilities;
- Population and traffic flow;
- Meteorological data; and
- Source of Ignition; and
- Construction and Operation Activities.

Details of Gas Facilities

11.2.9 HKCG gas installations and operational information has been collected during site visit and subsequent discussion with HKCG for further assessment of hazards and hence risks. These facilities within and adjacent to the KTD area include the following installations and the locations of these facilities are presented in **Figure 11.2.2** of this report.

- Ma Tau Kok Gas Works North Plant;
- Naphtha unloading Jetty and associated pipework;
- Towngas off-take station; and
- Submarine Pipeline and its associated pigging station.

Ma Tau Kok Gas Works North Plant

11.2.10 Towngas is produced at two production plants namely the Tai Po Gas Production Plant and the Ma Tau Kok Gas Works North Plant. Over 95% is produced at the Tai Po Gas Production Plant and the remaining 5% is produced at the MTKGWNP which acts as a peak shaving facility during peak consumption period.

11.2.11 Towngas is produced by means of catalytic cyclic reform using naphtha as feedstock. The process is based on the reaction between steam and naphtha feedstock in the presence of a catalyst at elevated temperature. There are 6 identical gas-making trains installed in MTKGWNP producing Towngas. Each gas train consists of a combustion chamber and reactor with burners, a naphtha vaporiser, a waste heat boiler, a water scrubber and exhaust and vent stacks.

11.2.12 Within the MTKGWNP, 2 water sealed full column guided gasholders, located at south of the site, is used to store the gas produced. Towngas produced by the gas works supplies to consumers at Kowloon as well as those at Hong Kong Island through submarine pipeline which are connected to the gas station at North Point.

11.2.13 In addition to the gas-production trains, there are other ancillary facilities installed in the plant site. These include 2 naphtha storage tanks, 2 water tanks, compressor, boiler and emergency generators etc. Layout plan for the MTKGWNP is on **Figure 11.2.3**. **Table 11.2.1** below summaries the flammable materials storage facilities in MTKGWNP.

Table 11.2.1 Flammable Materials Storage Facilities in MTKGWNP

Material	Storage Type	Quantity	Sizes
Naphtha	Fixed roof w/ internal floating roof Tank	2	1,779 m^3
Towngas	Water sealed type gasholder No. 4	1	25,740m^3 (909,000 ft^3)
Towngas	Water sealed type gasholder No.2	1	12,740m^3 (450,000 ft^3)

11.2.14 With respect to fire services installation, MTKGWNP is equipped with auto / manual fire alarm systems, gas detection system, fire ring main, hydrant hose reel, automatic sprinkler system, water spray system, base foam injection of oil tank, remote control foam monitor, BTM for DG store, CO2 system for boiler room & electrical switch rooms, siren system etc.

Naphtha unloading Jetty and associated pipework

11.2.15 Naphtha is pumped from barges at the jetty at the waterfront next to Grand Waterfront via underground pipework along San Ma Tau Street and across Tokwawan Road to the naphtha storage tanks at MTKGWNP.

11.2.16 All unloading operations are fully manned and with the provision of safety measures include excess flow valve, non-return valve; double wall stainless steel loading arm and differential flow trip system to ensure safe unloading of Naphtha.

Towngas off-take Station

11.2.17 A Towngas off-taking and pigging station is located at the seafront of the Grand Waterfront Development. The off-take unit in the station reduce the pressure of Towngas from Intermediate Pressure (IP) to Medium Pressure (MP) for distribution. The pig launching/receiving facility is provided at the landing point of the twin submarine pipeline which supply Towngas to Hong Kong Island.

Submarine Pipeline and its associated pigging station

11.2.18 HKCG is now operating a pair of 400mm diameter Intermediate pressure submarine pipelines running from Ma Tau Kok to North Point for supplying customer of Hong Kong Island.

11.2.19 It is noted that the existing submarine pipelines are in conflict with the proposed Central Kowloon Route at To Kwa Wan and the cruise terminal development of the KTD, these twin submarine pipelines and its associated facilities will be re-located. In accordance with the project profile (Ref.: ESB-171/2007) submitted to Environmental Protection Department (EPD), the proposed landing point will be located to the south of Hoi Sum Park (southward from existing location). The proposed location indicated in the project profile submitted to EPD is given in **Figure 11.2.4** of this report. Since the future alignment of the twin submarine pipelines is at least 300m further away from the Kai Tak Development in comparison with the existing alignment and the relocation needs to be completed before the operation of the cruise terminal, the impact of these pipelines and their landing points on the Kai Tak Development is lessened in construction and operation phases of the project.

Population

11.2.20 Residential, employment population and transient population (land and marine) in the proximity of the MTKGWNP has been estimated based on the data from the 2003-based Territorial Population and Employment Data Matrix (TPEDM) provided by the Planning Department. The detailed of the population groups assessed for Year 2012, 2016 and 2021 are detailed in **Appendix 11.2.1** of this report respectively. The locations of the population groups are presented in **Figure 11.2.5**.

Assumption of Population Distributions

11.2.21 The outdoor proportion of population groups have been estimated using an outdoor ratio to each group as listed in **Table 11.2.2.** For open space area, population has been estimated based on observation of other open space with similar nature when data is not available.

Table 11.2.2 Indoor/Outdoor Ratios for Different Population Categories

Population Category	Indoor (Outdoor) Ratio
Residential	0.95 (0.05)
School	0.95 (0.05)
Park	0.00 (1.00)
Road	0.00 (1.00)
Railway/Bus station	0.00 (1.00)
Marine	0.00 (1.00)

11.2.22 In order to reflect temporal distribution of population, time period is divided into 4 time modes namely daytime and night-time for both weekend and weekday. The distribution of population at each time mode is given in **Table 11.2.3**

Table 11.2.3 Temporal Changes in Population for Various Categories

Time period	Residential Dwellings	Shopping Centre	Industrial/Commercial Buildings
Weekday (day)	50%	50%	100%
Weekday (night)	100%	0%	10%
Weekend (day)	70%	100%	40%
Weekend (night)	100%	0%	5%

Meteorological data

11.2.23 The meteorological conditions affect the consequence of gas release in particular the wind direction, speed and stability which influences the direction and degree of turbulence of gas dispersion. Latest meteorological data (Year 2006) from Kai Tak Anemometer Station of the Hong Kong Observatory has been collected and adopted in the consequence model to determine the various gas dispersion, fire and explosion effect. The dominant sets of wind speed-stability class combination both daytime (**Table 11.2.4**) and night-time (**Table 11.2.5**) has been identified and adopted in the risk assessment.

Table 11.2.4 Wind Direction Frequencies at Kai Tak Weather Station 2006 (Day-time)

DIRECTION	WEATHER CLASS						TOTAL
	3B	1D	4C	7D	1F	3E	
0 – 30	0.60	0.12	1.12	0.12	0.30	0.67	2.93
30 – 60	0.88	0.19	2.81	0.26	0.40	0.86	5.40
60 – 90	0.98	0.14	3.28	1.49	0.23	0.72	6.84
90 – 120	2.40	0.19	13.40	8.09	0.33	2.00	26.40
120 – 150	4.86	0.28	11.44	3.02	0.74	2.84	23.19
150 – 180	1.56	0.258	1.51	0.05	1.14	0.30	5.14
180 – 210	1.28	0.16	1.95	0.33	0.35	0.14	4.21
210 – 240	2.98	0.37	3.58	0.88	0.33	0.35	8.49
240 – 270	2.02	0.30	2.98	0.86	0.21	0.33	6.70
270 – 300	0.70	0.14	1.58	0.14	0.30	0.58	3.44
300 – 330	0.67	0.14	1.79	0.33	0.40	0.58	3.91
330 – 360	0.70	0.26	1.30	0.40	0.40	0.33	3.37
All	**19.63**	**2.86**	**46.74**	**15.95**	**5.12**	**9.70**	**100.00**

Table 11.2.5 Wind Direction Frequencies at Kai Tak Weather Station 2006 (Night-time)

DIRECTION	WEATHER CLASS						TOTAL
	1B	1D	4D	7D	1F	3E	
0 – 30	0.00	0.02	0.41	0.25	1.07	2.46	4.21
30 – 60	0.00	0.00	0.80	0.30	1.14	3.35	5.58
60 – 90	0.00	0.00	2.09	1.12	1.02	3.21	7.44
90 – 120	0.00	0.00	8.51	5.85	1.98	11.99	28.33
120 – 150	0.00	0.00	1.80	0.25	5.05	11.36	18.46
150 – 180	0.00	0.00	0.14	0.05	4.03	1.39	5.60
180 – 210	1.82	0.00	0.75	0.07	2.07	2.03	6.74
210 – 240	0.00	0.00	1.07	0.41	1.80	2.82	6.10
240 – 270	0.00	0.00	0.61	0.36	1.89	2.66	5.53
270 – 300	0.00	0.00	0.50	0.25	1.37	1.55	3.66
300 – 330	0.00	0.00	0.73	0.11	1.09	1.48	3.41
330 – 360	0.00	0.00	0.66	0.16	2.89	1.23	4.94
ALL	**1.82**	**0.02**	**18.07**	**9.17**	**25.40**	**45.52**	**100.00**

Source of Ignition

11.2.24 The presence of ignition sources in the study area is primary concern in case of flammable gas release. Ignition sources other than onsite one, such as dwellings and vehicles along carriageways, contribute to delayed ignition in Vapour Cloud Explosion (VCE) and flash fire. The energy level, timing, location of ignition sources in the vicinity of the gas works and hence the probability of ignition of gas cloud have been reviewed and assessed.

11.2.25 The ignition sources identified are listed in the following table.

Table 11.2.6 Ignition Sources (Onsite and Offsite)

Type	Ignition Sources
Onsite (Within MTKGWNP)	Naphtha vaporisers
	Heaters
	Boilers
Offsite (Outside MTKGWNP)	Road vehicles
	Surrounding population

Construction and Operation Activities

11.2.26 The major construction works within the KTD adjacent to the MTKGWNP and the anticipated impact to the gas facilities are listed in the following Table. The locations of respective developments are given in **Figure 11.2.6**.

Area	Site No.	Use Designation	Use Specification	Anticipated Construction Works
5A	1	G	Sewage Pumping Station	Low-rise buildings with indoor Screening and pumping equipment installed
	2	IC	Electricity Substation	Low-rise substation with indoor electrical power equipment installed
	3	OU	Waterfront Related Commercial and Leisure Uses	Landscape and Leisure facilities
	4	R2	Residential	Potential High-rise buildings
	5	R1	Residential (Grand Waterfront)	Existing New High-rise buildings
5B	1	OU	Tunnel Ventilation Shaft	Air intake ventilation building
	2	G	Public Transport Interchange	Existing Facility
	3	OU	Public Pier	Existing Facility
	4	OU	Passenger Pier	Existing Facility
	5	OU	Waterfront Related Commercial and Leisure Uses	Landscape and Leisure facilities
	6	OU	Railway Ventilation Shaft	Air intake ventilation building
5C	1	G	Refuse Collection Point	Low-rise buildings with parking area
	2	IC	Electricity Substation	Low-rise substation with indoor electrical power equipment installed
	3	E	Primary School	Low-rise school buildings
	4	E	Primary School	Low-rise school buildings
	5	E	Secondary School	Low-rise school buildings
	6	E	Secondary School	Low-rise school buildings

Hazard Identification

General

11.2.27 Potential hazards associated unloading, storage and processing of liquid Naphtha during the gas production process and the hazards related to storage and transmission of Towngas need to be identified. The Hong Kong and China Gas Company Limited (HKCG) are consulted for operation information and parameters which are recorded in **Appendix 11.2.2**. This section outlined the hazards identification of the gas facilities including a review of historical accident database, Major Hazard Incident Data Services (MHIDAS).

11.2.28 Naphtha is a colourless flammable hydrocarbon liquid at normal conditions. It is a mixture of various hydrocarbons and its physical and chemical characteristics have been modelled as a composition of 50-mol% n-pentane and 50-mol% h-hexane. **Table 11.2.7** below presents the properties of Naphtha.

Table 11.2.7 Properties of Naphtha

Property	Details
Flammability	Flammable
Auto-Ignition Temperature	>220°C
Flash Points	-20°C
Flammable Limits	1.1% (LOWER) – 5.9% (UPPER)
Specific Gravity	0.67 (water = 1)
Vapor Pressure	0.6 kPa (@ 20°C)
Vapor Density	4 (air = 1)

11.2.29 Towngas is the final product of the gas works. It has neither colour nor odour and is buoyant gas under ambient condition. Odouriser is added to the gas in the final stage of the production process such that it can easily be detected in case of leakage. Towngas is both flammable and toxic while carbon monoxide, components of the Towngas, is chemical asphyxiant. **Table 11.2.8** presents the composition and physical properties of Towngas.

Table 11.2.8 Compositions and Properties of Towngas

Composition	% (By Volume)	Physical Properties	Values
Hydrogen	57.8%	Calorific Value MJ/M^3	17.27
Methane	2.7 %	Density @ 1atm (kg/m^3)	0.624
Carbon Dioxide	11.5 %	Wobbe Index	24
Carbon Monoxide	12.1 %	Weaver Flame Speed	35
Nitrogen, Oxygen & others	15.9 %		

Review of historical accidents related to Naphtha

11.2.30 A search of MHIDAS database for historical accidents related to Naphtha storage and transfer has been conducted. The causes of these accidents are summarised in **Table 11.2.9** below.

Table 11.2.9 Historical Accidents associated with Naphtha

Hazardous Events	Cause
Tank Fire	Earthquake, Fire escalation, lightning
Bund Fire	Spillage/Pipe Leakage and subsequent ignited
Pool Fire	Tank/Pipe Leakage or Spillage and subsequent ignited
Release but not ignited, bund contained	Earthquake lead to tank rupture

Review of historical accidents related to Gasholders

11.2.31 A search of MHIDAS database for historical accidents related gas storage and production has been conducted. Only 1 accident occurred in Brisbane, Australia is found and reviewed. The cause of the accident gas leak release was due to tank top tilted.

Hazards identified with Naphtha

11.2.32 Failures of gas facilities are subject to various initial events as shown in **Table 11.2.10**.

Table 11.2.10 Hazards associated with Naphtha

Location	Categories	Potential initial events
Naphtha Unloading Jetty	Loss of containment	• Naphtha leak from loading arm • Naphtha leak from unloading pipework and loading arm
Gas Plant - Naphtha Storage Tank	Loss of containment	• Naphtha leak from tank • Sealing failure of floating roof tanks • Naphtha leak from pipework
	Spillage	• Tank overflow due to overfilling
Gas Plant- Reforming plant	Loss of containment	• Naphtha leak from gland / seal of valves, pumps, compressor

Hazards associated with Towngas

11.2.33 Failures of gas facilities are subject to various initial events as shown in **Table 11.2.11**.

Table 11.2.11 Hazards associated with Towngas

Location	Categories	Potential initial events
Gas Station **Gas Plant-** Reforming Process **Gas Plant-** Gasholder **Gas Plant-** Pipeline	Spontaneous failure	• Gas holder failure • Process vessels failure • Pipework failure • Flange gasket failure • Valve leakage failure • Pump failure
	Partial failure	• Gas holder leakage • Process vessels leakage • Pipework leakage • Blown seal
	External Event	• Earthquake • Car crash • Aircrafts crash • Landslide • Severe environmental events • Lightning Strike • External Fire

11.2.34 Failure of gas holder and process vessels can be cold catastrophic, which may be caused by corrosion, fatigue due to thermal and pressure loading, material or construction defect, leading to instantaneous release of Towngas. In cold partial failure, it results in continuous release of Towngas to the atmosphere through a crack or leak.

11.2.35 Pipelines can be found connecting process vessels throughout a production train. Towngas is collected and transferred to the compressor room via pipelines. Pressurized Towngas is fed into distribution network after it has passed the compressor room. Failure along pipeline may be caused by undetected corrosion, fatigue, material or construction defect, or associated with flange gasket/valve leakage failure leading to instantaneous gas release. In cold partial failure, it results in continuous gas release to the atmosphere through a crack or leak.

11.2.36 Failures of gaskets and valve leak would only tend to give relatively small scale of leakage and will not contribute to the off-site risk. The results from gasket failure will not be considered separately but absorbed into pipework failure in the study.

11.2.37 No unauthorised vehicle is allowed and speed restriction is imposed within the MTKGWNP. Besides, safety markings and protective fencing are provided to the above ground pipelines and gas holders. Car crash leading to failure of gas facilities has been considered in the fault tree analysis **Appendix 11.2.3**.

11.2.38 In Hong Kong, buildings and infrastructures are designed to withstand earthquakes up to Modified Mercali Intensity (MMI) VII. It is estimated that MMI VIII is required to provide sufficient intensity to result in damage to specially designed structure. It is assumed that failure in earthquake is possible for gas holder rupture, leakage, pipeline rupture and leakage and probability of failure in earthquake is assumed 0.01 [2][3]. The probability of earthquake occurrence at MMI VIII and higher is very low comparing with other places and is estimated to be 1.0×10^{-5} per year [4].

11.2.39 The distance between the nearest arrival flight path and the MTKGWNP and associated gas facilities is more than 2 miles. The distance between the MTKGWNP and associated gas facilities and Chek Lap Kok International Airport is over 5 miles which is the criteria for the consideration of airfield accident. At such distances, MTKGWNP and associated gas facilities is not covered by critical takeoff and landing phases. The frequency of aircraft crash is estimated using the methodology of the HSE [5] which has been applied to LNG Terminal EIA study [4] and other EIA studies. The number of runway movements of aircraft is extracted from yearly statistics of the Hong Kong International Airport between years 1998 and 2006. Movement number in study years are estimated by linear regression. Accident rates on MTKGWNP being hit by an aircraft for years 2021 (the worst scenario) is 4.3×10^{-14} per year respectively. Since the calculated accident rates are much smaller than order of 10^{-9}, failure caused by aircraft crash is not considered further in the assessment. Sample calculation is provided in **Appendix 11.2.5**.

11.2.40 The MTKGWNP and associated facilities are not located close to hillside or slope and loss of containment due to landslide is not possible.

11.2.41 Loss of containment due to severe environmental event such as typhoon or tsunami (large scale tidal wave) is not possible as the MTKGWNP and gas facilities are designed to withstand wind load for local typhoon while Hong Kong is not threatened by tsunami. Subsidence is usually slow in movement and such movement can be observed and remedial action can be taken in time. Besides, the gas facilities were built for many years. Soil condition is rather stable. Failure caused by subsidence is not considered further in the assessment.

11.2.42 External fire means the occurrence of fire event which lead to the failure of the gas holder or other facilities. The key potential concern relates to the gas holder and pipelines being affected by the on-site diesel tank and naphtha tanks. By considering underground location of the diesel tank and provision of fire fighting equipment for naphtha tanks, it can be assumed that such external fire will not lead to any disastrous outcome.

11.2.43 Lightning protection devices are installed at the MTKGWNP while shielding is provided for gas station, naphtha jetty and associated gas facilities. Besides, height of nearby buildings is comparable with or higher than the MTKGWNP. Nearby buildings also provide shielding effect to prevent the gas facilities being struck by lightning. With sufficient protection system, no further consideration is given for effect of lightning strike in this assessment.

Construction Impact

11.2.44 The separation distances from the KTD construction site of various developments have been measured. The potential impact to the MTKGWNP has been reviewed and the findings are as follows.

Table 11.2.12 Potential Impact to MTKGWNP due to construction activities

Area	Site No.	Use Designation	Use Specification	Anticipated Impact to MTKGWNP due to construction works.
5A	1	G	Sewage Pumping Station	No impact, 200m away from MTKGWNP. General construction works are expected.
	2	IC	Electricity Substation	
	3	OU	Waterfront Related Commercial and Leisure Uses	No impact, more than 200m away from MTKGWNP. General landscape construction works are expected.
	4	R2	Residential	No impact, 100m away from MTKGWNP and located behind a high-rise building, the Grand Waterfront.
	5	R1	Residential (Grand Waterfront)	No impact. Newly developed Properties, no construction works are anticipated.
5B	1	OU	Tunnel Ventilation Shaft	Distance from the MTKGWNP around 50m. Close coordination with HKCG during design and construction stage for setting out monitoring requirements. Control of settlement and vibration levels to the required limits would not increase risk level of the MTKGW. During operation phase, it is possible that ingress of Towngas may occur in case of gas leakage. Ingress of the Towngas could be avoided by taking into account location and orientation of fresh air intake as well as using gas detection system. A separate EIA will be submitted by Project Proponent of Central Kowloon Route to assess the Hazard to Life.)
	2	G	Public Transport Interchange	Existing facilities, and assumed that no large scale construction works to be carried out.
	3	OU	Public Pier	No impact as site area is more than 300 m away from MTKGWNP
	4	OU	Passenger Pier	

Area	Site No.	Use Designation	Use Specification	Anticipated Impact to MTKGWNP due to construction works.
	5	OU	Waterfront Related Commercial and Leisure Uses	
	6	OU	Railway Ventilation Shaft	Distance from the MTKGWNP around 90m. Close coordination with HKCG during design and construction stage for setting out monitoring requirements. Control of settlement and vibration levels to the required limits would not increase risk level of the MTKGW. During operation phase of Shatin-Central Link, it is possible that ingress of Towngas may occur in case of gas leakage. Ingress of the Towngas could be avoided by taking into account location and orientation of fresh air intake as well as using gas detection system.
5C	1	G	Refuse Collection Point	No impact as site area is more than 300m away from MTKGWNP and more than 100m from new gas stations
	2	IC	Electricity Substation	
	3	E	Primary School	
	4	E	Primary School	
	5	E	Secondary School	
	6	E	Secondary School	Distance from new gas stations around 50m. Strictly follow of Code of Practices of Avoiding Danger from gas pipes and with close coordination with HKCG during design and construction stage.

11.2.45 With respect to the buried gas pipe in the KTD area, Code of Practices of Avoiding Danger from gas pipes will be strictly followed to prevent any interference to the gas pipes in accordance with general practice. In addition, close coordination and liaison with the HKCG on safety distance of work, precautionary measures, program of works, contingency planning, emergency procedures, requirements for construction work in vicinity of gas main will be commenced in the design stage till the end of construction stage to ensure no adverse impact to the gas facilities will be generated.

11.2.46 Population induced by construction activities is a transient one. Besides, the number of personnel involved in construction activities is considered much less than the population generated in the operation phase. Risk level for construction phase should be the same or lower than the operation phase. Thus, risk impact in construction phase is covered by 3 future scenarios in this assessment.

Scenarios for QRA Study

11.2.47 Scenarios for the QRA study were identified based on the hazard identified and a review of incident records. Losses of containment events have been identified for Tanker, Jetty, Gas Station, Gas production area, storage tanks and Gasholder are listed below.

Table 11.2.13 Hazardous scenario for QRA Study

Plant	**Material**	**Initiating Event**	**Potential Outcome Scenario**
Naphtha Jetty and Gas Stations			
Jetty Area: Loading arm & Piping at the jetty	Naphtha	Pipe Rupture & Leak	Pool fire/Jet fire/ Flash fire
Gas Station: Piping/Valve/Equipment	Towngas	Rupture	Jet fire/ Fireball/ Flash fire
		Leak	Jet fire/ Flash fire
Ma Tau Kok Gas Plant			
Naphtha Bund Area	Naphtha	Leak & Rupture & Spillage	Bund fire/Pool fire/Flash fire
Process Area: Piping/equipment	Naphtha	Rupture & Leak	Pool fire/Jet fire/ Flash fire
Process Area: Piping/equipment	Towngas	Rupture	Jet fire/ Flash fire/ Fireball
		Leak	Jet fire/ Flash fire
Gasholder	Towngas	Rupture	Jet fire/ Flash fire/ Fireball
		Leak	Jet fire/ Flash fire
Gas pipework	Towngas	Rupture	Jet fire/ Flash fire / Fireball
		Leak	Jet fire/ Flash fire

11.2.48 A list of assumptions for QRA modelling is attached in **Appendix 11.2.2** of this report.

Frequency Assessment

General

11.2.49 Subsequent to the hazard identification, the likelihood of occurrence of these hazardous scenarios is required to be determined. The aim of the frequency assessment is to estimate the likelihood of occurrence of the initial events and then the frequencies of hazardous outcomes.

11.2.50 Frequencies of occurrence of failure events of individual plant can be analysed using generic equipment failure data, historical data or assessment of frequencies from similar studies.

Frequency Estimation for Plant Failure

11.2.51 Fault tree analysis is used for deriving failure frequency of hazardous events, **Appendix 11.2.3**. Frequencies for rupture and leak failures of vessels and pipelines are adopted from the latest figures from the TNO Purple Book [6]. Frequency for rupture failure of a naphtha tank, 1×10^{-5} per year, is taken as sum of instantaneous release and 10-min continuous release for a single containment atmospheric tank. Frequency for leak failure of a naphtha tank, 1×10^{-4} per year, refers to continuous 10mm release for a single containment atmospheric tank. Failure frequencies for process area are derived from failure frequencies for process vessels (1×10^{-5} per year and 1×10^{-4} per year for rupture and leak failures) and pipelines (1×10^{-7} per m.year and 5×10^{-7} per m.year for rupture and leak failures).

11.2.52 Frequencies of hazardous events in **Table 11.2.14** are adopted in this study.

Table 11.2.14 Failure frequencies of hazardous events

Material/Location	Event Description	Failure Frequency (per year)
Naphtha Bund Area	Rupture failure of naphtha tank	2.01×10^{-5}
Naphtha Bund Area	Leak failure of naphtha tank	2.01×10^{-4}
Naphtha/Process area	50mm equivalent hole size naphtha spill in the process area	2.51×10^{-5} note a
Naphtha/ process area	25mm equivalent hole size naphtha spill in the process area	2.26×10^{-4} note a
Naphtha/Jetty	Full bore rupture of naphtha loading arm	3.82×10^{-6}
Naphtha/Jetty	20mm leak of naphtha loading arm	3.73×10^{-5}
Naphtha/Jetty	Full bore rupture of naphtha cargo line	1.12×10^{-7}
Naphtha/Jetty	10% leak of naphtha cargo line	1.62×10^{-7}
Towngas/Pipework	Full bore rupture of gas lines before new compressor house	6.16×10^{-6}
Towngas/Pipework	Leak failure of gas lines before new compressor house	3.06×10^{-5}
Towngas/Pipework	Full bore rupture of gas outlets	2.16×10^{-6}
Towngas/Pipework	Leak failure of gas outlets	1.06×10^{-5}
Towngas/Gas Stations	Full bore rupture of gas pipes at offtake/pigging station	9.58×10^{-7}
Towngas/Gas Stations	Leak failure of gas pipes at offtake/pigging station	4.62×10^{-6}
Towngas/Gasholder	Rupture failure of gasholder no.2/4	5.10×10^{-6}
Towngas/Gasholder	200mm leak of gasholder no.2/4	4.07×10^{-5}
Towngas/Gasholder	Blown seal in gas holder (1m equivalent hole)	4.07×10^{-5}

Note a: failure frequency for naphtha spill in process area is for each production train. Utilisation of 4 production trains is assumed in gas production.

Consequence Analysis

General

11.2.53 Both naphtha and Towngas are flammable materials. Possible outcomes are fireball, flash fire, vapour cloud explosion (VCE), jet fire, bund fire and pool fire. Releases from hazardous sources and their consequences have been modelled with the well-established software SAFETI Professional version 6.51.

Source Term Modelling

11.2.54 Towngas is modelled as mixture of hydrogen, methane, carbon dioxide and carbon monoxide. For instantaneous failure, whole content of the gas holder (18 tonnes) is used. In case of continuous release, release parameters such as release rate and exit velocity are calculated by discharge model according to storage conditions. Release duration is based on capacity of the gas holder. Release parameters together with release duration are then fed into dispersion model to calculate the effect.

11.2.55 For pipelines connecting to a gas distribution network, continuous release without shutdown mechanism is assumed. For pipelines connecting to a storage tank, release duration is based on time to empty the whole content.

11.2.56 Naphtha is modelled as a mixture of pentane, hexane and heptane. Pool size is calculated from the following equation when release is not within a bund or the pool size is smaller than the bund area; otherwise pool size is determined by the bund area.

For unconfined continuous release [4],

$$D = (4*Q/(\pi*b))^{0.5}$$

Where D is pool diameter in m
Q is release rate in kg/s
b is burning rate in kg/(m^2.s)

Effect Modelling

11.2.57 The following section briefly describes mathematical models applied to various fire and dense gas dispersion in the consequence model.

11.2.58 Following Probit equations (Thermal radiation [6]) have been used to determine lethal doses for various hazard scenarios.

$$Pr= -36.38 + 2.56 \ln (Q^{1.333} X t)$$

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

11.2.59 The AIChemE (1989) [7] toxic gas dispersion Probit Equation for Carbon Monoxide (CO) shows below is adopted after CO content of 12.1% (volume) in the Towngas mixture has been taken into account.

$$Pr = -45.79 + 3.7 \ln (C X t)$$

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

Gas Dispersion Model

11.2.60 The Unified Dispersion Model (UDM) of SAFETI software without rainout effect has been used for the dispersion of Towngas for non-immediate ignition scenarios. The model takes into account various transition phases, from dense cloud dispersion to buoyant passive gas dispersion, in both instantaneous and continuous releases. Besides, toxic effect has been evaluated using the UDM dispersion model when the cloud reaches population sites for release of town gas without ignition.

11.2.61 Upon release of flammable gas, a number of possible outcomes may be occurred depended on whether the gas is ignited immediately or ignited after a period of time. The dispersion characteristics may be influenced by the meteorological conditions and the material properties, such as density, of the released gas.

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

Fire/Explosive Scenarios

11.2.63 **Fireball** - For immediate ignition of an instantaneous gas release, a fireball will be formed. Fireball is more likely for immediate ignition of instantaneous release from vessels/tankers due to cold catastrophic failure. Instantaneous ignition of a certain mass of fuel (flammable gas) results in explosion and fire of hemispherical shape. Heat is evolved by radiation. The principal hazard of fireball arises from thermal radiation. Due to its intensity, its effects are not significantly influenced by weather, wind direction or source of ignition. Sizes, shape, duration, heat flux and radiation will be determined in the consequence analysis.

11.2.64 **Jet Fire** - A jet fire is typically resulted from ignition of gas from a pressurised containment. The major concern regarding jet fire is the heat radiation effect generated from the fire. The thermal effect to adjacent population will be quantified in the consequence model.

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

11.2.66 **Vapour Cloud Explosion (VCE)** - A vapour cloud explosion can occur when a flammable vapour is ignited in a confined or partially confined situation.

11.2.67 **Pool Fire** - Pool fire is resulted from a release of flammable liquid and subsequent ignited. In a pool fire, an ignited pool of liquid fuel burns in the atmosphere.

11.2.68 **Bund Fire** - A bund fire can be resulted from release of flammable liquid from a tank and contained inside the bund area caused by catastrophic failure, overfilling or pipe failures together with a subsequent ignition of the released fuel. The fire developed will be contained in the bund area.

Risk Assessment

Risk Summation

11.2.69 By combining the population data, meteorological data, results of frequency estimation and consequence analysis, risk levels due to the operation of the MTKGWNP and related gas facilities at 2012, 2016 and 2021 have been characterised in terms of individual risk (presented by individual risk contours) and societal risk (presented by FN curves and Potential of Loss of Life).

11.2.70 The parameter list of the SAFETI programme is attached in **Appendix 11.2.4** of this report.

Individual Risk Contour

11.2.71 With the event frequencies and consequences, the individual risk contours for the study years are produced and presented in **Figure 11.2.7**.

11.2.72 The 10^{-5} per year individual risk contour is located inside the boundary of the MTKGWNP. As advised by HKCG, MTKGWNP is equipped with emergency shut down valves, auto / manual fire alarm systems, gas detection system, fire ring main, hydrant hose reel, automatic sprinkler system, water spray system, base foam injection of oil tank, remote control foam monitor, BTM for DG store, CO2 system for boiler room & electrical switch rooms, siren system. In addition, with implementation of safety management system including emergency plan and procedures, the actual risk to offsite population would be lower. Therefore, the offsite individual risk is considered in compliance with the Risk Guidelines.

11.2.73 For the Naphtha Jetty, the jetty and its surrounding (extending beyond the jetty into the sea) fall into the 10^{-6} per year contour. Besides, the risk of fire hazard at the jetty should only be occurred during naphtha unloading period at mid-night. During this period, no vessel is expected to stay in proximity of the jetty during unloading of Naphtha.

11.2.74 Regarding the risk at the proposed pigging and offtake stations located at the seafront south of the Hoi Sam Park, Individual Risk to the magnitude of 10^{-7} to 10^{-9} per year are determined and is much lower than the 10^{-5} per year criteria at both onsite and offsite locations. Therefore, risk to individual offsite of the gas stations meets the individual risk criteria as stipulated in Annex 4 of the EIAO TM (Offsite Individual Risk criteria is 10^{-5} per year).

Societal Risk – FN Curves

11.2.75 The societal risk results for the Year 2012, 2016 and 2021 are presented in **Figure 11.2.8** in a form of FN curves for comparison with the Government Risk Guidelines.

11.2.76 As shown in **Figure 11.2.8**, it can be seen that most part of the FN curves for all assessment years falls within the "ALARP" region of the criteria. There is no significant increase in risk level throughout the 3 future scenarios.

11.2.77 Breakdown on the Potential Loss of Life for major contributing events is tabulated in **Table 11.2.15**.

Table 11.2.15 Breakdown of PLL ordered by Percentage of Total PLL

Event Description	PLL (per year)	Percentage of Total PLL
Rupture failure of gasholder no.2/4	2.99E-04	40.36
Blown seal in gas holder (1m equivalent hole)	2.90E-04	39.23
Full bore rupture of gas pipes at offtake/pigging station	9.71E-05	13.11
Full bore rupture of gas outlets	4.58E-05	6.19
Leak failure of naphtha tank	4.33E-06	0.58
Leak failure of gas pipes at offtake/pigging station	2.42E-06	0.33
Rupture failure of naphtha tank	1.09E-06	0.15
Leak failure of gas outlets	3.88E-07	0.05
Full bore rupture of naphtha loading arm	3.49E-08	0.00
50mm equivalent hole size naphtha spill in the process area	1.05E-08	0.00
25mm equivalent hole size naphtha spill in the process area	6.94E-09	0.00
Full bore rupture of naphtha cargo line	1.01E-09	0.00
2.01E-100.008.66E-130.007.41E-0420mm leak of naphtha loading arm	2.01E-10	0.00
10% leak of naphtha cargo line	8.66E-13	0.00
Total	**7.40E-04**	**100.00**

Risk Mitigation Measures

11.2.78 When the estimated off-site individual risk level is found to be >1x10^{-5} per year or the societal risk level is found to be at the “ALARP” region, practicable and cost effective risk mitigation measures should be identified and assessed to reduce the risk level for the compliance of the risk guidelines.

11.2.79 Having reviewed operation of the MTKGWNP and the associated gas facilities, event frequencies and population data, the societal risk level is lowered in comparison with the approved EIA Study of SEKD, Fatalities mainly come from nearby existing development while dense population area of Kai Tak Development is located outside of the study area. Besides, relocation of pigging/offtake station by moving away from the 150m consultation zone can further reduce the risk impact on the surrounding population.

Summary

11.2.80 The risk impact from the two existing 400mm submarine pipelines on the Kai Tak Development will be reduced due to the increase in distance between the Kai Tak Development and the future alignment. The level of risk in terms of Individual Risks and the FN curves determined from the risk summation process has been compared with the criteria stipulated in Annex 4 of the TM. The individual risk is in compliance with the TM. Although societal risk falls into the ALARP region, the risk level is found to be lower than the approved EIA Study of SEKD. In the Kai Tak Development project, practicable measures have been considered to ensure that risk level can be reduced as low as practicable for meeting requirements stipulated in the Hong Kong Risk Guidelines.

Reference

[1] Major Hazard Incidents Data Service (MHIDAS), AEA Technology

[2] Approved EIA Report "Proposed Headquarters and Bus Maintenance Depot in Chai Wan" (EIA-060/2001).

[3] Kathleen J. Tierney, Preliminary Paper #152 "Risk of Hazardous Materials Release Following an Earthquake", University of Delaware, Disaster Research Centre, 1990

[4] EIA Report for Liquefied Natural Gas (LNG) Receiving Terminal and Associated Facilities

[5] The Calculation of Aircraft Crash Risk in the UK, HSE, 1997.

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

[7] AIChemE 1989, Guidelines for Chemical Process Quantitative Risk Analysis

11.3 Hazard assessment for the existing Kwun Tong DG Vehicular Ferry Pier (DGVFP)

Introduction

11.3.1 The DGVFP is located at Kwun Tong opposite to the south end of runway, **Figure 11.3.1**. It provides one of a few transit points for delivery of Dangerous Goods (DGs) to Hong Kong Island while vehicles carrying DGs are banned from using any vehicular tunnels or cross-harbour tunnels under the law of Hong Kong, Road Tunnels (Government) Regulations (Cap 368A).

11.3.2 In accordance with the EIA study brief (ESB-152/2006), a hazard assessment is required to carry out to evaluate the risk to future occupants due to operations the Kwun Tong DG Vehicular Ferry Pier. This section of the report outlines the details of assessing the risk to future occupants of the development.

Assessment Approach

General

11.3.3 The hazard assessment will consist of the following tasks:

1. ***Data / Information Collection****:* collects relevant data / information which is necessary for the hazard assessment.
2. ***Hazard Identification****:* identifies hazards associated with operation of the DGVFP to future occupants of Kai Tak Development.

3. ***Frequency Assessment****:* assess the likelihood of occurrence of the identified hazardous scenarios by reviewing historical accident data, previous studies or using Fault Tree Analysis. Event Tree Analysis, which is already built into the SAFETI package (v6.51), is adopted to determine the possible outcome from the identified hazardous events and to estimate their respective occurrence frequencies.
4. ***Consequence Assessment****:* the consequences are established for every outcome developed from initial event by using ***PHAST*** consequence model to assess the impacts from gas leaks, fires, explosions, toxicity and other process hazards.
5. ***Risk Assessment****:* evaluates the risks level, in terms of individual risk and societal risk, associated with the identified hazardous scenarios. The overall risk level is compared with the criteria as stipulated in Annex 4 of the TM to determine their acceptability. Mitigation measures will be identified where the risk is considered in the ALARP (As Low As Reasonably Practicable) region or above. The reduction in risk achievable by these means will then be quantified.
6. ***Recommendation of Safety Measures****:* Upon completion of the risk assessment, mitigation measures may be identified to reduce risk to future occupants.

11.3.4 The hazard assessment would cover three (3) future scenarios:

- Construction phase (year 2012 scenario) - The first berth of the Cruise Terminal is commissioned. It assesses risk impact to the planned population and peak construction workforce level in year 2012 due to the DGVFP. Construction activities pose potential damage to the facilities will be addressed and accounted for in the assessment.

- Operation phase (year 2016 scenario) – It assesses risk impact to the overall population including the second phase of population intake of KTD population in year 2016 due to the DGVFP during operation phase.

- Ultimate scenario (year 2021 scenario) – It assesses risk impact to the overall population including the third phase of population intake of KTD population in year 2021 due to the DGVFP during operation phase.

Data / Information Collection

General

11.3.5 Data / information presented in the approved EIA study of "Comprehensive Feasibility Study for the Revised Scheme of South East Kowloon Development" (Agreement No. CE32/99) (SEKD) were reviewed and adopted as appropriate. The following relevant data / information were collected:

- Details of the DGVFP
- Population
- Meteorological data
- Source of Ignition
- Construction and Operation Activities

Details of DGVFP

11.3.6 The DGVFP is operated by The Hongkong & Yaumati Ferry Co. Ltd. (HYFCO). The pier is accessible from Kei Yip Street and vehicles leave the pier via Hoi Bun Road. Once a DG vehicle has entered the pier area, the driver is asked to park at a designated parking slot and wait for boarding. While the vehicle is waiting for a ferry, an inspector of the pier records vehicle registration number, number of persons on vehicle and category of dangerous goods on vehicle. Once registration has completed, the inspector carries out visual inspection to check if the vehicle and associated facilities are in normal condition and ensure no leakage of gas or liquid. If the vehicle passes the visual inspection, the inspector issues a ticket according to the weight and length of the vehicle.

11.3.7 On arrival of DG Ferry, the inspector will arrange the onboard vehicle depart first and then the vehicles waiting in the waiting area will be instructed for boarding.

11.3.8 The pier operator imposes certain measures to ensure a safety operation of the pier including no naked fire and smoking within the pier area, regular fire drill and emergency plan. Besides, no parking is allowed within the pier area except approved vehicles and vehicles of the operator. Dedicated parking areas with markings are assigned to different categories (Cat 1, 2 and 5) of DG vehicle.

11.3.9 For Category 1 DGs, specific vessel operation guideline should be followed during loading and unloading operations. This included the procedures to switch off all radar and radio to eliminate the risk of disturbance of electromagnetic wave.

11.3.10 At presence, portions of lower deck and upper deck of the DGVFP has been designated as a driving school. The driving school is currently operated by the Kwun Tong Driving School with opening hours between 09:00 and 23:30.

11.3.11 The operator currently scheduled 20 daily transits from both Kwun Tong and North Point in which 2 transits are optional and are available on demand. Journey time is about 12 minutes.

11.3.12 Based on information provided by ferry operator and government departments, average utilization of the DGVFP is estimated with breakdown by DGs onboard. Details of the delivery frequencies are documented in **Appendix 11.3.2** of this report. As neither quantity per delivery nor destination can be obtained for hydrocarbon deliveries, it is assumed that all vehicles are loaded to either maximum capacity or maximum quantity quoted from information sources for a more conservative assessment.

Population

11.3.13 Residential, employment population and transient population (land and marine) in the proximity of the DGVFP has been estimated based on the data from the 2003-based Territorial Population and Employment Data Matrix (TPEDM) provided by the Planning Department. Population for Kwun Tong Driving School, which is located at upper deck of the DGVFP, and pedestrian at the nearby waterfront are estimated based on onsite survey. Traffic population along nearby streets including Hoi Bun Road, Kei Yip Street, Tsun Yip Street and Kwun Tong Bypass are estimated from Annual Traffic Census by Transport Department. A monorail system connecting the South Apron the Kwun Tong Station is planned after year 2021. Transient population for the monorail system has been accounted for in the ultimate scenario.

11.3.14 The population groups assessed for Year 2012, 2016 and 2021 are detailed in **Appendix 11.3.1**. The locations of the population groups are presented in **Figure 11.3.2**.

Assumption of Population Distributions

11.3.15 The outdoor population will be calculated by applying an outdoor ratio to each population group as mentioned in previous section. **Table 11.3.1** summarises the indoor/outdoor ratio for different population categories. For open space area, population will be estimated based on observation of other open space with similar nature when data is not available.

Table 11.3.1 Indoor/Outdoor Ratio for Different Population Categories

Population Category	Indoor (Outdoor) Ratio
Residential	0.95 (0.05)
School	0.95 (0.05)
Park	0.00 (1.00)
Road	0.00 (1.00)
Railway/Bus station	0.00 (1.00)
Marine	0.00 (1.00)

11.3.16 In order to reflect temporal distribution of population, time period is divided into 4 time modes namely daytime and night-time for both weekend and weekday. In general, assumption of temporal variation in population for different population categories is tabulated in **Table 11.3.2.**

Table 11.3.2 Temporal Changes in Population for Various Categories

Time period	Residential Dwellings	Shopping Centre	Industrial/Commercial Buildings
Weekday (day)	50%	50%	100%
Weekday (night)	100%	0%	10%
Weekend (day)	70%	100%	40%
Weekend (night)	100%	0%	5%

Meteorological Data

11.3.17 Meteorological data for year 2006 from Kai Tak Anemometer Station of the Hong Kong Observatory has been used for the assessment. Details of dominant sets of wind speed-stability class combination both daytime (**Table 11.2.4**) and night-time (**Table 11.2.5**) given in Section 11.2.23 of this report.

Source of Ignition

11.3.18 The presence of ignition sources in the study area is primary concern in case of flammable gas release. Ignition sources other than onsite one, such as dwellings and vehicles along carriageways, contribute to delayed ignition in VCE and flash fire. The energy level, timing, location of ignition sources in the vicinity of the DGVFP and hence the probability of ignition of gas cloud will be reviewed and assessed.

11.3.19 Major ignition source is the surrounding road network. Traffic volume, travelling speed (speed limit) and length of a road are used to calculate the presence time.

Construction works near DGVFP

11.3.20 A technically feasible option to provide a link for 3 modes of transportation has been identified. A steel double deck bridge, with an upper deck level of 44mPD, is proposed to connect the runway tip to the Kwun Tong Area between the DGVFP and the Kwun Tong Public Transportation Interchange (PTI). The general layout of the transportation link is given in **Figure 11.3.3** of this report. The facilities to be constructed are listed below.

- Link Bridge;
- Lift Tower;
- Ramp for vehicle to Kwun Tong PTI; and
- Station and depot for Environmental Friendly Transportation System (EFTS), such as monorail.

Hazard Identification

Hazardous Source – Dangerous Goods

11.3.21 According to information provided by the pier operator and other government departments, such as WSD, road tankers, cylinder wagons and trucks with Cat.1, 2 and 5 DGs are currently using the ferry services. To enable further assessment, hazardous substances involving in the operation of the DGVFP are classified into 4 types based on flammability and toxicity.

Explosives (Cat.1 DG)

11.3.22 Category 1 Dangerous Goods includes Blasting Explosives, such as blasting agents, detonators, and Explosive for Industrial and other uses (Non-blasting).

11.3.23 The control on the classification, manufacture, storage, conveyance on land, use and destruction of explosives in Hong Kong is under the Dangerous Goods Ordinance (Cap. 295). The control is more stringent than that in many advanced countries such as the United Kingdom, the United States, Canada and Australia, due to the dense population in Hong Kong.

11.3.24 The SAR Government is directly involved in carrying out storage and transportation of almost all explosives. The Explosives Delivery Unit of the Mines and Quarries Division of CEDD controls the delivery of explosives. Specially made vehicles with specially trained Explosives Supervisors, car attendants and drivers, under stringent supervision, are responsible for explosive delivery.

11.3.25 All blasting explosive deliver via the Kwun Tong DGVFP must use CEDD's delivery services except those owned by the Hong Kong Police Force or other disciplinary force of the HKSAR government. Some Cat.1 explosive are not transported by CEDD, such as non-blasting explosives transported by commercial companies such as gun clubs.

11.3.26 As advised by Mines Division of CEDD, the department did not use the Kwun Tong DGVFP. However, there may have the possibility to use the pier to deliver explosives 2200 kg (Net Explosives Quantity (NEQ)) per day to Hong Kong Island after year 2008 and an estimation of explosive transport is given as below. These will be used to estimate the risk of Cat.1 DGs transportation using the pier.

Table 11.3.4 Estimation of Category 1 DG transportation using the DGVFP

Type of Cat.1 DGs	Max. Loading per truck	Max. Qty per Ferry	Max. Ferry transit per day	Max. Ferry transit per yr.
Cartridge explosive, Booster, Detonating Cords, Detonators (delivered by disciplinary forces of the HKSAR government)	200 kg (NEQ)	200 kg (NEQ)	2	Less than 50
Cartridge explosive, Booster, Detonating Cords, Detonators (delivered by CEDD)	800 kg (NEQ) Note A	800 kg (NEQ)	3	936 Note B

*Note: NEQ – Net Explosive Quantity.
Operation hours from 7am to 7 pm.
*Note A: (quantity of explosive to be delivered per day) / (max. ferry transit per day) = (2200)/(3) ≈ 800kg
*Note B: (no. of transits per day) * (no. of days per week having delivery) * (no. of weeks per year) = 3*6*52=936

11.3.27 To ensure safety of transportation, explosives and detonators should not be carried on the same vehicle to prevent explosives being detonated accidentally.

LPG

11.3.28 LPG found in Hong Kong is usually a mixture of 30% propane and 70% butane by mass. It is stored as pressurised liquid under ambient temperature and is highly flammable. It is transported over the territory by road tankers or cylinder wagons. Road tankers with capacity between 7 and 9 tonnes are normally used in Hong Kong. Sizes of LPG cylinder varies from 2kg to 50kg are delivered by licensed cylinder wagons. Lower Flammability Limit and Upper Flammability Limit are 2% and 9% by volume respectively.

Chlorine (Cat.2 DG)

11.3.29 Chlorine is stored under ambient temperature in saturated liquid form. 1-tonne drum and 50kg cylinder are currently used for storage and local transport. Chlorine gas is light greenish-yellow gas with an irritating odour. Chlorine is toxic by inhalation, ingestion and through skin contact. Inhalation can cause serious lung damage and may be fatal.

11.3.30 As proposed by WSD, after the relocation of the Chlorine Dock, Kwun Tong DGVFP will not be used to deliver chlorine to the Silvermine Bay WTW. However, a fallback plan is adopted in this assessment in case the proposal of using road transportation is not approved. As Silvermine Bay WTW will be converted for using chlorine cylinders, chlorine delivery to the Silvermine Bay WTW by 50-kg chlorine cylinders is assumed. Therefore, chlorine cylinders delivery to WTWs in Hong Kong Island and Silvermine Bay WTW via Kwun Tong DGVFP is considered in this study.

Fuel Oil (Cat.5 DG)

11.3.31 Diesel, petrol and kerosene are under the Cat. 5 DG. However, petrol is highly flammable among the other two with lowest flashing point -40^{o}C. With flash point well below ambient temperature, petrol forms explosive air/vapour mixture in spillage or leakage. Although diesel and kerosene are also flammable, they have relatively high flashing points, typically >66^{o}C and 38^{o}C respectively, and are ignited only being heated above the flashing points or open flame.

Others

11.3.32 This type of DG, such as paint, has high flashing point and boiling point. Although substances of this type give off inflammable vapour, the quantity is considered to be significantly less than petrol and kerosene.

Review of MHIDAS database

11.3.33 A review on the Major Hazard Incident Data Services (MHIDAS) database [1] of the relevant historical incidents of the same genus to DGVFP is conducted to confirm if the hazardous scenarios identified are acceptable.

Explosive (Cat.1 DG)

11.3.34 There are total 84 incidents relevant to road transport of explosive in the MHIDAS database. Hazardous materials including ammonium nitrate, blasting caps, detonators, dynamite, ammunition, gunpowder, fireworks and general explosives, were involved. Accidents led to 29 spillage/leakage only incidents, 29 explosion incidents and 2 fire incidents.

LPG

11.3.35 There are total 62 incidents relevant to road transport of LPG in the MHIDAS database. 5 incidents associate with LPG cylinders and the rest relates to LPG road tankers. Incidents led to 10 release only incidents, 18 fire incidents, 24 explosion incidents, 4 BLEVE and 10 flash-fire incidents.

11.3.36 A local incident is found from the MHIDAS database. In 1992, a kerosene truck was set on fire in Tuen Mun. There were cans on truck exploded setting off explosions in other lorry loaded with small cylinders of LPG. Fireballs blew out windows and affected 23 vehicles.

Fuel Oil (Cat.5 DG)

11.3.37 MHIDAS database records 121 diesel road transport incidents which include 96 release only incidents, 11 fire incidents and 9 explosion incidents. Total number of 308 incidents for gasoline road traffic is found. They include 143 release only incidents, 83 fire incidents, 73 fireball explosion incidents and 1 flash-fire incidents.

11.3.38 Total 32 records are found relevant to road transport of kerosene in which 26 incidents are release only, 2 each for fire incidents and fireball explosion incidents.

Chlorine (Cat.2 DG)

11.3.39 Total 29 records are found relevant to road transport of chlorine in which 24 incidents are release only. 2 incidents involved external fire accidents.

11.3.40 From MHIDAS database, only 1 local accident is retrieved. The road accident occurred in 1990 with two men injured was a lorry loaded with six canisters Chlorine over-turned in Shek Kong and one canister fell from vehicle without release. It was believed to be related to brake failure.

11.3.41 Further researching of local DGs transportation accident statistics data in public domain has been conducted. No specific register of accidents related to DGs transportation is identified.

11.3.42 Due to limitation of local accident data can be found, incidents related to road transport happened in US are extracted for analysis. There are totally 326 entries corresponding to 317 incidents in the MHIDAS database fulfills our criteria with incident data occurring between 1938 and 2005. Some of the incidents involving several hazardous materials are represented by more than one entry. **Table 11.3.5** presents the numbers of accidents related to different material transport.

Table 11.3.5 Accidents Distribution of DG transportations in US from MHIDAS

Accident Type	Number of Accidents in US	Percentage %
Fireworks	3	1
Chlorine	13	4
LPG	42	13
Hydrocarbon (Gasoline and Diesel)	268	82
Total:	**326**	**100**

11.3.43 Other sources of information related to DGs transportation study have been reviewed. A comprehensive review of LPG road and transport accidents worldwide was conducted and reported in a study paper [2]. In this study, it was identified that there have been several incidents involving DGs on large ocean-going Ro-Ro ferries and no cases are known of accidents on ferries affecting third parties.

Number of Vehicular Movement within DGVFP

11.3.44 The number of vehicular movement within DGVFP for future scenarios have been projected from the current average utilisation according to change in population within the territory. Other factors such as consumptions of fuel, import data has been considered.

Hazardous Events

11.3.45 Hazardous events involving the DGVFP are classified into 2 types, transportation and stationary. The first type is due to movement of DG vehicles along access road within the pier area. The second type is due to DG vehicles waiting at queue area for boarding or departure. Layout of the DGVFP showing queue area can be found on **Figure 11.3.4**.

Transport Risk

11.3.46 Failure events identified are tabulated in **Table 11.3.6.** Events for LPG and Petrol/Diesel have also been selected in the approved EIA study of SEKD [3].

Table 11.3.6 Failure Events for Transport Risk Cat.1, Cat.2 and Cat.5 DG

Material	**Vehicle Type**	**Hazardous Event Description**
Cartridge explosive	Explosive Delivery Truck	Fire/Explosion
LPG	Road tanker	BLEVE *
LPG	Road tanker	Cold rupture
LPG	Road tanker	Large (50mm) leak (liquid)
LPG	Road tanker	Large (50mm) leak (vapour)

Material	Vehicle Type	Hazardous Event Description
LPG	Road tanker	Medium (25mm) leak (liquid)
LPG	Cylinder Wagon	Multiple BLEVE
LPG	Cylinder Wagon	Rupture
Petrol/Diesel	Road tanker	Medium (25mm) spill/leak (liquid)
Petrol/Diesel	Road tanker	Large (100mm) spill/leak (liquid)
Petrol/Diesel	Road tanker	Fireball explosion
Petrol/Diesel	Road tanker	Fire
Chlorine	Cylinder / drum truck	Medium (7.5mm) leak (liquid)
Chlorine	Cylinder / drum truck	Medium (7.5mm) leak (vapour)
Chlorine	Cylinder / drum truck	Rupture

Note: *BLEVE : Boiling Liquid Expanding Vapour Explosion

11.3.47 However, severe traffic accident leading to loss of containment is not considered possible while speed control is imposed within the DGVFP. Moreover, this study is different from the approved EIA study of SEKD and does not involve change of delivery route for relocation of the DGVFP. Road transport risk is not assessed further in this study.

Stationary Risk

11.3.48 As failure events for the stationary risk involve the same vehicle types as in transport risk, events for transport risk are also applied. Apart from those events, hazards associated with the DGVFP are tabulated in **Table 11.3.7**.

Table 11.3.7 Hazards Associate with DG vehicles Waiting at Queue Area

Hazard event	Potential Cause
Spontaneous failure	• LPG/Petrol/Diesel Road Tanker failures • LPG cylinder failures • Chlorine drum/cylinder failure
External event	• Earthquake • Car crash • Dropped object • Collapse and strike by object • Aircrafts crash
Escalation	• BLEVE/fireball/explosion due to fire initiated by other DG vehicles • Collapse of building/structure due to detonation of explosives

11.3.49 In Hong Kong, buildings and infrastructures are designed to withstand earthquakes up to Modified Mercali Intensity (MMI) VII. It is estimated that MMI VIII is required to provide sufficient intensity to result in damage to specially designed structure. The DGVFP is a single storey structure and made of reinforced concrete. It is sufficient strong to withstand forces generated by earthquake. Thus, the probability of building failure in earthquake is assumed 0.01[4][5]. The probability of earthquake occurrence at MMI VIII and higher is very low comparing with other places and is estimated to be 1.0×10^{-5} per year [6]. There are total 11 parking slots and 3 of them are fully or partially underneath concrete cover. Besides, probability of a DG vehicle being hit by debris is assumed 0.5. Hence, frequency of a DG vehicle being damaged in an earthquake is calculated as 1.35×10^{-8} per year. Earthquake damage is considered for all failure events.

11.3.50 The DGVFP is fenced off by boundary wall and is protected by the upper deck from dropped object. While speed control is imposed within the DGVFP and dedicated parking slot is assigned to queuing vehicles, car impact at low speed does not lead to loss of containment. Dropped object and car crash are not further assessed in this study. The frequency for aircraft crash has been addressed for the MTKGWNP, the calculated accident rates are much smaller than order of 10^{-9}, aircraft crash causing failure of DG vehicles within the DGVFP is not considered further in the assessment.

Knock-on Effect

11.3.51 Schedule for delivery of explosives can be arranged with the DGVFP such that there is no vehicle of other DG categories waiting within the premise. Thus, there is no knock-on effect of an explosives delivery truck to other DG vehicles except other queuing explosives delivery trucks. Similarly, knock-on effect of other DG vehicles is not applicable to explosives delivery trucks. Since BLEVE and fireball explosion happen in very short period of time, there is insufficient time for evacuation. Loss of containment of other queuing DG vehicles is resulted. However, drivers may have sufficient time for evacuation in other incidents such as LPG leak and petrol/diesel spill depending on whether a leak/spill is ignited. In case of LPG leak and petrol/diesel spill, probability of ignition 0.05 [7] and probability of driver failed to drive away with DG vehicles 0.1 [8] are assumed. In rupture cases, probability of ignition 0.9 [7] and driver failed to drive away with DG vehicles are assumed. Event failure frequencies are modified to account for this knock-on effect, **Appendix 11.3.3**.

Construction Hazard to DGVFP

11.3.52 Construction Hazards with potential impact to the DGVFP have been preliminarily identified. However, there is a minimum separation distance of 250m from the KTD worksite at the Kai Tak Runway to the pier, hence there will be no hazard to the pier caused by the construction works of the core development such as cruise terminal.

11.3.53 However, construction of link bridge and monorail system may have following potential hazards,

- Fire hazard caused by accidents involving hot works at construction site;
- Flying objects projected from construction site;
- Damage to DG vehicles due to overturn of mobile crane / crashes of mobilising equipment (e.g. backhoe, bulldozer, dump truck, site vehicle etc) used in construction phase.

11.3.54 Use of hoarding and solid fence wall can prevent damage to DG vehicles within the DGVFP from fire and flying objects caused by construction works. By better coordination with the DGVFP operator, arrangement of work schedule and using of pre-fabricated modules, construction works involving high risk processes can be carried out when the DGVFP is not occupied by DG vehicles. Besides, upper deck of the DGVFP provides shielding protection to DG vehicles. Since damage to DG vehicles can be avoided during construction phase of link bridge and monorail system, construction hazard is not further assessed in this study.

Frequency Estimation

11.3.55 There is no tracked record on accident or spillage incident within the DGVFP area according to the pier operator. Statistics on traffic accidents between year 2002 and 2006 have been reviewed [9]. Frequency for fatal traffic accident involving medium and heavy goods vehicles (MGV & HGV) 9.56x10^{-7} per veh.yr is derived from average of annual traffic accident rate between 2002 and 2006. The annual traffic accident rate is calculated from formula {[(number of traffic fatal accidents involving MGV/HGV) / [(number of registered MGV/HGV) * (number of trips per vehicle in a year)] * [(number of fatal traffic accidents) / (number of traffic accidents involving injury)]) where number of trips per vehicle in a year is assumed 300. On the other hand, the sum of likelihood for failure of LPG road tanker/cylinder wagon, petrol and diesel road tanker as adopted in the approved EIA study of SEKD is 7.17x10^{-6} per veh.yr [3]. By comparing these 2 figures, the latter one is considered more conservative and is adopted in this study.

11.3.56 Frequency for explosives truck failure is derived from frequency for mass detonation of explosive magazine (1x10^{-5} per year) [10]. With respect to stationary risk, time for vehicles staying inside the DGVFP waiting area, external events and escalation have been considered in deriving of the frequencies of hazardous events. **Table 11.3.8** lists out failure event frequencies and details of calculation are given in **Appendix 11.3.3**.

Table 11.3.8 Frequency for Failure Events of Stationary Risk

Material	Vehicle Type	Release Description	Frequency (/yr)
Explosive	Explosive Truck	Fire/Explosion (200kg)	2.79E-08
Explosive	Explosive Truck	Fire/Explosion (800kg)	4.67E-07
LPG	Road tanker	BLEVE	3.16E-08
LPG	Road tanker	Cold rupture	4.68E-08
LPG	Road tanker	Large (50mm) leak (liquid)	4.53E-08
LPG	Road tanker	Large (50mm) leak (vapour)	4.53E-08
LPG	Road tanker	Medium (25mm) leak (liquid)	4.53E-08
LPG	Cylinder Wagon	Multiple BLEVE	3.16E-08
LPG	Cylinder Wagon	Rupture	2.63E-06
Petrol	Road tanker	Medium (25mm) leak (liquid)	4.33E-08
Petrol	Road tanker	Large (100mm) leak (liquid)	4.33E-08
Petrol	Road tanker	Fireball explosion	3.01E-08
Petrol	Road tanker	Fire	4.47E-08
Diesel	Road tanker	Medium (25mm) leak (liquid)	4.33E-08
Diesel	Road tanker	Large (100mm) leak (liquid)	4.33E-08
Diesel	Road tanker	Fireball explosion	3.01E-08

Material	Vehicle Type	Release Description	Frequency (/yr)
Diesel	Road tanker	Fire	4.47E-08
Chlorine	Cylinder truck	Medium (7.5mm) leak (liquid) (WTWs in HK)	6.52E-08
Chlorine	Cylinder truck	Medium (7.5mm) leak (vapour) (WTWs in HK)	7.29E-09
Chlorine	Cylinder truck	Rupture (WTWs in HK Island)	7.86E-09
Chlorine	Cylinder truck	Medium (7.5mm) leak (liquid) (SMB WTW)	4.07E-08
Chlorine	Cylinder truck	Medium (7.5mm) leak (vapour) (SMB WTW)	4.55E-09
Chlorine	Cylinder truck	Rupture (SMB WTW)	4.91E-09

Consequence Analysis

11.3.57 Releases from hazardous sources and their consequences have been modelled with the well-established software SAFETI version 6.51. The software calculates individual consequence, such as fireball and flash fire, using its built-in event trees depending on probability of ignition and release conditions. Description of individual consequence model is given in the following paragraphs and hazard distances for representative cases are presented in **Appendix 11.3.5**.

Source Term Modelling

11.3.58 Chlorine is modelled as 50-kg cylinder. Except chlorine, DGs involving in this study are mixtures of hydrocarbons and chemicals. To enable the assessment, simple mixtures or representative component will be used for the risk model building. Assumptions are made as follows:

- LPG is modelled as mixture of propane and n-butane in 30:70 ratios by mass.
- Petrol and diesel/kerosene – are modelled as mixture of low molecular weight hydrocarbons (C5 to C10).

11.3.59 For continuous release, release duration is based on time to empty the whole content of tank/cylinder.

11.3.60 Explosives are assumed packaged emulsion type. TNT equivalence factor of 61% is applied for converting to TNT equivalent mass in effect modelling.

Effect Modelling

11.3.61 The following section briefly describes mathematical models applied to various fire and dense gas dispersion in the consequence model.

11.3.62 Following Probit equations will be used to determine lethal doses for various hazard scenarios.

Thermal radiation (TNO) [10]

$$Pr = -36.38 + 2.56 \ln(Q^{1.333} \times t)$$

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

Toxicity for chlorine (TNO, 1992) [11]

$$Pr = -14.3 + \ln(C^{2.3} X t)$$

where C is concentration in mg/m^3 and t is exposure time in minutes

Gas Dispersion

11.3.63 The Unified Dispersion Model (UDM), without rainout effect, of the SAFETI software has been used for the dispersion in non-immediate ignition scenarios. The model takes into account various transition phases, from dense cloud dispersion to buoyant passive gas dispersion, in both instantaneous and continuous releases. Besides, toxic effect has been evaluated using the UDM dispersion model when the cloud reaches population sites for release of gas without ignition.

11.3.64 Upon release of flammable gas, a number of possible outcomes may be occurred depended on whether the gas is ignited immediately or ignited after a period of time. The dispersion characteristics will be influenced by the meteorological conditions and the material properties, such as density, of the released gas.

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

11.3.66 For Chlorine dispersion, cloud height for of gas release has been considered and assessed.

Fireball

11.3.67 For immediate ignition of an instantaneous gas release, a fireball will be formed. Fireball is more likely for immediate ignition of instantaneous release from vessels/tankers due to cold catastrophic failure. Instantaneous ignition of a certain mass of fuel (flammable gas/LPG) results in explosion and fire of hemispherical shape. Heat is evolved by radiation. The principal hazard of fireball arises from thermal radiation. Due to its intensity, its effects are not significantly influenced by weather, wind direction or source of ignition. Sizes, shape, duration, heat flux and radiation will be determined in the consequence analysis.

11.3.68 Although a fireball affects dwellings which have direct line of sight to it, shielding factor is not applied to buildings within the study area for conservative results.

BLEVE

11.3.69 A Boiling Liquid Expanding Vapour Explosion (BLEVE) is a sudden rupture due to fire impingement of a vessel, LPG tanks on road tankers or cylinders on LPG wagons, containing liquefied flammable gas under pressure, which results in a fireball as the flashing liquid ignited. For LPG cylinders transport by wagon, cylinders are placed closely with each other or in stacks in the cargo bay. It is possible that multiple cylinders fail at the same time due to cylinder wall weakening and high pressure built up inside the cylinder after the cylinder wagon has been engulfed in fire with flame spreading to the cargo bay.

Jet Fire

11.3.70 A jet fire is typically resulted from ignition of gas/liquid from a pressurised containment. The major concern regarding jet fire is the heat radiation effect generated from the fire. The thermal effect to adjacent population will be quantified in the consequence model.

Flash Fire

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

Vapour Cloud Explosion (VCE)

11.3.72 A vapour cloud explosion can occur when a flammable vapour is ignited in a confined or partially confined situation. TNO vapour cloud explosion correlation is used for calculating the consequences of an explosion. The early explosion occurs at the release source and is the most common for instantaneous releases. The late explosions occurs at downstream of releases. The model calculates early and late explosions according to ignition probability. TNT Multi-Energy model is used for detailed consequence analysis which accounts for confinement effect by specifying confined strength and confined volume.

Blasting Effect (Explosives)

11.3.73 Several levels of impacts to people may be anticipated due to blasting effects. Sensitive human organs, such as lung and ear, may be directly impacted. Further blasting injuries of human such as displacement of whole body may lead to extensive damage of internal organs by shock wave of explosion. People in the proximity of explosion may also be injured by the collapse of the nearby structures or by the fragment from the containers of the explosive in case of a massive explosion.

11.3.74 To estimate the effect to human due to explosion of explosive, the affected distance of overpressure and heat radiation have been calculated.

11.3.75 Sizes of the fireball and thermal radiation have been modelled based on the Fire Ball Model by Prank P. Lees [12]. The overpressure and the respective probability of fatality have been modelled based on ESTC Blast model of HSE [13]. Building collapse model proposed by Gilbert, Lees and Scilly [8] is adopted for calculating indoor fatality due to building collapse. **Table 11.3.9** summarise the result of the analysis.

Fireball model [12]

$r = 1.75 * M(1/.3)$

where r is fireball radius of in m
M is mass of TNT explosive in kg

$E = F_r * Q_c / A_f$

$t = 0.3 * M^{(1/3)}$

where E = surface emissive power (kW/m2)
F_r = fraction of heat radiated, typical value 0.4
A_f = surface area of fireball (m^2)
Q_c = total heat release rate (kW)
t = duration of fireball (s)

$I = E * t_a * (r/L)^2$

where I = thermal radiation intensity (kW/m^2)
t_a = transmissivity, 0.75 for 70% humidity
L = distance from centre of fireball (m)

Probit equation for thermal radiation of the fireball,

$Y = -14.9 + 2.56 * \ln(t * I^{(4/3)})$

ESTC Outdoor Blast model [13]

Lo = e^[-5.785*S + 19.047] / 100

For S ≤ 2.5, Lo = 1
S ≥ 5.3, Lo = 0

where Lo is the probability of death for population outdoors
$S = R/(M^{1/3})$
R is distance from blast (m)
M is mass of TNT explosive (kg)

Building Collapse model [8]

d = k * M(1/3)/ [1 + (3175 / M)2](1/6)

where

d is distance from explosion source in m
M is mass of TNT explosive in kg
K is a constant and varies according to level of damage
Values of K 4.8, 7.1 and 12.4 represent probability of fatality 0.62, 0.086 and 0.009 respectively.

Table 11.3.9 Overpressure, Fireball and Building Collapse Hazard Distances

Quantity of Explosive (NEQ/TNT equivalent)	Consequence	Hazard Distance, radius (m)	Probability of Fatality
200 kg / 122 kg	Overpressure	13	0.62
	Overpressure	15	0.086
	Overpressure	16	0.009
	Fireball	9	1
	Fireball	10	0.62
	Fireball	13	0.086
	Fireball	15	0.009
	Building Collapse	8	0.62
	Building Collapse	12	0.086
	Building Collapse	21	0.009
800 kg / 478 kg	Overpressure	20	0.62
	Overpressure	23	0.086
	Overpressure	26	0.009
	Fireball	14	1
	Fireball	20	0.62
	Fireball	25	0.086

Quantity of Explosive (NEQ/TNT equivalent)	Consequence	Hazard Distance, radius (m)	Probability of Fatality
	Fireball	29	0.009
	Building Collapse	20	0.62
	Building Collapse	30	0.086
	Building Collapse	52	0.009

11.3.76 Although neither nearby building nor the proposed monorail system falls into hazard zones for building collapse from the above assessment, the DGVFP itself may collapse or partially collapse in an explosion. This knock-on effect has been taken into account when derivation of event frequencies for other DG vehicles. Besides, population at the driving school, waterfront and small section of Kei Yip Street, Hoi Bun Road and Kwun Tong Bypass would be affected by overpressure and fireball.

Risk Assessment

Risk Summation

11.3.77 By combining the population data, meteorological data, results of frequency estimation and consequence analysis, risk levels due to the operation of the DGVFP at 2012, 2016 and 2021 have been characterised in terms of individual risk (presented by individual risk contours) and societal risk (presented by FN curves).

Individual Risk Contour

11.3.78 With the event frequencies and consequences, the individual risk contours for the study years are produced and presented in **Figure 11.3.5**.

11.3.79 The maximum Individual Risk level is calculated to be 10^{-6} per year as indicated in the **Figure 11.3.5**.

11.3.80 The offsite individual risk is found to be 10^{-7} per year which is considered acceptable in comparison with the Risk Guidelines (1×10^{-5} / year i.e. 1 in 100,000 per year).

Societal Risk – FN Curves

11.3.81 The societal risk results for the Year 2012, 2016 and 2021 are presented in **Figure 11.3.6** in a form of FN curves for comparison with the Government Risk Guidelines stipulated in Annex 4 of the TM.

11.3.82 From the FN Curves, it is demonstrated that the societal risk level is acceptable since all FN curves for the assessment years are located within the “acceptable” region of the criteria and hence the societal risk to future occupant of the project is considered acceptable. Therefore, no mitigation measure is required.

Summary

11.3.83 The level of risk in terms of Individual Risks and the FN curves determined from the risk summation process has been compared with the criteria stipulated in Annex 4 of the TM and confirmed acceptable.

<u>Reference</u>

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11.4 Hazard assessment for the existing Kerry DG Warehouse

<u>Introduction</u>

11.4.1 The Kerry DG Godown (Kowloon Bay) is located at 7 Kai Hing Road, which is a 6-storey high warehouse providing storage services for dangerous goods. The DG Godown is within the Kai Tak Development (KTD), and in accordance to the Brief and the EIA Study Brief (ESB-152/2006) of the Project, hazard assessment is required to evaluate the risk of the DG Godown on the proposed KTD, in particular the Tourism Leisure Hub and the Cruise Terminal.

11.4.2 Under the approved Outline Zoning Plan, the site of the Kerry DG Godown will be changed to commercial use, in other words, the Godown will be decommissioned in the long term. There is a recent planning application submitted by the owner of the Kerry DG Godown for a landing step at the sea frontage of the site for future development. The application has been approved by the Town Planning Board and this is a strong indication of the owner's intention to re-develop the site as per the Outline Zoning Plan.

Assessment Approach

11.4.3 The hazard assessment consists of the following tasks:

1. *Data / Information Collection*: collects relevant data / information which is necessary for the hazard assessment.

2. *Hazard Identification*: identifies hazards associated with operation of the DG Godown to future occupants of Kai Tak Development

3. *Frequency Assessment*: assess the likelihood of occurrence of the identified hazardous scenarios by reviewing historical accident data, previous studies or using Fault Tree Analysis. Event Tree Analysis, which is already built into the SAFETI package (v6.51), is adopted to determine the possible outcome from the identified hazardous events and to estimate the frequencies.

4. *Consequence Assessment*: the consequences are established for every outcome developed from initial event by using internationally well recognised consequence model – PHAST in the SAFETI package (v6.51), to assess the impacts from the identified hazards.

5. *Risk Assessment*: evaluate risk levels, in terms of individual risk and societal risk, associated with the identified hazardous scenarios. The overall risk level is compared with the criteria as stipulated in Annex 4 of the TM to determine their acceptability. Mitigation measures will be identified where the risk is considered in the ALARP (As Low As Reasonably Practicable) region or above. The reduction in risk achievable by these mitigation measures will then be quantified.

Location and Facility

11.4.4 **Figure 11.4.1** indicates the location of the Kerry DG Godown, relative to the Kai Tak Development.

11.4.5 The following information was understood from the Consultant's site visit and the review of reference [11]:

- The DG Warehouse is licensed to take Category 2 to 10 inventories.
- The warehousing is arranged over 6 stories, with a total of 22 stores.
- Category 2, flammable DG inventories are commonly accommodated on the ground floor.

11.4.6 The license allows for the following to be stored (**Table 11.4.1**), with only one category of dangerous goods stored in any store at one time. **Table 11.4.2** represents the inventories in **Table 11.4.1** in terms of mass (te).

Table 11.4.1 Dangerous Goods (DG) and the Maximum Storage Quantity Allowed

Category of DG being Stored	No. Store	Maximum Quantity to be Stored
5	2	471,000L / 559,000L
2 or 3 or 5 or 6 or 7 or 8 or 9 or 10	1	593,500kg
3 or 5 or 6 or 7 or 8 or 9 or 10	12	504,000L / 575,000L / 640,000L / 750,000L / 664,000L / 520,000L / 720,000L / 745,000L / 702,000kg/L / 554,000kg/L / 720,000L / 690,000L
3 or 4 or 5 or 6 or 7 or 8 or 9 or 10	2	740,000kg/L / 715,000kg/L
3 or 4 or 6 or 7 or 8 or 9 or 10	1	417,000kg
2 or 3 or 4 or 6 or 7 or 8 or 9 or 10	4	750,000kg / 745,000kg / 460,000kg / 745,000kg

Table 11.4.2 Maximum Allowable Quantity by DG Category

DG Category	No. of Stores allowed for storage the mentioned DG Category	Maximum Allowable Quantity (te)
2	5	3293.5
3	20	12949.5
4	7	4572.0
5	17	10862.5
6	20	12949.5
7	20	12949.5
8	20	12949.5
9	20	12949.5
10	20	12949.5
Total	22	13979.5

11.4.7 It is noted that due to the space occupied by packaging and space reserved for forklift manoeuvring, the stores cannot accommodate goods at a level of storage capacity as stated in the DG license issued by the Fire Services Department.

11.4.8 Under the warehouse operation practice, goods could probably be stored at an amount less than the license capacity. The DG Warehouse operators provided information to the Consultant concerning the inventory of stored dangerous goods in the Warehouse in mid-April 2007, as presented in **Table 11.4.3**. Nevertheless these quantities are allowable under the license. Therefore for the purposes of this study, the quantities summarized in **Table 11.4.2** are also applied to the study to a certain extent to provide a reasonable worst case basis to the study. For details please see **Warehouse Generic DG Substances** in **Section 11.4.62** of this report.

Table 11.4.3 DG Inventory Information provided by the DG Warehouse Operators

DG Category	Description	Inventory (m^3)	Most Dominant Chemical(s) Stored
2	Compressed gas	1306	Aerosol
3	Corrosive	1082	Cleaning compound
4	Poisonous	1062	Methyl Diphenyl Diisocyanate (MDI)
5	Evolving inflammable vapour	5039	Paint and thinner
6	Reacts with water	Nil	Nil
7	Support combustion strongly	392	Chromic acid solid
8	Combustible	910	Aluminum and bronze powder
9	Spontaneous combustion liable	Nil	Nil

11.4.9 An external loading bay is used to receive/dispatch goods, which are loaded/unloaded by forklift on the platform to/from trucks. Categories of goods are not specifically segregated in the loading bay area. Goods are also temporarily stored at the unloading/loading area for a short period (several hours in some cases), before transfer to the stores or dispatch by truck. During the site visit, it was noted that goods were also stored in the parking bays adjacent to the loading platform. It is understood that this is a normal practice.

11.4.10 Deliveries and dispatches are controlled by manifest sheets and risk assessment performed before goods are allowed to be stored. Highly toxic inventories, such as Chlorine, have not been stored recently.

11.4.11 Gas leakage detectors able to detect gas leakage are installed in 2 of the DG stores (those commonly used for flammable Category 2 storage on the ground floor). It is understood that the installed detectors are Sentox 4 detectors. Product sheets for the detectors [12] indicate they are designed specifically to detect flammable gas in boiler rooms and kitchens.

11.4.12 It is understood there is no system of containment for any vapour release (toxic or flammable). From the site visit and information provided by the Kerry DG Godown operator, gas will be vent out from a DG store in the event of a detected release if there is no toxic gas in the store; otherwise gas will be confined within the store until the arrival of fire service. No information has been provided on the size, design or ventilation rate of the store vents though. It is however understood that a vent exists for each store.

11.4.13 All electrical equipment inside the DG stores and elevators is explosion-proof; DG store compartment walls are understood to have 4 hours of Fire Resisting Period.

11.4.14 There is a sunken design in DG stores with Category 5 DG license.

11.4.15 Fire detection (thermal and smoke detectors installed) and fire-fighting (BTM fire-fighting system and automatic shut-down of ventilation system) systems are installed in the DG stores. Flammable gas detectors are also installed. It is understood that an alarm is raised in the DG store when thermal or smoke detectors are activated. The alarm in the store indicates that BTM fire fighting system will be activated shortly, if it were set to automatic. During this period, any personnel present in the DG store would evacuate out of the DG store.

11.4.16 FSD informed the Consultant that each DG store is equipped with a BTM fire-fighting system and all door / wall openings through which BTM gas may escape during operation of the system are covered by an asbestos curtain operated by pressure trip.

11.4.17 The BTM system is set to manual by the operators on entry to a store and remains in manual setting while the store is occupied. The switch is turned to automatic when personnel leave the store.

Population

Residential and Employment Population

11.4.18 Estimates of population densities in and around the Kai Tak Development (KTD) area have been made to assess the numbers of people that may be impacted by hazardous events. For the estimation of the residential and employment population within the KTD area for the three assessment years, reference is made to [50] taking into account the implementation programme of the KTD. See **Appendix 11.4.1** for further details. The locations of the population groups are presented in **Figure 11.4.2**.

11.4.19 Residential and employment population at locations out of the KTD area are estimated based on the data from the 2003-based Territorial Population and Employment Data Matrix (TPEDM) - Scenario I [1] provided by the Planning Department, which estimates the population in various areas of Hong Kong at year 2006, 2011, 2016 and 2021. The TPEDM data of year 2016 and 2021 are adopted for the assessment scenarios for year 2016 and 2021 respectively.

[1] The essential postulation underlying the Scenario-I matrix is that some of the development proposals will not be fully materialized or according to the recommended schedule because the total supply of residential units and working space under these proposals exceeds the requirements of the future population and employment as projected. Scenario-II matrix, which has been assumed that all development proposals will be implemented on schedule and occupied with normal vacancy level, has also been prepared by Planning Department for year 2012 and 2016 only. Since population estimate at year 2021 is only available from Scenario I TPEDM, for sake of consistency in population data adopted in various hazard assessments, Scenario I TPEDM data will be adopted.

11.4.20 The population data at year 2012 is estimated by interpolation from the TPEDM data of years 2011 and 2016, assuming the percentage of population change remains uniformly over the 5-year period. For example, when the estimated population at location P is x and y in 2011 and 2016 respectively, the population at location P in 2012 is estimated to be $x.(y/x)^{1/5}$.

Exposed Population

11.4.21 Plume height, evacuation and smoke ingress factors are considered in the risk calculation for warehouse fire. Details of these factors are described in the consequence analysis section of this report.

Kai Tak Development

11.4.22 The Kai Tak Development includes a number of flats and a hotel on the former runway area. The flats are assumed to have an average floor area of $100m^2$ and an occupancy level of 2.66 people per flat in accordance with data from **Appendix 11.4.1**. The hotel is assumed to have an average room size of $70m^2$ and an occupancy level of 2.3 people per room in accordance with **Appendix 11.4.1**.

11.4.23 The first berth of the Cruise Terminal is commissioned by 2013. However as a conservative assumption for this QRA, the population associated with the first berth of the Cruise Terminal is assumed to be in place in assessment year 2012. This is a conservative assumption based on a large cruise liner of the Genesis class [51]. The second berth is assumed to be commissioned after 2015 with the same assumptions applying.

11.4.24 The Kai Tak development includes a hospital. It is assumed that the number of patients is twice the number of staff (the number of staff is outlined in **Appendix 11.4.1**), with the patients considered to be present twenty four hours a day.

Roadside Population

11.4.25 Roadside population density was estimated from the TPEDM data according to land use zone.

11.4.26 In order to reflect temporal distribution of population, time period is divided into 4 time modes namely daytime and night-time for both weekend and weekday. The distribution of population at each time mode is given in **Table 11.4.4**.

Table 11.4.4 Temporal Changes in Population for Various Categories

Time period	Residential Dwellings	Shopping Centre	Industrial/Commercial Buildings
Weekday (day)	50%	50%	100%
Weekday (night)	100%	0%	10%
Weekend (day)	70%	100%	40%
Weekend (night)	100%	0%	5%

11.4.27 The outdoor proportion of population groups have been estimated using an outdoor ratio to each group as listed in **Table 11.4.5**. For open space area, population has been estimated based on population density of 0.01.

Table 11.4.5 Indoor/Outdoor Ratios for Different Population Categories

Population Category	Indoor (Outdoor) Ratio
Residential	0.95 (0.05)
School	0.95 (0.05)
Park	0.00 (1.00)
Road	0.00 (1.00)
Railway/Bus station	0.00 (1.00)
Marine	0.00 (1.00)

Marine Population

11.4.28 A survey was conducted in [6] to estimate marine traffic population. As presented, the marine population density at the Victoria Harbour was estimated to be 3.6 x 10^{-4} people/m^2 [6]. However, since the KTD dock area is located away from the main passenger ferry routes that operate in Victoria Harbour, this is an overestimate of the marine population around the KTD. In order to estimate a more realistic marine population density for the dock, the marine survey data of [6] is used but with the passenger ferry data excluded. Using an assumption of 10 occupants per boat, this gives a marine population density of 2.5 x 10^{-5} people/m^2.

Traffic Population

11.4.29 Traffic data for existing roads within a 1km radius of the DG Warehouse obtained from the Annual Traffic Census of the Transport Department is used to estimate the road population. The road population is predicted based on the following equation:

Traffic Population = No. of person/vehicle x No. of vehicles/hr x Road Length within the assessment area / Speed

11.4.30 An adjustment factor is applied to extrapolate the road population at the assessment years by assuming that the traffic population grows proportionally to the roadside population of an area.

11.4.31 For future roads that will be commissioned in various development phases of KTD, the population is estimated based on predicted traffic flow in [50].

Information Review

11.4.32 The hazardous scenarios considered in this report are limited to those associated with storage and transfer operations within the Kerry DG Godown.

11.4.33 Further meetings between the Consultant and EPD have clarified the scope of the QRA to require consideration of a ‘reasonable worst case estimate’. This is the basis of the hazard identification and scenario selection process performed below.

11.4.34 Previous LPG study for the warehouse was not made available. The license for the warehouse places only limited restrictions on the substances allowable within the categories. As such a generic assessment has been necessarily performed, considering reasonable worst case substances, referencing approaches established by the UK HSE for similar generic assessments [19], [20].

11.4.35 A hazardous scenario can have many different causes that all lead to the same basic initial hazardous event (e.g. a toxic release arising from loss of forklift control, generic / spontaneous failure of containment etc). The initial hazardous scenario may then have a number of different consequences, depending on the specific location of the hazardous scenario, the time it occurs, etc. The facilities have been reviewed to identify the potential hazardous scenarios, based on historical experience (principally the MHIDAS database [13]) and relevant industry guidelines (UK Safety Report Assessment Guidelines (SRAG) [20], [22], HSE exemplar substances [19]; surveys and guidelines for warehouses [23], [24], [25], [26], [27], [28] and the Dutch "Purple Book" [15]).

11.4.36 The UK HSE approach [19] presents assumptions which can be applied to activities involving generic classes of substances (under the UK definition). Note under the UK definition, generic substances exclude those listed as 'named substances' under COMAH [26]. Reference [19] suggests substances which may be used as exemplars to represent generic (ie unnamed) substances. These are summarized below, with **Table 11.4.6** summarizing which DG Category each is considered to apply to:

- Liquified flammable gases – Di methyl ether
- Extremely flammable gases/liquefied gases – Ethylene
- Flammable gases – Methane
- Flammable liquids – Xylene
- Highly flammable Liquids – Pentane
- Oxidising substances – Hydrogen peroxide
- Toxic Liquids – Methyl iodide
- Liquified toxic gases – Anhydrous Ammonia
- Toxic solids – Lindane
- Very toxic solids - Paraquat dichloride
- Very toxic liquids - Methyl Chloroformate
- Liquified very toxic gases <15 bar – Anhydrous Hydrogen Fluoride
- Liquified very toxic gases >15 bar – Hydrogen Sulphide
- Reacts with water – Oleum (DG Category 3)

11.4.37 As mentioned above, the system in the UK is to consider substances as either 'named' or 'generic', with 'named' substances representing those considered to require specific consideration [26]. These substances are outlined in **Table 11.4.6**, against the Hong Kong DG Category into which each falls.

Table 11.4.6 Summary of UK Named Substances by Hong Kong DG Categorization

DG	Equivalent UK Dangerous Substance Generic Categories	Named UK substance falling into the respective DG Category
2	Highly flammable, flammable, toxic and highly toxic compressed gases	Chlorine, ethylene oxide, oxygen, fluorine, hydrogen, hydrogen chloride, phosgene, acetylene, phosphine, liquified extremely flammable gas
3	Not cited	Sulphur Dichloride, sulphur Trioxide, 4 4-methylenebis, sulphur trioxide
4	Very toxic / toxic (excluding compressed gases)	Arsenic pentoxide, arsenic trioxide, toluene diisocyanate, arsine, bromine, formaldehyde , lead alkyl, 4 4-methylenebis, polychloridibenzofurans / dioxins
5	Very flammable/flammable (excluding compressed gases)	Propylene oxide, nickel compounds, ethyleneimine, methanol, natural gas, petrols and spirits
6	Reacts with water	-
7	Oxidizers	Ammonium nitrate

11.4.38 The study has also reviewed worldwide experience of the genus of the warehouse, to ensure all hazardous events associated with the Kerry DG Godown have been identified. The findings of the review are summarized below:

11.4.39 The UK HSE Chemical Warehouse SRAG [20] lists a number of accident initiators for warehouse events. These are summarized below:

External events:

- Aircraft impact
- Seismic event
- Fire / explosion from adjacent plant
- Extreme environmental conditions, including lightning strike
- Subsidence / landslip
- Flooding
- Collapse of overhead cables,
- Extreme weather,
- Land slip
- Other offsite events listed in the SRAG can be discounted from this study, since they are not relevant to the Warehouse facilities. These include impact by offsite vehicle and offsite missile impact by offsite road / rail vehicle.

Onsite initiators:

- Malfunctioning fork-lift truck
- Overloaded cable
- Arson
- Lorry fire during unloading
- Cutting / grinding welding
- Spillage of grinding, welding operations
- Spillage of non compatible chemicals
- Employees smoking
- Ignition of highly flammable substances
- Fire during battery charging
- LPG/diesel fire – fuel fire

11.4.40 We note from the ignition control procedures, smoking is not allowed on the facility. The safety consequences of a major fire event in a warehouse to people are listed in [20] as:

- Emission of a toxic smoke plume
- Explosion
- Thermal radiation from the flame pillar

11.4.41 Fires are considered the major hazardous event in [20], with toxic hazards being formed from the result of a major fire, rather than as an initiator, since loss of containment of a single toxic inventory item would most likely be contained to the warehouse, rather than impacting local populations significantly.

11.4.42 The guidance [20] recommends analysis should be based on the annual worst case inventories, taking account of the maximum quantity of each substance that is likely to be stored. Note this approach is not currently possible for the DG Warehouse, since this information has not been made available to the study.

11.4.43 A review of warehouse fires was reported in the UK ICHEME Loss Prevention Bulletin, covering the period 1980-1994 [22]. This is summarized below:

Table 11.4.7 Summary of Warehouse Incidents reported in [22]

Date	Location	Description	Cause	Fatalities
1980	Essex, UK	100 chemicals involved in fire at warehouse	Not cited	
1980	Cleveland UK	12000 bags (1te bags) of terephthalic acid stored as powder destroyed by fire in warehouse. Molten metal from oxy-acetylene torches during hotwork ignited inventory.	Hotwork/human error	
1980	Cleveland UK	1500 bags(1te bags) of terephthalic acid stored in bags as powder involved in fire. Also stored and involved was 31,000l of paraffin, some of which exploded.	Malicious damage	
1980	Yorkshire, UK	Chemical steel drum overheated by heater and burst, igniting other chemicals in store. 200 different chemicals involved.	Overheating	
1982	Salzburg, Austria	400te fertilizer and pesticide involved in fire from a welding spark.	Hotwork	
1982	Leeds, UK	1.5 Million Liters of paraquat solution and diquat. 20te of octyl phenal entered drains leading to environmental damage	Not cited	
1982	Pennsylvania, USA	Warehouse destroyed in 9 hours. Cause thought to be ignition from electric forklift and rupture of an aerosol. Sprinkler system not sufficient to control fire, since the system was designed for general storage. Random stacking of flammable liquids rendered the system ineffective.	Forklift electrical fault	
1982	Manchester, UK	2000te chemical, including sodium chlorate stored. A fire and explosion occurred leading to 60 injuries. Vandalism suspected. Investigation revealed no segregation of chemicals in stores leading to rapid escalation.	Vandalism	
1982	Suffolk, UK	1380 te of fertilizer ignited due to stray welding spark. Storage included ammonium nitrate.	Hotwork	
1983	Buffalo, USA	A 0.5 te propane tank leaked and explosion occurred. The tank was being moved by a forklift and rolled off, fracturing a valve.	Forklift dropped load	6
1984	Canada	Heavy rain penetrated warehouse causing release of acetylene from calcium carbide. Explosion and fire occurred.	Heavy rain	
1984	Sheffield, UK	Fire in furniture store, with small chemical store. Fire destroyed warehouse, with the exception of a protected area. Fire due to heater in cabin.	Fault electrical heater.	

Date	Location	Description	Cause	Fatalities
1984	Auckland, NZ	70x60m warehouse containing 1414 te mixed chemicals (including 28 te Chlorine in cylinders) caught fire. Chemicals included paraquat and a range of others. Chemicals released into drains polluting estuary. Warehouse had no fixed fire protection system or segregation system	Not cited	1
1985	Melbourne, Australia	Fire and explosion in chemical store involving pesticide. Rivers polluted.	Not cited	
1986	Nova Scotia, Canada	Chemical warehouse caught fire. 23 injured	Not cited	
1986	Chesapeake, USA	15000 te of sodium nitrate and potash destroyed in warehouse by lightning strike.	Lightning Strike	
1986	Florida, USA	Chemical warehouse fire led to Chlorine fumes. Electrical fault suspected	Electrical fault	
1986	Basle, Switzerland	1.5 acre chemical warehouse fire. Firewater runoff including mercury compounds led to significant river pollution in 5 countries.	Not cited	
1987	Seoul, South Korea	Warehouse of highly flammable and explosive materials holding 3000 barrels. Explosions led to collapse of 3 houses nearby and the roof of an airport building	Not cited	4
1987	Nantes, France	Cable passing over metal beams inside a warehouse short circuited and started to burn. Sparks fell onto 450te of fertilizer. And led to a large fire. Fire was confined to the stored fertilizer and did not spread to nearby ammonium nitrate.	Short Circuit	
1988	Dorset, UK	6 bay building used as a chemical store. Fire broke out in end bay, storing oxidizing chemicals. Fire check wall separated it from the rest of the building. Drums of solvent stored outside of bay exploded. Incompatible products had been stored in the bay. Due to overloaded system.	Storage of incompatibles	
1988	Canada	Fire involving plastics led to fumes over Quebec	Not cited	
1988	Sibenik, Yugoslavia	17000 te of chemical fertilizer in warehouse fire.	Not cited	
1988	Hull, UK	Fire/explosion at paint factory. Acetone on forklift spilled and ignited by electrical apparatus	Fork lift spill and electrical ignition	1
1989	New Jersey, USA	140l hydrobromic acid drum broke open during transfer. Toxic vapour developed.	Handling – spontaneous failure	

Date	Location	Description	Cause	Fatalities
1990	Avon, UK	2 events of yellow phosphorus under water in drums caught fire. First event involved 1 drum, second multiple drums. Drum corrosion exposed the inventory to air leading to fire.	Generic failure/corrosion	
1991	Bangkok, Thailand	Explosion/fireball, with phosphorous in chemical warehouse	Not cited	15
1991	Canada	Toxic smoke from a fire with sodium, phosphorous, cyanide. Evacuation of 300 people	Not cited	
1992	Delhi, India	Explosion in acid/chemical warehouse	Not cited	43
1992	Bradford, UK	Explosions of raw material warehouse led to fire. No fatalities, large scale environmental damage.	Not cited	
1993	Shenzen, China	Small explosion spread to 8 warehouses storing flammable materials. Explosion followed on fire reaching gas storage depot and chemical warehouse	Not cited	15
1993	Texas, USA	Propane cylinders exploded in paper/plastic warehouse. Sprinkler system destroyed quickly in fire. Roof collapsed	Not cited	
1994	Karachi, Pakistan	50-60 te of pesticide destroyed in fire.	Not cited	

11.4.44 Reference [23] lists causes of chemical warehouse fires which are consistent with the results of the review given in [22], and summarized in **Table 11.4.7**, above. These are:

- Arson
- Smoking
- Hotwork
- Electrical faults
- Heating systems
- Vehicles/battery charging
- Mixing of incompatible chemicals
- Thermally unstable chemicals pyrophoric/water reactive chemicals.

11.4.45 Fire scenarios were summarized in [23] from the above into:

- Small controlled fires
- Fire spread to compartment
- Fire involving whole warehouse.

11.4.46 A further survey was reported in [24]. The survey noted 160 chemical warehouse fires reported in MHIDAS for the period 1945-89. Common causes were listed as:

- Lack of awareness of materials stored
- Operator error
- Arson
- Hotwork
- Inadequate design
- Poor storage facilities

11.4.47 The MHIDAS database was reviewed by the Consultant of this study. Incidents in the genus of the Kerry DG Godown were reviewed. The database listed 444 incidents in which 'Warehouse' was cited as the primary origin of fires or release. Of these, a number were directly related to processing activities and Category 1 storage, which were not considered of relevance to the study. Other events, considered to be of the same genus were also reviewed. These related to 'transfer' operations, involving for example fork lift operations. **Table 11.4.8** summarizes the hazards identified from the review which may be considered of relevance to the Kerry DG Godown facilities.

11.4.48 In the MHIDAS report it is not clear in many cases whether warehouses could be classed as DG warehouses, with associated safety controls above those of general warehousing facilities. No attempt has therefore been made to analyse the data in this way.

Table 11.4.8 Summary of Relevant Warehouse Incidents reported in MHIDAS

Cause	Description	Number of Records
Generic fire	Internal/external causes not cited. Large scale warehouse fire with external consequences	177
Generic/Spontaneous failure cylinders/drums	Spontaneous failure (eg erosion/corrosion/design fault, maintenance error, handling error)	17
Manual handling	Spillage leading to release/fire	14
Lightning strike	Lighting strike escalating to fire/release in warehouse	2
Forklift fault	Electrical/mechanical failure in forklift leading to fire	4
Arson/sabotage	Targeted arson/sabotage at warehouse leading to escalation	15
Hotwork	Hotwork in warehouse generating spark on inventory and subsequent fire	5
Vehicle fire	Escalation of vehicle fire to warehouse loading bay/stores	3
Extreme temperature	Overheating of inventory - exposure to sun	1
Heavy rain/flooding	Fire /wash out of inventory	2
Negligence	Poor management, no ignition control, no segregation, illegal store keeping, low/illegal standard, abandoned facilities	11
Arson/human error	Arson/external fire not directed at warehouse spreads to warehouse	2
Fire in supporting equipment/office failure	Office/Supporting equipment (eg compressor) fire spreads	8
Electrical cabling failure	Overhead cabling fire leading to fire	1
Vehicle Collision	Collision with inventory at loading bay leading to fire	2
Dropped load	Forklift/overturn/lorry/heavy object dropped & shed load damages inventory leading to release/fire	12
Forklift impact	Puncturing of inventory by forklift	16
Piercing	Sharp object punctured inventory during transfer	3
Aircraft impact	Aircrash hits gas mains leading to warehouse fire	1
Electrical fault	Non-ex equipment/short circuit	7

11.4.49 From the review of worldwide experience, principally reported in MHIDAS, it is considered that all fall within the range of scenarios previously identified from [23], [24], [25].

11.4.50 From the Purple Book [15] and CPR 15 [31] scenarios identified related to loss of containment resulting from generic failure (catastrophic or hole), impact, unloading / loading and external fire. It also considers the generic scenario of major warehouse fire. It is considered that these events are adequately represented by those indicated above from MHIDAS.

11.4.51 Reference [27], summarizes a review of warehouse fires performed in 2000. The survey concluded the main causes of warehouse fires to be those given in **Table 11.4.9**. Again these would appear consistent with those of MHIDAS.

Table 11.4.9 Summary of Warehouse causal factors from Willis Review [27]

Cause	Percentage Occurrence
Exposures (to hostile fire)	11
Natural causes	8
Heating equipment	7
Smoking	3
Other equipment	12
Other	9
Electrical	10
Open flame	17
Arson/suspicious	23

Scenario Selection

11.4.52 Scenarios selected for Kerry DG Godown are described in the discussion below, based on the above review of information, which considered the genus of the facilities.

11.4.53 The potential causes, and consequences of each of these potential hazardous scenarios are discussed and the scenario frequency and potential numbers of fatalities are quantified in **Section 11.4.111** of this report onwards.

11.4.54 Any workplace may also give rise to occupational hazards such as slips, trips and falls for the workers at the plant. These hazards are not generally quantified in a hazard to life assessment. However, the fatal accident rate per year is typically around 5 per 100,000 workers for the extractive and utility supply industries; i.e. an occupational accident individual risk level of ~5×10^{-5} /year. This is an on-site individual risk level, not covered by the risk criteria in the Technical Memorandum [1] and is not included further in the assessment.

11.4.55 Following the review of worldwide data, scenarios have been selected for consideration in the QRA of the Kerry DG Godown.

11.4.56 Each scenario represents events that have the potential for significantly different consequences. For example, a toxic release from a single loss of containment event would have significantly different hazards and consequences of populations than a large scale fire at the warehouse involving both thermal and toxic hazards.

11.4.57 Some scenarios have many causes; e.g. major fire at the warehouse may be caused by aircraft crash, external fire, impact etc. Each scenario however has a potentially different outcome.

11.4.58 **Table 11.4.10** summarizes the scenarios selected for the QRA of the Kerry DG Godown required under [5].

11.4.59 Due to the relatively unrestricted nature of storage within the licensing limits of the DG warehouse to Category 2 to 10, and the limited information on the storage profile made available to the study, it would be necessary to derive reasonable assumptions so as to understand the consequences of any fire/release at the warehouse.

11.4.60 Substances, and associated inventories, have therefore been selected to generically represent the warehouse inventories. These have been chosen to represent a realistic worst case estimate of potential consequences during a warehouse fire or major toxic release. **Table 11.4.10** summarizes these representative substances. The basis for their selection is presented below.

11.4.61 The further basis of the study is that the warehouse is not, and will not become, a PHI installation. Inventory levels can therefore be assumed to remain below PHI threshold levels. The most common PHI threshold quantities are summarized in [32] and are generally in line with those indicated in the UK Notification of Installations Handling Hazardous Substances Regulation 1982 [70]. Although [70] is now superseded by the Control of Major Accident Hazards Regulation 2005, UK [26], threshold values from [70] are assumed to apply as upper warehouse limits where substances are not included in [32].

11.4.62 Information in [70] is also reviewed and the PHI threshold limits for most of the critical chemicals including ammonia and phosgene are greater in [70] as compared to [26].

Warehouse Generic DG Substances

11.4.63 As a worst case fire/toxic evaluation to human life, it is assumed that the maximum Category 2 inventory allowable in the license (3,293.5te) is stored and that the remaining inventory is nominally Category 5 as a worst case flammable hazard. Category 4 substances were also considered but discounted, as discussed below.

11.4.64 The bounding Category 2 flammable substance is taken to be liquefied petroleum gas (LPG). Ethylene is suggested in the UK exemplar recommendations but it is not considered reasonable to assume ethylene would be stored at the warehouse, given the enclosed nature of the stores. LPG is therefore considered the reasonable worst case Category 2 flammable substance. A PHI threshold limit of 25te for LPG storage is applied as a limiting value [32].

11.4.65 It is understood the Warehouse has not recently stored, and does not intend to store, any very toxic compressed gas inventory (eg Chlorine). A reasonable worst case estimate for a toxic release in Category 2 has therefore been taken as Chlorine, up to the PHI threshold limit of 10te [32].

11.4.66 Given that Chlorine has not been stored on the site recently, Chlorine is considered to be a reasonable upper bounding substance. Substances such as HF are excluded from consideration given the restriction on use of “special gases”.

11.4.67 The remaining Category 2 inventory is 3,258te of which 100te has been represented in the study by a further toxic inventory, liquefied Ammonia (equivalent to the threshold limit for a generic toxic substance [26]), and the residual Category 2 inventory is assumed to be neither toxic nor flammable, to remain below the PHI limits, and is therefore not specifically considered.

11.4.68 The remaining Warehouse inventory (Category 3 and above) is calculated 10,686 te in weight. The figure is within the allowable quantity for Category 5 DG. By comparing DG inventory information (**Table 11.4.3**) with this figure, the Kerry DG Godown stored up to 50% of the allowable quantity. Having taken into account unused space and space occupied for operation, 75% of the remaining inventory (8,015 te) has been assumed and modelled as ‘pentane’.

11.4.69 Category 4 inventories have also been considered for the evaluation. It is considered as a basis to the study that allowable toxic quantities would be broadly in line with the UK COMAH threshold values [26] (Very Toxic 5te and Toxic 50te). Under UK definitions, these would be classed as 'Toxic', 'Very Toxic' or substances which were 'Dangerous for the Environment'. Under the UK categorization, Toxic/Very Toxic inventories would also include toxic substances in compressed gas form, which would be classed under DG Category 2 in Hong Kong.

11.4.70 A premise of the study is that the warehouse would not become a PHI. Assuming UK threshold quantities apply, this would limit the 'Very Toxic' quantities to 5te, and 'Toxic' quantities to 50te. These quantities have already been included in the assessment under Category 2. For the purposes of the hazards to life study, it is therefore not considered appropriate to assume further contribution from toxic materials, since the premise of the study is to assume the warehouse is not a PHI installation. The 'poisonous' Category 4 substances are therefore assumed to be those such as Methyl Diphenyl Diisocyanate in liquid form, which would not be expected to form a hazard to populations outside of the warehouse, other than in combustion products, which are considered in the warehouse fire cases below.

11.4.71 During a warehouse fire, combustion products may be released from an inventory, and some of these may be highly toxic. The UK SRAG for Chemical Warehouses [20], indicates that very toxic/toxic substances such as phosgene, Ammonia, Chlorine, hydrogen chloride and hydrogen cyanide may evolve from warehouse fires (for example, phosgene could be produced from some fires involving chlorinated solvents though in a small fraction). The substance and concentration would depend on the substance combusted, which in this case is generic.

11.4.72 A coarse estimate has been necessary to provide an assessment of the potential for toxic components evolving in a fire, since the Consultant has no information on the specific substances stored in the warehouse, other than the DG category. The following approach has therefore been applied to estimate possible toxic components in a large fire:

Approach

- In the DG inventory information provided by the warehouse operator, Cat.3 and Cat.4 products are assumed that toxic combustion products can be form in warehouse fire. Total quantity of this type of materials is taken to be the inventory level in mid-April 2007 as advised by the warehouse operator, ie 2,144m^3 (see **Table 11.4.3**).
- With reference to the inventory information in mid-April 2007 provided by the warehouse operator, 1,062 m^3 will be considered as MDI, with atomic composition C15-H10-N2-O2. The rest is treated as a mixture of phosphoric acid, hydrochloric acid and hydrofluoric acid. This quantity of inventory is fed into the warehouse fire model in SAFETI.
- The release rate of toxic combustion products is then treated as source term in the dispersion model in SAFETI.

11.4.73 For smaller releases, consideration has also been loss of an area of a warehouse/pallet and loss of a single cylinder/drum. Nominal estimates of 1te continuous release and 50kg instantaneous release have been nominally applied.

Table 11.4.10 Summary of Proposed DG Warehouse Scenarios

ID	Summary	Scenario Description	Contributing factors	Representative Substance/Inventory	Phase	Release / Event Duration
D-WF	Major Warehouse Fire & escalating toxic release	Loss of warehouse or multiple compartments with release of toxic combustion products in a fire lasting for hours	Generic fire - unknown source Internal escalating fire (hotwork, Electrical cabling fault/short circuit, Incompatible materials, forklift malfunction, impact/dropped load) External escalating fire (eg fire from adjacent works, vehicle, loading bay/office, heating systems, electrical fire) Arson/sabotage Human error/Negligence	Max. warehouse inventory: Combustion products (HCl, SO2, NO2) from burning of Methyl Diphenyl Diisocyanate and cleaning compound (2,144 m^3)	Liquid, vapour and solid	Extended duration. Indoor release - loss of building integrity (breakdown of containment system). Multiple failures of inventories as fire progresses.
D-WF-EX	Major Warehouse Fire & escalating toxic release	Loss of warehouse with release of toxic combustion products in a fire caused by an extreme external event	Aircraft crash Seismic Extreme environmental conditions (eg Lightning strike, Heavy rain/flooding) Design of warehouse (Subsidence/landslip)	Max. warehouse inventory: Combustion products (HCl, SO2, NO2) from burning of Methyl Diphenyl Diisocyanate and cleaning compound (2,144 m^3)	Liquid, vapour and solid	Multiple failures of inventories as fire progresses. Outdoor release - loss of building integrity (building collapsed).
D-SF	Fire in Single Store & escalating toxic release	Loss of a store in fire with release of toxic combustion products	Generic fire - unknown source Internal escalating fire (hotwork, Electrical cabling fault/short circuit, Incompatible materials, forklift malfunction, impact/dropped load) External escalating fire (eg fire from adjacent works, vehicle, loading bay/office, heating systems, electrical fire) Arson/sabotage Human error/Negligence	Max. store inventory: Combustion products (HCl, SO2, NO2) from burning of Methyl Diphenyl Diisocyanate and cleaning compound (643 m^3)	Liquid, vapour and solid	Indoor release Multiple failures of inventories as fire progresses.

ID	Summary	Scenario Description	Contributing factors	Representative Substance/Inventory	Phase	Release / Event Duration
D-LF-AI	LPG release - loss of area (internal)	Damage of Single Category 2 inventory with thermal or explosion effects. No escalation to nearby inventories; No offsite impact.	Generic/spontaneous failure (corrosion, erosion, poor management, maintenance/handling error etc) Forklift malfunction Impact/dropped/shed load (truck, forklift, sharp object, heavy load) Human error	LPG Loss of area: 10 x 50kg cylinders (approx. 1 pallet)	Liquid	Indoor instantaneous release. Detected and suppressed.
D-LF-CI	LPG release - loss of containment (internal)	Damage of Single Category 2 inventory with thermal or explosion effects. No escalation to nearby inventories. No offsite impact.	Generic/spontaneous failure (corrosion, erosion, poor management, maintenance/ handling error etc) Forklift malfunction Impact/dropped/shed load (truck, forklift, sharp object, heavy load) Human error	LPG Loss of containment: single 50kg cylinder	Liquid	Indoor instantaneous release; Detected and suppressed.
D-LF-EX	LPG release – loss of warehouse	Damage of Category 2 inventory with thermal or explosion effects caused by an extreme external event	Aircraft crash Seismic Extreme environmental conditions (eg Lightning strike, Heavy rain/ flooding) Design of warehouse (Subsidence/landslip)	LPG Loss of area: multiple 50kg cylinders (5 cylinders or more)	Liquid	Outdoor instantaneous release. Loss of building integrity (building collapsed).
D-LF-AE	LPG release – loss of area (external)	Damage of Category 2 inventory with external thermal or explosion effects at loading bay	Generic/spontaneous failure (corrosion, erosion, poor management, maintenance/ handling error etc) Forklift malfunction Impact/dropped/shed load (truck, forklift, sharp object, heavy load) Human error Vehicle fire/battery recharging	LPG Loss of area: 10 x 50kg cylinders (approx. 1 pallet)	Liquid	Outdoor instantaneous release.

ID	Summary	Scenario Description	Contributing factors	Representative Substance/Inventory	Phase	Release / Event Duration
D-LF-CE	LPG release – loss of containment (external)	Damage of Category 2 inventory with external thermal or explosion effects at loading bay	Generic/spontaneous failure (corrosion, erosion, poor management, maintenance/ handling error etc) Forklift malfunction Impact/dropped/shed load (truck, forklift, sharp object, heavy load) Human error Vehicle fire/battery recharging	LPG Loss of containment: single 50kg cylinder	Liquid	Outdoor instantaneous release.
D-PF-AI	Pentane fire - loss of area (internal)	Damage of Category 5 inventory with thermal or explosion effects. No escalation to nearby inventories. No offsite impact.	Generic/spontaneous failure (corrosion, erosion, poor management, maintenance/ handling error etc) Forklift malfunction Impact/dropped/shed load (truck, forklift, sharp object, heavy load) Human error	Pentane Loss of area: multiple 50kg drums	Liquid	Indoor fire. Detected and suppressed.
D-PF-CI	Pentane fire - loss of containment (internal)	Damage of Category 5 inventory with thermal or explosion effects. No escalation to nearby inventories. No offsite impact.	Generic/spontaneous failure (corrosion, erosion, poor management, maintenance/ handling error etc) Forklift malfunction Impact/dropped/shed load (truck, forklift, sharp object, heavy load) Human error	Pentane Loss of containment: single 50kg drum	Liquid	Indoor fire. Detected and suppressed.
D-PF-EX	Pentane fire – loss of warehouse	Damage of Category 5 inventory with thermal or explosion effects caused by an extreme external event	Aircraft crash Seismic Extreme environmental conditions (eg Lightning strike, Heavy rain/ flooding) Design of warehouse (Subsidence/landslip)	Pentane 8015te	Liquid	Outdoor pool fire. Loss of building integrity (building collapsed).

ID	Summary	Scenario Description	Contributing factors	Representative Substance/Inventory	Phase	Release / Event Duration
D-PF-AE	Pentane fire - loss of area (external)	Damage of Category 5 inventory with external thermal or explosion effects at loading bay	Generic/spontaneous failure (corrosion, erosion, poor management, maintenance/ handling error etc) Forklift malfunction Impact/dropped/shed load (truck, forklift, sharp object, heavy load) Human error Vehicle fire	Pentane Loss of area: multiple 50kg drums	Liquid	Outdoor pool fire.
D-PF-CE	Pentane fire - loss containment (external)	Damage of Category 5 inventory with external thermal or explosion effects at loading bay	Generic/spontaneous failure (corrosion, erosion, poor management, maintenance/ handling error etc) Forklift malfunction Impact/dropped/shed load (truck, forklift, sharp object, heavy load) Human error Vehicle fire	Pentane Loss of containment: single 50kg drum	Liquid	Outdoor pool fire.
DG-CT-W	Chlorine release - loss of warehouse	Damage of Category 2 Chlorine inventory caused by an extreme external event	Aircraft crash Seismic Extreme environmental conditions (eg Lightning strike, Heavy rain/ flooding) Design of warehouse (Subsidence/landslip)	Chlorine 10te	Liquid	Outdoor instantaneous release. Loss of building integrity (building collapsed).
DG-AT-W	Ammonia release - loss of warehouse	Damage of Category 2 Ammonia inventory caused by an extreme external event	Aircraft crash Seismic Extreme environmental conditions (eg Lightning strike, Heavy rain/ flooding) Design of warehouse (Subsidence/landslip)	Ammonia 100te	Liquid	Outdoor instantaneous release. Loss of building integrity (building collapsed).

ID	Summary	Scenario Description	Contributing factors	Representative Substance/Inventory	Phase	Release / Event Duration
DG-CT-AI	Chlorine release – loss of area (internal)	Damage of Category 2 Chlorine inventory	Generic/spontaneous failure (corrosion, erosion, poor management, maintenance/ handling error etc) Impact/dropped/shed load (truck, forklift, sharp object, heavy load) Human error/spillage Incompatible materials	Chlorine Loss of area: multiple 50kg cylinders (1te)	Liquid	Indoor continuous release.
DG-CT-CI	Chlorine release – loss of cylinder (internal)	Damage of Category 2 Chlorine inventory	Generic/spontaneous failure (corrosion, erosion, poor management, maintenance/ handling error etc) Impact/dropped/shed load (truck, forklift, sharp object, heavy load) Human error/spillage Incompatible materials	Chorine Loss of containment: single 50kg cylinder	Liquid	Indoor instantaneous release.
DG-AT-AI	Ammonia release – loss of area (internal)	Damage of Category 2 Ammonia inventory	Generic/spontaneous failure (corrosion, erosion, poor management, maintenance/ handling error etc) Impact/dropped/shed load (truck, forklift, sharp object, heavy load) Human error/spillage Incompatible materials	Ammonia Loss of area: multiple 50kg cylinders (1te)	Liquid	Indoor continuous release.
DG-AT-CI	Ammonia release – loss of cylinder (internal)	Damage of Category 2 Ammonia inventory	Generic/spontaneous failure (corrosion, erosion, poor management, maintenance/ handling error etc) Impact/dropped/shed load (truck, forklift, sharp object, heavy load) Human error/spillage Incompatible materials	Ammonia Loss of containment: single 50kg cylinder	Liquid	Indoor instantaneous release.

ID	Summary	Scenario Description	Contributing factors	Representative Substance/Inventory	Phase	Release / Event Duration
DG-CT-AE	Chlorine release – loss of area (external)	Damage of Category 2 Chlorine inventory at loading bay	Generic/spontaneous failure (corrosion, erosion, poor management, maintenance/ handling error etc) Impact/dropped/shed load (truck, forklift, sharp object, heavy load) Human error/spillage Incompatible materials	Chlorine Loss of area: multiple 50kg cylinders (1te)	Liquid	Outdoor continuous release.
DG-CT-CE	Chlorine release – loss of cylinder (external)	Damage of Category 2 Chlorine inventory at loading bay	Generic/spontaneous failure (corrosion, erosion, poor management, maintenance/ handling error etc) Impact/dropped/shed load (truck, forklift, sharp object, heavy load) Human error/spillage Incompatible materials	Chorine Loss of containment: single 50kg cylinder	Liquid	Outdoor instantaneous release.
DG-AT-AE	Ammonia release – loss of area (external)	Damage of Category 2 Ammonia inventory at loading bay	Generic/spontaneous failure (corrosion, erosion, poor management, maintenance/ handling error etc) Impact/dropped/shed load (truck, forklift, sharp object, heavy load) Human error/spillage Incompatible materials	Ammonia Loss of area: multiple 50kg cylinders (1te)	Liquid	Outdoor continuous release.
DG-AT-CE	Ammonia release – loss of cylinder (external)	Damage of Category 2 Ammonia inventory at loading bay	Generic/spontaneous failure (corrosion, erosion, poor management, maintenance/ handling error etc) Impact/dropped/shed load (truck, forklift, sharp object, heavy load) Human error/spillage Incompatible materials	Ammonia Loss of containment: single 50kg cylinder	Liquid	Outdoor instantaneous release.

Frequency Analysis

11.4.74 A frequency analysis has been performed for the scenarios listed in **Table 11.4.10**. A summary of the evaluation is given below;

Natural Hazards

11.4.75 Natural hazards also figure within the SRAG for Chemical Warehouses [20], as a potential source of warehouse fires. In this case, the source of concern is considered to relate to 5 events involving lightning strike, extreme temperature exposure of chemicals, and heavy rain/flooding.

11.4.76 This, together with the Consultant's experience, suggests that fires/releases from the Warehouse operations in an earthquake are not generally expected to produce a likely event. In the worst of cases, failure modes may include dropped / disturbed loads leading to impact, or impact of the hazardous inventories from damage arising from local buildings / loss of integrity of the structure.

11.4.77 Information presented in recent Hazard to Life Assessment for the Permanent Aviation Fuel Facility (PAFF) [33], suggests that *"the inferred rate of earthquake activity in the vicinity of Hong Kong can be considered similar to that of areas of Central Europe and the Eastern areas of the USA and that currently, there is no requirement for consideration of seismic hazards in the building codes of Hong Kong"* [34]. Likelihood of seismic hazard is $1x10^{-5}$ per year, based on 0.4g ground acceleration, to which a 0.1 probability of roof collapse was assigned. Thus, the frequency of building collapse in an earthquake is estimated $1x10^{-6}$ per year.

11.4.78 There remains a small possibility that an earthquake could lead to a major event, but from the Consultant's experience, the magnitude of the ground acceleration would need to be sufficient that the level of damage elsewhere in the vicinity would also be massive.

11.4.79 No design basis is available for the Warehouse against typhoon conditions or lightning protection standards. No specific information has been made available to the study on the structure of the warehouse, or its design basis against lightning, subsidence and landslide.

11.4.80 Extremes of weather were noted in [35] and [36]. Extreme hot weather is not considered to impact the warehouse, since inventories are kept undercover, though externally stored materials in warehouses have been shown to fail on one occasion due to prolonged exposure to the sun.

11.4.81 Between 1961 and 1990, 46 days were shown with lightning activity. The Warehouse is considered to be relatively low rise compared to other buildings in the area and not therefore particularly prone to lightning strike [67].

11.4.82 While external environmental occurrences cannot be ruled out, the frequency of these external causes is considered adequately represented within the generic historical failure frequencies identified.

11.4.83 Other failures due to natural hazards will remain possible, e.g. tsunami, but are only likely under conditions where the surrounding area is simultaneously devastated and are not expected to cause any significant increase in risks to the adjoining population.

External Causes

11.4.84 Historical records for warehousing do indicate some specific instances of arson and sabotage leading to major events. Some of these were targeted on the facility, 15 events are noted in **Table 11.4.8** from a review of the MHIDAS database, while others related to acts of vandalism /misadventure in which warehouses caught fire due to fires located adjacent to the warehouse (scrub land clearance/children fire lighting etc). It is not clear from the review how many related to DG warehouses, as opposed to general warehousing facilities. Safety features are understood to be in place for the Kerry DG Godown to minimize acts of vandalism/sabotage. For example, stores are understood to be locked, access to the facility restricted, high walls surround the warehouse to prevent road access and the facility is manned permanently.

11.4.85 While sabotage, vandalism, acts of terrorism cannot be ruled out, the frequency of these external causes is considered adequately represented within the historical failure frequencies identified.

Aircraft Impact

11.4.86 One of the identified potential hazards is major release or fire following an aircraft crash. The DG Warehouse is located approximately 30 km from the Hong Kong International Airport.

11.4.87 In the event that an aircraft crash onto the warehouse, the overall consequences would depend on the aircraft type, point of impact, horizontal momentum at the time of impact. The types of aircraft using Hong Kong International Airport include large passenger jets such as Boeing 747, Boeing 777, Airbus A330, and Airbus A340 [33]. These were noted in [33] to have a typical wing span of 65m and a length of 73m. The next generation of aircraft, which are likely to be using the airport in 2016, were suggested to be larger; eg the Airbus A380 with a wing span of 73m and a length of 73m. The area of destruction assumed in [33] as typical for aviation risk assessments was ~1 hectare (100m × 100m). Given the impact area, it is reasonable to assume damage could occur to sizable areas of the Warehouse, given their close proximity and dimensions (approximately 63m x 85m for the Warehouse plot area). Catastrophic levels of damage could be expected for direct impact, particularly of the fuselage but lesser damage resulting from impacting debris etc. The impact itself may also lead to ignition of fires within the warehouse. The predicted aircraft impact frequency for the facilities has been estimated. The main assumptions in the analysis are:

- The main potential hazard comes from the volume of aircraft activity from Hong Kong International Airport

- The chance of an aircraft crashing from flight at a given location in the vicinity of an airport depends on the lateral orientation and displacement of the location from the runway centerline. HSE [71] presented a method to calculate the aircraft crash frequency per unit ground area (per km2) using the following expressions

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

where N is the number of runway movements per year R is the probability of an accident per movement (landing or take-off). F(x,y) gives the spatial distribution of crashes and is given by:

For aircraft landing, x >-3.275 km

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

For aircraft take-off, for x >-0.6 km

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

Parameters x and y are 25km and 9km respectively for Kerry DG Godown. From [33], movements were estimated as 98,423 /yr in 1998 growing to 380,000 /yr by 2016. Potentially a third runway will be commissioned by 2040, which would result in an increase in movements to 700,000 /yr. For operational and safety reasons, aircraft usually land and take off into the wind. The prevailing wind directions at the airport mean that about 55% of aircraft movements are from the West.

- Currently the North runway is generally used for departure, and the South runway for arrivals, though exceptions exist (eg certain cargo and government flights). In the longer term, aircraft may land and depart simultaneously at the airport. The study has assumed arrivals and departures to be divided equally between the North and South Runways [33], [38].

- The probability of an accident per movement R is interpreted from National Transportation Safety Board (NTSB) data for fatal accidents in the U.S. involving scheduled airline flights during the period 1986-2005. The 10-year moving average suggests a downward trend with recent years showing a rate of about $2\text{x}10^{-7}$ per flight. There are only 13.5% of accidents associated with the approach to landing, 15.8% associated with take-off and 4.2% are related to the climb phase of the flight. Thus it is assumed that the accident frequency for the approach to landings is taken $2.7\text{x}10^{-8}$ per flight and for take-off/climb $4.0\text{x}10^{-8}$ per flight.

- The target area of the warehouse estimated as approximately 63m x 85m for the plot area. The calculated aircraft crash frequency is $5.5\text{x}10^{-14}$ per year.

- Consideration of aircraft crash is discounted from further analysis and considered appropriately reflected in the generic data below.

Kerry DG Godown

11.4.88 The assessment for the Kerry DG Godown has necessarily been performed at a high level in the absence of detail on the inventory, unit quantities, storage practices and number of movements etc for the Warehouse. The following assumptions, based on engineering judgment have therefore been applied in order to facilitate the evaluation. It is strongly recommended that the validity of the assumptions be tested once specific information on the warehouse is available.

Table 11.4.11 DG Warehouse Assumptions

Item	Quantity
Stores	22
Category 2 stores	5
Category ‘other’ stores	17
Floors	6
Non – Category 2 inventories nominally pentane	213,720 units as 50 kg containers
Category 2 – nominally Chlorine containers	200 units as 50kg containers
Category 2 – nominally Ammonia containers	2000 units as 50kg containers
Category 2 – nominally LPG containers	500 units as 50kg cylinders

Probability of Toxic Gas Inventories and 50kg LPG Cylinders

11.4.89 Our understanding is that toxic inventories such as Chlorine and Ammonia have not been stored at the Kerry DG Godown recently, nor it is the intention that such storage would ever take place. However, the license does not specifically prohibit their storage in future the operational considerations could theoretically change and such toxic inventories (Chlorine, Ammonia or other) could potentially be stored.

11.4.90 Under Gas Safety Ordinance, no person shall store and transport gas imported or manufactured by a registered gas supply company unless he is an employee of the company or he has the approval in writing of the company. Besides, registered gas supply companies store LPG cylinders at their own premises by current practise. According to the inventory information provided by the operator of the Kerry DG Godown, the Godown normally stores small disposable LPG containers. Sizes of disposable LPG containers in Hong Kong are typically ranging from 2.5g to 480g. It is understood that registered gas supply companies had not and have no intention to store 50kg LPG cylinders at the Kerry DG Godown although there is no restriction on storage of 50kg LPG cylinders in the Godown. Accordingly, the probability of storing 50kg LPG cylinders in the Kerry DG Godown is very remote. In the assessment, 50kg LPG cylinders are selected to represent the worst scenario

11.4.91 As per above and the information provided by the Godown operator (ie. that they have not stored Chlorine/Ammonia for at least the past 10 years), consideration have been taken to account the local use and application of Chlorine/Ammonia, current practice of storing LPG cylinders and no recent record (past 10 years) storing such inventories. The probability of this rare event is 1/(total number of independent events) and equal to 2.74×10^{-4}, based on total number of 3,650 records over the past 10 years. The figure is applied to the study for the potential for such storage of Chlorine, Ammonia or 50kg LPG cylinder over a year.

Warehouse Fires

11.4.92 Warehouse fires are considered to be the most dominant major hazard associated with warehouses historically. Several of the scenarios given in **Table 11.4.10** involve this type of fire which can lead to both thermal effects and effects associated with toxic release from combustion products.

11.4.93 The Consultant applies generic warehouse fire frequencies and proportioning these for each warehouse scenario given in **Table 11.4.10**, by reference to the causal factors of warehouse fires given in **Table 11.4.8** and those provided more generally in **Table 11.4.7**.

11.4.94 A number of references are available which provide estimates of generic warehouse fires. These are summarized in **Table 11.4.12**:

Table 11.4.12 Generic Warehouse Fire Frequencies

Reference	Description	Frequency
Hymes/Flynn [52]	General Warehouse	1×10^{-2} to 1×10^{-3}
Qest [40]	DG Warehouse	1×10^{-3} to 1×10^{-4}
Purple Book [15]	DG Warehouse	1.8×10^{-4}
UK [53]	Warehouse fire – Urban	2.5×10^{-2} to 5×10^{-3}

11.4.95 The likelihood of a warehouse fire depends on the location of the warehouse, site security, safety management culture, sources of ignition, presence of flammable or combustible materials inside the warehouse, use of flammable materials in construction, and hazardous processes close to the warehouse.

11.4.96 The lower bound estimate of 10^{-3} /yr [52] would appear appropriate for this assessment given that the warehouses on which the generic data are based range from unclassified to Dangerous Goods warehouses, and Dangerous Goods warehouses can be considered to be subject to controls above those in unclassified warehouses.

11.4.97 Not all fires would escalate to the entire warehouse, given that we understand a fire suppression system exists in each store and walls have some form of fire resistance. Outcomes may range from loss of a single store to loss of an area (within a store or out on the loading bay). Factors have therefore been applied to account for the probability of a warehouse fire developing into each outcome. These have been based on a high level review of probabilities recommended in [47], which considers the potential for escalation of an initial fire given a range of safety measure controls. A detailed assessment is not possible since only very limited understanding of the Kerry DG Godown systems has been made available to the study. The assumptions applied to the evaluation are given below:

- It is understood an automatic fire suppression (BTM) system is in place in the store actuated on fire/smoke detection. Ref [47] suggests a 0.9 probability for successful heat and smoke detection and a 0.94 probability of successful suppression where 'Halon' type systems are applied. For the Kerry DG Godown, the suppression system is set to manual while the store is occupied and therefore potential exists for a fire to be initiated in a store which is occupied by the staff of the Warehouse or where the switch has not been returned to automatic, followed by a failure of the control room to manually initiate the system. A probability of failure 0.05 is applied to account for this failure, based on judgment of similar systems and an assumption that the control room would be alerted to the fire and status of the suppression system, and would be trained to initiate the system manually. This leads to an overall probability of successfully isolating the fire to the store(s) by use of the suppression system of 0.8. It is assumed that where the suppression system operates successfully, the fire would be limited to a store(s) area (D-LF-AI, D-PF-AI).

- Ref [47] suggests a probability of success of passive systems in compartments maintaining segregation as 0.81 for masonry segregation. It is understood that the warehouse is fire resistant for 4 hours, though the Consultant has no information on whether this applies to each store, or for what type of fires the protection is designed. A nominal probability of 0.5 is therefore applied for the control of the fire being maintained due to physical compartmentalization. It is assumed that where the fire suppression system has failed, but the integrity of the store has been maintained, fires would be limited to loss of a single store (D-SF).

- From the Willis Review [27], approximately 80% of events can be considered to start within a compartment. For the purpose of the study, all other events (20%) have been assumed to lead to loss of multiple stores. The factors outlined above have therefore been applied to the 80% of fires which are assumed start within a single store.

- In extreme initialising events such as earthquake leading to building collapse, likelihood for those events is assumed $1x10^{-6}$ /yr. Hazardous scenarios warehouse fire (D-WF-EX), LPG release (D-LF-EX) and pool fire (D-PF-EX) under this extreme environment are considered separately.

- All other events which either impact multiple stores simultaneously, or are not controlled to a single store/area due to failure of suppression or passive systems are assumed to impact the entire warehouse (D-WF).

Warehouse Fires in Loading Bay

11.4.98 Fires in the loading bay area have also been considered in the analysis. The causes of such fires were shown (**Table 11.4.10**) to include spontaneous/generic failure, failures due to impacting vehicles/forklifts or vehicle fires escalating to nearby inventories. The discussion below applies to scenarios (D-LF-AE, D-PF-AE).

Generic release

11.4.99 The likelihood of a generic/spontaneous loss of pressurized flammable inventory has been taken as the rupture frequency for a single cylinder. From previous section, this is estimated to be 6.8 x 10^{-6} per vessel year [6]. It is nominally assumed an average of 100 x 50kg cylinders would be placed in the loading area awaiting storage with an ignition probability of 0.1, leading to an overall estimated failure frequency of $6.8x10^{-5}$ /yr for a pressurised drum. However, probability for simultaneous failure of multiple, say 10 (in 1 pallet), LPG cylinders tends to zero.

11.4.100 Applying the same argument to non-pressurized flammable inventories and assuming a rupture frequency of $5x10^{-6}$ per vessel year [15] leads to an overall estimated frequency of $5x10^{-5}$ /yr.

Impact

11.4.101 Limited information is available on impacts in warehouses. The Consultant considers the most appropriate data to use is that for spill events in warehousing, which estimates a spill frequency of $1x10^{-5}$ per handling [15]. This is considered to be based on generic warehouse operations involving mainly uncategorized substances. A probability of 0.1 has been applied to the above handling probability to reflect the assumed dangerous goods practices and packaging at the warehouse, which may be conservative, depending on the actual practices at the warehouse.

11.4.102 The Consultant has based its assessment on an assumed 10 forklifts operating throughout a 12 hour day for 6 days per week, and 15 minutes per handling to establish a frequency for release from impact scenarios. This gives an estimated 150,171 handlings a year, of which 0.33 have been assumed to take place outside of the stores. It is also important to estimate how many of these potential releases would involve Category 2, or other flammable inventories. The number of movements involving each type based on its estimates on the proportion of each flammable inventory type (25te Category 2 flammable inventory and, conservatively, 8,015 te other flammable inventories) compared to the overall inventory of the warehouse from **Table 11.4.2** (13,979.5 te).

11.4.103 The above provides estimates of overall release frequency to which an ignition probability must be applied. The Consultant has applied an ignition probability to the above release frequency estimates of 0.01 (based on Cox, Lees and Ang data [54] for a continuous1 kg/s release in an industrial/refinery environment).

Vehicle fires

11.4.104 The potential for vehicle fires (including truck/forklift), has been estimated in [40] at $2.9x10^{-4}$ per vehicle year. The Consultant has assumed 10 forklifts and 5 trucks at any time leading to an overall fire frequency of $4.35x10^{-3}$/yr. Account has also been taken for the operational hours of the warehouse, assuming operation 6 days per week for 12 hours a day). The Consultant has again based its estimates on the proportion of each flammable inventory type (25te Category 2 flammable inventory and, conservatively, 8,015 te other flammable inventories) compared to the overall inventory of the warehouse from **Table 11.4.2** (13,979.5 te).

Toxic Warehouse Releases

11.4.105 Toxic hazards associated with combustion products from warehouse fires are considered. Additional scenarios were identified in **Table 11.4.10**, which relate to a loss of containment from pressurized toxic inventories (nominally Chlorine and Ammonia, see **Table 11.4.10** and the associated discussion).

Loss of containment of full toxic inventory (DG-CT-W and DG-AT-W)

11.4.106 Instantaneous loss of the entire toxic inventory is considered to be a very unlikely event. A generic approach has been taken to estimate those events which may lead to large scale toxic continuous release through from a leak, without associated fire. An estimate of $1x10^{-6}$ /yr is applied to the potential for catastrophic loss of a toxic inventory (nominally 2 inventories are considered; Chlorine and Ammonia). The estimate can be favourably compared against reported information in [39] for seismic activity of $1x10^{-5}$ per year, based on 0.4g ground acceleration, to which a 0.1 probability of roof collapse was assigned and the generic rupture frequency for a single pressurized vessel of $6.8x10^{-6}$ /yr based on historic data, of which a small proportion would be associated with multiple failure events.

Loss of containment of single container in store (DG-CT-CI and DG-AT-CI)

11.4.107 The likelihood of a generic/spontaneous loss of pressurized toxic container has been taken as the rupture frequency for a single cylinder. From previous section, this is estimated to be $6.8x10^{-6}$ per vessel year and $6.38x10^{-5}$ per vessel year for Ammonia and Chlorine respectively. Based on the assumed maximum inventories of 10te for Chlorine and 100te for Ammonia, and nominally assuming 50kg containers throughout, leads to an estimated 200 Chlorine cylinders and 2000 Ammonia cylinders, with an associated failure frequency of $3.5x10^{-6}$ and $3.73x10^{-6}$ per year, respectively after the probability of storing toxic inventory $2.74x10^{-4}$ has also been applied.

11.4.108 Conservatively no account is taken of any potential special containment of the release by the warehouse store, since the Consultant has no information on the size of venting and understands on detection of any release the store is vented.

Loss of containment of single container in loading bay (DG-CT-CE and DG-AT-CE)

11.4.109 For generic/spontaneous loss of containment of toxic pressurized cylinders in the loading bay, a similar approach to that described in previous section has been applied, assuming generic failure rates of $6.8x10^{-6}$ per cylinder year for Ammonia and 6.38×10^{-5} per cylinder year for Chlorine. A nominal 5 cylinders (250kg) are assumed to be at the loading bay being handled at any one time for the Chlorine and Ammonia scenarios.

Impact in loading bay and in store (DG-CT-AE, DG-AT-AE, DG-CT-AI, DG-AT-AI)

11.4.110 The potential for impact has been estimated for toxic inventories applying the same approach as described in previous section. The likely number of movements involving each type of nominal toxic inventory estimates have been based on the proportion of each inventory type (10te Chlorine and 100te Ammonia) compared to the overall inventory of the warehouse from **Table 11.4.2** (13,979.5 te).

Summary of DG Warehouse Frequencies

11.4.111 After probability of toxic inventories (Chlorine and Ammonia) has been taken into account the frequency calculation, event frequencies used in the assessment are obtained and summarised in **Table 11.4.13**. Details on deriving the event frequencies are presented in **Appendix 11.4.2**.

Table 11.4.13 Summary of Kerry DG Godown Frequencies by Scenario

ID	Description	Estimated Frequency (/yr)
D-WF	Major Warehouse Fire	1.68E-04
D-SF	Fire in Single Store	1.12E-04
D-LF-AI	LPG Fire Loss area Internal (no offsite effect)	4.48E-08
D-LF-CI	LPG Fire Loss cylinder Internal (no offsite effect)	- Note 1
D-LF-AE	LPG Fire Loss area External	1.16E-09
D-LF-CE	LPG Fire Loss cylinder External (no offsite effect)	- Note 1
D-PF-AI	Pentane fire Loss Area Internal (no offsite effect)	7.20E-04
D-PF-CI	Pentane fire Loss drum Internal (no offsite effect)	- Note 1
D-PF-AE	Pentane fire Loss Area External	1.40E-03
D-PF-CE	Pentane fire Loss drum External (no offsite effect)	- Note 1
DG-CT-W	Chlorine toxic release (building collapsed)	2.74E-10
DG-AT-W	Ammonia toxic release (building collapsed)	2.74E-10
DG-CT-AI	Chlorine–Loss of Area Internal	1.97E-08
DG-CT-CI	Chlorine–Loss of Cylinder Internal	3.50E-06
DG-AT-AI	Ammonia–Loss of Area Internal	1.97E-07
DG-AT-CI	Ammonia–Loss of Cylinder Internal	3.73E-06
DG-CT-AE	Chlorine–Loss of Area External	9.71E-09
DG-CT-CE	Chlorine–Loss of Cylinder External	8.74E-08
DG-AT-AE	Ammonia–Loss of Area External	9.71E-08
DG-AT-CE	Ammonia–Loss of Cylinder External	9.32E-09
D-WF-EX	Major Warehouse Fire (building collapsed)	1.00E-06
D-LF-EX	LPG Fire Loss Area (building collapsed)	0.00E+00
D-PF-EX	Pentane fire Loss Area (building collapsed)	1.00E-06

Note 1: not further considered due to no offsite effect.

Consequence Analysis

11.4.112 Meteorological data based on 2006 data from Kai Tak Weather Station is collected and adopted in the consequence model to determine the various gas dispersion, fire and explosion effect. The dominant sets of wind speed-stability class combination both daytime and night-time (**Table 11.4.14**) are identified and adopted in the risk assessment.

Table 11.4.14 Stability Category-Wind Speed Frequencies at Kai Tak Weather Station

DAYTIME							
DIRECTION	WEATHER CLASS						TOTAL
	3B	1D	4C	7D	1F	3E	
0 – 30	0.60	0.12	1.12	0.12	0.30	0.67	2.93
30 – 60	0.88	0.19	2.81	0.26	0.40	0.86	5.40
60 – 90	0.98	0.14	3.28	1.49	0.23	0.72	6.84
90 – 120	2.40	0.19	13.40	8.09	0.33	2.00	26.40
120 – 150	4.86	0.28	11.44	3.02	0.74	2.84	23.19
150 – 180	1.56	0.258	1.51	0.05	1.14	0.30	5.14
180 – 210	1.28	0.16	1.95	0.33	0.35	0.14	4.21
210 – 240	2.98	0.37	3.58	0.88	0.33	0.35	8.49
240 – 270	2.02	0.30	2.98	0.86	0.21	0.33	6.70
270 – 300	0.70	0.14	1.58	0.14	0.30	0.58	3.44
300 – 330	0.67	0.14	1.79	0.33	0.40	0.58	3.91
330 – 360	0.70	0.26	1.30	0.40	0.40	0.33	3.37
All	**19.63**	**2.86**	**46.74**	**15.95**	**5.12**	**9.70**	**100.00**

NIGHT-TIME							
DIRECTION	WEATHER CLASS						TOTAL
	1B	1D	4D	7D	1F	3E	
0 – 30	0.00	0.02	0.41	0.25	1.07	2.46	4.21
30 – 60	0.00	0.00	0.80	0.30	1.14	3.35	5.58
60 – 90	0.00	0.00	2.09	1.12	1.02	3.21	7.44
90 – 120	0.00	0.00	8.51	5.85	1.98	11.99	28.33
120 – 150	0.00	0.00	1.80	0.25	5.05	11.36	18.46
150 – 180	0.00	0.00	0.14	0.05	4.03	1.39	5.60
180 – 210	1.82	0.00	0.75	0.07	2.07	2.03	6.74
210 – 240	0.00	0.00	1.07	0.41	1.80	2.82	6.10
240 – 270	0.00	0.00	0.61	0.36	1.89	2.66	5.53
270 – 300	0.00	0.00	0.50	0.25	1.37	1.55	3.66
300 – 330	0.00	0.00	0.73	0.11	1.09	1.48	3.41
330 – 360	0.00	0.00	0.66	0.16	2.89	1.23	4.94
ALL	**1.82**	**0.02**	**18.07**	**9.17**	**25.40**	**45.52**	**100.00**

Venting Out Procedures for Toxic Gas Release

11.4.113 Ventilation arrangement in case of toxic gas release in the warehouse was further explored. The Warehouse operator has confirmed the following in the event of activation of gas detectors:

- If no toxic gas was stored, ventilation would continue
- If toxic gas was stored, fans would be shut down and gas would be confined within the storeroom until arrival of fire service, FSD.

11.4.114 From our understanding, the gas detectors are installed only for flammable gas detection but not toxic gas detection. As such, the detectors may not be able to sensitively detect toxic gas leakage. There is also uncertainty in terms of future statutory regulations in terms of gas detection installation at the Warehouse.

11.4.115 In view of these, two cases were considered for consequence of toxic release, namely successful shutdown and shutdown failure. These modifications were applied to scenarios under Internal Toxic Releases (DG-AT-AI/CI and DG-CT-AI/CI) on the assumption that:

- 50% for the fan shutdown fails (6 air changes per hour)
- 50% for the fan shutdown succeed (2 air changes per hour).

Consequence Analysis Software

11.4.116 Releases from hazardous sources and their consequences have been modelled with the well-established software SAFETI version 6.51. The software calculates individual consequence, such as fireball and flash fire, using its built-in event trees depending on probability of ignition and release conditions. Description of individual consequence model is given in the following paragraphs. Hazard distances for selected cases are presented in **Appendix 11.4.4**.

Effect Modeling

11.4.117 The following section briefly describes mathematical models applied to various fire and dense gas dispersion in the consequence model.

11.4.118 Following Probit equations are used to determine lethal doses for various hazard scenarios.

Thermal radiation (TNO) [15]

$$Pr = -36.38 + 2.56 \ln(Q^{1.333} \times t)$$

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

Toxicity for chlorine (TNO, 1992) [73]

$$Pr = -14.3 + \ln(C^{2.3} \times t)$$

where C is concentration in mg/m^3 and t is exposure time in minutes

Toxicity for Ammonia (TNO) [15]

$$Pr = -16.21 + \ln(C^{2} \times t)$$

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

Toxicity for HCl (toxic smoke plume in warehouse fire) (TNO) [15]

$$Pr = -15.59 + 1.69 \times \ln(C^{1.18} \times t)$$

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

Gas Dispersion

11.4.119 The Unified Dispersion Model (UDM), without rainout effect for LPG, of the SAFETI software has been used for the dispersion in non-immediate ignition scenarios. The model takes into account various transition phases, from dense cloud dispersion to buoyant passive gas dispersion, in both instantaneous and continuous releases. Besides, toxic effect has been evaluated using the UDM dispersion model when the cloud reaches population sites for release of gas without ignition.

11.4.120 Upon release of flammable gas, a number of possible outcomes may be occurred depended on whether the gas is ignited immediately or ignited after a period of time. The dispersion characteristics will be influenced by the meteorological conditions and the material properties, such as density, of the released gas.

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

Fireball

11.4.122 For immediate ignition of an instantaneous gas release, a fireball will be formed. Fireball is more likely for immediate ignition of instantaneous release from vessels/tankers due to cold catastrophic failure. Instantaneous ignition of a certain mass of fuel (flammable gas/LPG) results in explosion and fire of hemispherical shape. Heat is evolved by radiation. The principal hazard of fireball arises from thermal radiation. Due to its intensity, its effects are not significantly influenced by weather, wind direction or source of ignition. Sizes, shape, duration, heat flux and radiation will be determined in the consequence analysis.

11.4.123 Although a fireball affects dwellings which have direct line of sight to it, shielding factor is not applied to buildings within the study area for conservative results.

Flash Fire

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

Vapour Cloud Explosion (VCE)

11.4.125 A vapour cloud explosion can occur when a flammable vapour is ignited in a confined or partially confined situation. TNO vapour cloud explosion correlation is used for calculating the consequences of an explosion. The early explosion occurs at the release source and is the most common for instantaneous releases. The late explosions occurs at downstream of releases. The model calculates early and late explosions according to ignition probability.

Pool Fire

11.4.126 The ignition of a spill of flammable liquids typically results in a pool fire. The pool fire size for a major fire, e.g. following catastrophic failure of the warehouse, has been determined from the extent of the pool based on the building dimensions (36m wide x 80m long giving an effective pool diameter of 60m) and assuming pentane as an indicative hydrocarbon fuel. A nominal 10m pool size has also been used to represent small flammable liquid spills external to the warehouse. This is approximately the distance from the edge of the warehouse to the boundary line. Small pool fires within the warehouse have not been modelled since these are likely to be contained within the building and not present any significant thermal hazard outside the warehouse. A cylindrical shape of the pool fire is presumed Burn rate, pool fire dimensions (tilted cylinder, fire diameter, fire height and tilted angle) and surface emissive power of the flame are calculated from the model and the model subsequently sets the radiation.

Warehouse Fire

11.4.127 The warehouse fire model calculates the composition and flow rates of the combustion products released to the atmosphere. The model is based on a subset of the risk-analysis methodology adopted in a TNO report by Molag and Blow-Bruggerman [72]. The model calculates the average chemical structure for MDI. Assuming complete combustion and NO_2, SO_2 and halides as combustion products, mass emission factor and burning rate are calculated according to the building ventilation characteristics, the oxygen requirement. Outputs from the warehouse fire model are used as source terms for dispersion model for evaluation of toxic effects.

11.4.128 Several hours are required for developing a fire into a major warehouse fire due to containment and attenuation effects. At this extended duration, it is possible to carry out a large scale evacuation unless the fire is initiated by some extreme events and in short duration such as earthquake (D-WF-EX). The number of population being threaten for the major warehouse fire is only a small portion. In this assessment, it is assumed 99% population can be evacuated to a safe place.

11.4.129 A smoke plume generated from a fire follows the tilt angle of the flame initially and rises upward due to high buoyancy caused by high temperature. Plume height (H) is calculated as [L x tan(90^o - tilt angle)] where L is horizontal distance from the fire site boundary. The approach has been applied to various approved EIA studies [74][75][76] for evaluating the impact of smoke plume to elevated population. Tilt angle is taken as 60^o to represent the worst scenario. **Table 11.4.15** tabulates smoke plume distance against horizontal distance from boundary of a fire site. According to the plume height analysis, a smoke plume does not affect population in a 40-storey building at 210m or further downstream from the fire site. Taking into account land use of population sites, population zones 253.06, 253.07 and 253.08 (all for commercial use) are subject to the impact of a smoke plume in a fire. Having considered location of the 3 population zones, population can be divided into 3 distances ranges as below for further analysis. Fraction population in a 40-storey commercial building affected by the smoke plume for the 3 distance ranges are listed as follows.

- 0m – 35m : 1.00 (max.), 0.83 (min.), 0.92 (average)
- 35m – 115m: 0.83 (max.), 0.45 (min.), 0.64 (average)
- 115m – 195m: 0.45 (max.), 0.06 (min.), 0.26 (average)

Table 11.4.15 Smoke Plume Height Against Horizontal Distance From Fire Site Boundary

Horizontal Distance From Fire Site Boundary (m)	Smoke Plume Height (m)	Equivalent to Number of Storeys*
0	0.0	0
35	20.2	7
70	40.4	13
105	60.6	20
140	80.8	27
175	101.0	34
210	121.2	40

** floor height of 3m is assumed*

11.4.130 Moreover, indoor fatality probability for population at zones 253.06, 253.07 and 253.08 is significantly lower than direct exposure to toxic smoke at outdoor. Since the smoke plume is assumed a mixture of NO_2, SO_2 and HCl, fatality probability can be calculated by the probit equation for the most toxic substance HCl. The probit equation can be written in terms of cumulative dosage, D, as below,

$$Pr = -15.59 + 1.69 \times \ln(D)$$

11.4.131 Toxic smoke plume enters into a building through mechanical or natural ventilation. Indoor toxic gas concentration increases with time due to mixing with air from outdoor when the toxic smoke plume hits the building. Indoor concentration, C_i, can be obtained from the equation for continuous smoke plumes

$$C_i = C_o \times (1 - \exp(-\lambda \times t))$$

Where C_o is the average outdoor concentration in ppm over a period of time t, λ is air changes per minute and t is time after the arrival of the plume in minutes.

11.4.132 The indoor fatality probability relative to the outdoor fatality probability can be calculated by the following equation together with probit equations for HCl.

For cumulative dosage,

$$D = \int_0^{t_p} \left[C_o\left(1-\exp(-\lambda t)\right)\right]^n dt + \int_0^{t_e} \left[C_o\left(1-\exp(-\lambda t_p)\right)\exp(-\lambda t)\right]^n dt$$

Probit equation for outdoor fatality probability calculation,

$$Pr = -15.59 + 1.69 \times \ln(C_o^{1.18} \times t_p)$$

Where t_p is the cloud passage time in minutes and t_e is time of escape after cloud passage in minutes. For continuous release, time of escape after cloud passage is dropped and the cloud passage time is assumed the escape time. Indoor / outdoor fatality probability ratios are tabulated in Appendix C with outdoor concentration (C_o), air change rate (λ) and cloud passage time (t_p) as variables.

11.4.133 According to the consequence assessment for warehouse fire, toxic plume with concentration of LD90 reaches the adjacent commercial sites. For the purpose of this assessment, it is assumed that these adjacent commercial sites would be centrally air-conditioned and would not rely on openable windows for ventilation. Fresh air change rates of the air conditioning systems of these commercial sites were taken to be approximately 1 air changes per hour in case of smoke plume hitting a building facade. It is further assumed population inside a building can take action and escape in 30 minutes. After these factors have been taken into account, the indoor fatality probability is calculated as 5% of the outdoor one and is adopted in the assessment.

Risk Calculation

Comparison of Risk Levels with Criteria

11.4.134 By combining the population data, meteorological data, results of frequency estimation and consequence analysis, risk levels due to the operation of the Kerry DG Godown at 2012, 2016 and 2021 have been characterised in terms of individual risk (presented by individual risk contours) and societal risk (presented by FN curves). Risk levels are compared with the criteria in the EIAO TM Annex 4.

Individual Risk

11.4.135 With the event frequencies and consequences, the individual risk contours for the study years are produced and presented in **Figure 11.4.3 (A – E)**. The maximum Individual Risk level is calculated to be 10^{-6} per year as indicated in the **Figure 11.4.3 A** without offsite impact which is considered acceptable in comparison with the Risk Guidelines ($1x10^{-5}$ / year i.e. 1 in 100,000 per year).

Societal Risk

11.4.136 The societal risk results for the Year 2012, 2016 and 2021 are presented in **Figure 11.4.4 (A – E)** in a form of FN curves for comparison with the Government Risk Guidelines. As shown in **Figure 11.4.4 A**, it can be seen that FN curves for all assessment years fall into the "ACCEPTABLE" region. The FN curves indicate that the Kerry DG Godown is in compliance with the Risk Guidelines.

11.4.137 Although the completion year for Cruise Terminal has been deferred beyond 2012, the population at the Cruise Terminal in this assessment has taken a conservative assumption by including the first berth. The population is estimated to be around 6300 in Year 2012 (population of 2100 at the cruise terminal + population of 4200 at the Phase I Berth). The risk impact of the Kerry DG Godown to population at the Cruise Terminal only is also acceptable while the overall risk is acceptable, **Figure 11.4.4 A**. Contribution of the Cruise Terminal to the overall risk is not significant.

11.4.138 Population of the Tourism and Leisure Hub (including commercial, hotel and entertainment) is expected to increase to around 12,000 at Year 2016 (Population of Tourism node of 5271 + population of 6400 at Phase II Berth). Given that the Tourism Hub at Year 2016 is to be located in the same area next to the cruise terminal with a population increase of 5271, the population of the Tourism and Leisure Hub will not be threatened by the Kerry DG Godown.

11.4.139 During construction phase, population induced by construction activities is a transient one. Besides, the number of personnel involved in construction activities is considered much less than the population generated in the operation phase. Risk level for construction phase should be the same or lower than the operation phase. Thus, risk impact associated with construction phase is covered by 3 future scenarios in this assessment and is at acceptable level.

Conclusions and Recommendations

Conclusions

11.4.140 Our study has taken into account snapshot of the warehouse inventory and the UK HSE guidelines on hazard assessment for chemical warehouse which specifies that the stock should be "the maximum quantity that is liable to be stored in the near future". In the absence of actual inventory records, the rationale of using PHI threshold in the hazard assessment is in line with international practice.

11.4.141 The assessment results indicate that the Societal Risk fall into "ACCEPTABLE" region in all scenarios Year 2012, 2016 and 2021. The offsite individual risk is also acceptable since it is less than $1x10^{-5}$ /year.

11.4.142 In particular, the following key points have been addressed,

- Maximum Inventory Level of Toxic Gases – The current assessment has taken into account the probability of storing toxic gases up to PHI limits based on the information provided by Kerry DG Godown operator and the prevailing market conditions, instead of based on the allowable licence limit of the godown. The probability for storing toxic gases up to PHI limits in Kerry DG Godown is therefore taken as 1/3650.

- Very Remote Possibility of Storing 50kg LPG Cylinder – As per the inventory information provided by the operator of the Kerry DG Godown, the Godown normally stores small disposable LPG containers. It is understood that registered gas supply companies had not and have no intention to store 50kg LPG cylinders at the Kerry DG Godown although there is no restriction on storage of 50kg LPG cylinders in the Godown. Accordingly, the probability of storing 50kg LPG cylinders in the Kerry DG Godown is very remote. Given the very remote possibilities for Kerry DG Godown to store 50kg LPG cylinders, a conservative probability of 1/3650 had been employed in the QRA.

- Individual Risk Criteria – The individual risk criteria stipulated in the EIAO-TM could take into account the probability of any individual present at any one location.

- Buoyancy and Dilution of Hot Smoke Plume – The SAFETI model has already take into account the dispersion and dilution of smoke plume by nature wind flow, further factors to account for the buoyancy of hot plume and smoke ingress are accounted for based on the approach adopted in the previously approved EIA reports.

- Evacuation of Affected Population for Warehouse Fire Events – It is understood that under warehouse fire events, FSD will make on-site assessment and implement necessary evacuation procedures to reduce risk to off-site population and a 99% successful rate of evacuation of the impacted off-site population was adopted in this QRA.

11.4.143 Contribution from the Tourism and Leisure Hub of the project is insignificant. The risk imposed by the Kerry Godown is within the "ACCEPTABLE" region and in compliance with the Hong Kong Risk Guidelines stipulated in Annex 4 of the TM.

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[76] Hazard to Life Assessment for Permanent Aviation Fuel Facility for Hong Kong International Airport (EIA-127/2006).

11.5 Hazard assessment for the existing Petrol cum LPG Filling Stations and Dedicated LPG Filling Stations

Introduction

11.5.1 There are five petrol cum LPG filling stations and two dedicated LPG filling stations within the boundary or in close vicinity of the Kai Tak project (**Figure 11.5.1**). **Table 11.5.1** shows the locations of the petrol cum LPG stations / dedicated LPG stations.

Table 11.5.1 Locations of the Petrol cum LPG Stations / Dedicated LPG Stations within Kai Tak Development

Type	No.	Address
Petrol cum LPG Filling Stations	1	Wang Chin Street, Kowloon Bay
	2	4 Kai Fuk Road, Kowloon Bay (West Bound)
	3	8 Kai Fuk Road, Kowloon Bay (West Bound)
	4	7 Kai Fuk Road, Kowloon Bay (East Bound)
	5	5 Kai Fuk Road, Kowloon Bay (East Bound)

Type	No.	Address
Dedicated LPG Filling Stations	6	Wai Lok Street, Kwun Tong
	7	Cheung Yip Street, Kowloon Bay

Assessment Approach

11.5.2 The hazard assessment follows the methodology for QRA of LPG installations [Ref 6] in Hong Kong and consists of the following four major tasks:

1. *Data / Information Collection*: collects relevant data / information which is necessary for the hazard assessment.

2. *Hazard Identification*: identifies hazardous scenarios associated with the petrol cum LPG stations / dedicated LPG stations.

3. *Frequency Estimation and Consequence Analysis*: estimates the frequencies of the identified hazardous scenarios, with consideration of the petrol cum LPG stations / dedicated LPG stations operation conditions. Then, analyzes the consequences of the identified hazardous scenarios.

4. *Risk Evaluation*: evaluates the risks associated with the petrol cum LPG stations / dedicated LPG stations operations. The evaluated risks would be compared with the Criteria for Evaluating Hazard to Life stipulated in Annex 4 of the TM to determine their acceptability. Risk mitigation measures would be identified if they are needed for the compliance of the Criteria.

11.5.3 The study area of 150m radius from the petrol cum LPG station / dedicated LPG station is adopted in the assessment. It is consistent with the previous approved EIA studies[2] where 150m study area of the LPG sites was considered.

11.5.4 The hazard assessment covers three scenarios:

- The risk of the petrol cum LPG station / dedicated LPG station at year 2012, the year that the first berth of the Cruise Terminal is commissioned.
- The risk of the petrol cum LPG station / dedicated LPG station at year 2016 represents the conditions of the second phase of population intake of KTD.
- The risk of the petrol cum LPG station / dedicated LPG station at year 2021 represents the conditions of the third phase of population intake of KTD.

Data / Information Collection

11.5.5 The following relevant data / information were collected:

- Layout plan of the petrol cum LPG stations / dedicated LPG stations
- LPG throughput and average number of vehicles visiting the petrol cum LPG stations / dedicated LPG stations
- Offsite Population
- Meteorological data near the stations (including atmospheric stability class, wind speed and wind direction)

[2] Allied Environmental Consultants Ltd. (2002). EIA for the Proposed Joint User Complex and Wholesale Fish Market at Area 44 Tuen Mun
Ling Chan + Partners Limited (2001). EIA for Proposed Headquarters and Bus Maintenance Depot in Chai Wan.

Layout Plan of the Petrol cum LPG Station / Dedicated LPG Stations

11.5.6 Site surveys have been carried out on 6 December 2007and 10 January 2008 respectively. General layouts and number of dispensers have been obtained during the site surveys. **Table 11.5.2** summarizes the details of the petrol cum LPG filling stations / dedicated LPG stations.

LPG Throughput and Average Number of Vehicles Visiting the petrol cum LPG stations / dedicated LPG stations

11.5.7 Information request on the LPG throughput and average number of vehicles visiting the stations was made to the oil companies. However, data could not be obtained from the oil companies due to business sensitivity.

11.5.8 Site surveys have been carried out on 6 December 2007, 10 January 2008 and 2 April 2008 to obtain the number of vehicles for LPG and petrol refueling. The forecast LPG and petrol consumptions and number of vehicle visiting the petrol cum LPG stations / dedicated LPG stations were estimated based on the number of vehicles visiting each station. **Table 11.5.2** summaries the estimated throughput and the average number of vehicles visiting the petrol cum LPG stations. The raw data of the site survey and detailed calculations are presented in **Appendix 11.5.1.**

Table 11.5.2 Estimated Throughput and estimated number of vehicles visiting the petrol cum LPG Filling Stations / dedicated LPG Filling Stations

Type	Station No.	Company	Tank Capacity	Estimated Annual LPG Throughput (tonnes)	Estimated Number of LPG Tankers visiting the stations (per year)	Estimated Number of Vehicles Visiting the stations (per day)	
						For LPG refuel	For LPG and Petrol refuel
Petrol cum LPG Filling Stations	1	Sinopec	2 x 16kL	3087	343	205	462
	2	ExxonMobil	1 x 30kL	1857	207	180	1192
	3	Shell	1 x 24kL	2710	301	180	626
	4	ExxonMobil	1 x 30kL	2560	285	240	1286
	5	Shell	1 x 25.4kL	4667	519	310	1167
Dedicated LPG Filling Stations	6	Sinopec	2 x 25.4kL	22509	2501	1495	1495
	7	Sinopec	2 x 25.4kL	10089	1121	984	984

Offsite Population

Residential and Employment Population

11.5.9 Residential and employment population at locations out of the KTD area were estimated based on the data from the 2003-based Territorial Population and Employment Data Matrix (TPEDM) - Scenario I[3,4] provided by the Planning Department, which estimates the population in various areas of Hong Kong at year 2006, 2011, 2016 and 2021. The TPEDM data of year 2016 and 2021 were adopted for the assessment scenarios.

[3] The essential postulation underlying the Scenario-I matrix is that some of the development proposals will not be fully materialized or according to the recommended schedule because the total supply of residential units and working space under these proposals exceeds the requirements of the future population and employment as projected. Scenario-II matrix, which has been assumed that all development proposals will be implemented on schedule and occupied with normal vacancy level, has also been prepared by Planning Department for year 2012 and 2016 only.
[4] The risk level at year 2021 is required for the assessment. Since population estimate at year 2021 is only available from Scenario I TDEDM, for sake of consistency in population data adopted in various hazard assessments, Scenario I TDEDM data will be adopted.

11.5.10 For population data at year 2012, it would be estimated by extrapolation method based on the TPEDM data of year 2011 and 2016, assuming the population would increase/decrease uniformly over the 5-year period.

11.5.11 It is noted that the Working Group on Population Distribution Projections (WPGD) produced projections of population distribution for 2006 to 2015 in October 2006. However, the data in the projections provides distribution only at the District Council District level (the whole territory is divided into 18 District Council districts) and only covers the residential population. For the TPEDM data, it provides distribution at the Planning Vision and Strategy (PVS) Zones (the whole territory is divided into 338 PVS zones) level and covers both residential and employment population. It can be noted that the TPEDM provides more population distribution data in a more detailed manner. Therefore, it is considered that adopting TPEDM data in the hazard assessment is more appropriate than adopting the WPGD projections data for year 2012.

11.5.12 For the estimation of the residential and employment population within the Kai Tak Development area for the three assessment scenarios, reference would be made to the population estimated in the current Study "Kai Tak Development Engineering Study cum Design and Construction of Advance Works – Investigation, Design and Construction" (Agreement No: CE 35/2006 (CE)), taking into account of the implementation programme of the KTD. Other populations such as the passengers and crews of berthing cruises and supporting vessels would also be estimated and considered in the hazard assessment.

Road Population

11.5.13 Traffic data of existing roads near the stations are obtained from the Annual Traffic Census of Transport Department to estimate the road population. The future traffic growth for assessment years 2012, 2016 and 2021 were forecasted based on the 2004-based Base District Traffic Models (BDTMs) provided by Transport Department with necessary updating and fine tuning. The road population was predicted based on the following equation and adjustment factor would be applied to extrapolate the road population at the assessment years:

Traffic Population
= No. of person/vehicle * No. of vehicles/hr * Road Length within the assessment area / Speed

11.5.14 Detailed data and calculation of the traffic populations are presented in **Appendix 11.5.2**.

11.5.15 As shown in Figure 1 of EIAO TM Annex 4, the criterion for hazard to human life is to meet the Risk Guidelines; the maximum offsite individual risk is specified. Therefore, only offsite population will be considered in the hazard assessment to quantify the offsite risk. In view that the public in cars waiting for refilling are located within the site boundary, those population are considered as on-site population and therefore are not considered in the current assessment that quantify the offsite risk. Populations outside the site boundary are considered in road population in offsite population above.

Indoor/Outdoor Population Distribution

11.5.16 The outdoor population would be calculated by applying an outdoor ratio to each population group. **Table 11.5.3** summarises the indoor/outdoor ratio for different population categories. For open space area, population would be estimated based on observation of other open space with similar nature when data is not available.

Table 11.5.3 Indoor/Outdoor Ratios for Different Population Categories

Population Category	Indoor (Outdoor) Ratio
Residential	0.95 (0.05)
School	0.95 (0.05)
Park	0.00 (1.00)
Road	0.00 (1.00)
Railway/Bus station	0.00 (1.00)
Marine	0.00 (1.00)

11.5.17 In order to reflect temporal distribution of population, time period is divided into 4 time modes namely daytime and night-time for both weekend and weekday. In general, assumption of temporal variation in population for different population categories is tabulated in **Table 11.5.4.**

Table 11.5.4 Temporal Changes in Population for Various Categories

Time period	Residential Dwellings	Shopping Centre	Industrial/Commercial Buildings
Weekday (day)	50%	50%	100%
Weekday (night)	100%	0%	10%
Weekend (day)	70%	100%	40%
Weekend (night)	100%	0%	5%

Meteorological Data

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

11.5.19 Meteorological data of year 2006 from Kai Tak Anemometer Station of the Hong Kong Observatory has been used for the assessment. Details of dominant sets of wind speed-stability class combination both daytime (**Table 11.2.4**) and night-time (**Table 11.2.5**) given in **Section 11.2.23** of this report.

Hazard Identification

Overview

11.5.20 Properties of LPG, petrol and diesel are reviewed and summarized in subsequent sections below. The hazardous scenarios associated with the petrol cum LPG station / dedicated LPG station operations were identified by the three essential tasks of Hazard Identification Process. The three tasks include: (1) Review of Historical Industry Incidents, (2) HAZID study and (3) Review of Relevant Studies.

Properties of LPG

11.5.21 LPG is a mixture of butane and propane. The gas is twice heavier than that of air. For a release of LPG, the nature of the combustion will depend on the timing of ignition and the size of the release.

11.5.22 Release of several tonnes of LPG, if ignited immediately, will produce a fireball. Initially the gas concentration in the mixture will be above the Upper Flammability Limit (UFL). As burning occurs around the edges of the release, this will entrain more air into the mixture and more combustion will take place. The process accelerates until the mixture rises above the ground as a ball of fire. A fireball may also result from a boiling liquid expanding vapour explosion (BLEVE). This results from the bursting of a vessel (due to a high internal pressure and a weakening of the vessel material, due to a fire for example). The vessel contents rapidly vaporise and are ignited.

11.5.23 If not ignited immediately, the gas will disperse and dilute. If ignition occurs when the gas concentration is between lower Flammability Limit (LFL) and Upper Flammability Limit (UFL), a flame front will propagate to produce a flash fire.

11.5.24 For small releases, immediate ignition will produce a long vigorous jet flame from the point of release. As for large releases, delayed ignition will generally produce a flash fire.

11.5.25 For all sizes of release the LPG will disperse harmlessly if there is no source of ignition.

Properties of Petrol/Diesel

11.5.26 Petrol is a mixture of low molecular weight hydrocarbons (C5 to C10) with a boiling point in the range 40-180℃. The flash point of petrol is below the average ambient temperature in Hong Kong (about 23℃). Petrol gives off flammable vapour. When the vapour is mixed with air in certain proportions, a risk of fire or explosion will exist. A concentration of 1% of petrol vapour in air can create a flammable atmosphere. If released, immediate ignition of petrol vapour will produce a pool fire. In a confined space, with delayed ignition, vapour could accumulate and produce an explosion. Without confinement, delayed ignition would produce a vapour flash back and a pool fire. Petrol is categorized as CAT5 Class 1 dangerous goods.

11.5.27 Diesel contains higher molecular weight compounds (C13 to C25) than petrol and is less volatile. Its boiling point ranges from 220-350℃. Due to its low flash point (around 76℃), a release of diesel will only present a hazard if exposed to excessive temperatures such as those resulting from a fire. Diesel is categorized as CAT5 Class 3 dangerous goods.

11.5.28 The fuel vapour is heavier than air and does not disperse easily in still air conditions. It tends to sink to the lowest possible level of its surroundings and may accumulate in tanks, cavities, drains, pits or other depressions.

11.5.29 Petrol and diesel float on the surface of water and may, along with its vapours, be carried for long distances from the initial source by water courses, sewers, ducts, drains or groundwater.

11.5.30 In general, petrol and diesel are considered safe when they are contained in an appropriate tank or container and only become hazardous when liquid or vapour escapes and comes in contact with an ignition source.

Review of Historical Industry Incidents

11.5.31 A review of incidents of LPG filling stations was carried out. Incident records over the last few decades show events such as BLEVE, explosion, and release of LPG.

11.5.32 Incident records of petrol/ gasoline filling stations over the last few decades show leakage / release of petrol products to be the dominant event. There were also some fire and explosion incident, but no offsite fatality caused by the petrol/gasoline release at the filling station was found.

11.5.33 A review on MHIDAS database of the relevant historical incidents of the same genus petrol cum LPG filling station / dedicated LPG filling station has been conducted. A search in the MHIDAS using the **keywords "LPG station", "petrol station" and "gasoline station"** has been conducted to identify incidents involving in the stations. A summary of these incidents are given in **Appendix 11.5.6.** The following scenarios were identified from the incidents review exercise:

For LPG

- Failure of tanker
- Failure of pipeline
- Failure of storage tank valve
- BLEVE of road tanker

For Petrol

- Spillage from road tanker
- Spillage from storage tank
- Spillage from delivery pipe
- Spillage from dispenser
- Ignition of vapour

11.5.34 Spillage scenarios of petrol can lead to fire and fireball explosion. For the petrol cum LPG filling stations, petrol fire and fireball explosion could escalate into LPG scenarios and vice versa.

HAZID Study

11.5.35 Structured What-If Technique (SWIFT) analyses were conducted in previous QRA studies to systematically identify potential hazardous scenarios associated with the petrol cum LPG stations / dedicated LPG stations. In view that the design and facilities for all the petrol cum LPG stations / dedicated LPG stations in Hong Kong should be standardized, hazard scenarios identified in the previous QRA studies in Hong Kong are reviewed.

Review of Relevant Studies

11.5.36 The methodology of QRA for the petrol cum LPG stations / dedicated LPG stations would be reference to "Quantitative Risk Assessment Methodology for LPG Installations" [Ref 6]. In addition, previous relevant EIA studies approved under the EIA Ordinance were reviewed which includes:

- EIA for Comprehensive Feasibility Study for the Revised Scheme of South East Kowloon Development
- EIA for the Proposed Joint User Complex and Wholesale Fish Market at Area 44 Tuen Mun
- EIA for Proposed Headquarters and Bus Maintenance Depot in Chai Wan
- EIA for Route 9 Between Tsing Yi and Cheung Sha Wan

Scenarios for QRA study

For LPG

11.5.37 The standard methodology of QRA for LPG filling stations is reference to "Quantitative Risk Assessment Methodology for LPG Installations" [Ref 6]. In addition to the previous relevant EIA studies[5] approved under the EIA Ordinance and the incidents review, hazardous scenarios associated with the LPG stations were identified. **Table 11.5.5** summarizes the identified failure cases of the petrol cum LPG filling stations / dedicated LPG filling stations.

[5] Allied Environmental Consultants Ltd. (2002). EIA for the Proposed Joint User Complex and Wholesale Fish Market at Area 44 Tuen Mun.
Ling Chan + Partners Limited (2001). EIA for Proposed Headquarters and Bus Maintenance Depot in Chai Wan.

Table 11.5.5 Identified Failure Case of the Petrol cum LPG Filling Stations / Dedicated LPG Filling Stations

Failure Types	Failure Cases
Spontaneous Failure of Pressurized LPG equipment	• Storage Vessel Failure • Road Tanker Failure • Pipework Failure • Dispenser Failure • Hose Failure • Vapour Return Line Failure • Release from Storage Vessel Pump Flange • Release from Storage Vessel Drain Valve
External Event	• Earthquake MMI VIII • Aircrafts crash
Delivery Failure	• Hose Misconnection Error • Hose Disconnection Error • Tanker Drive-away Error • Tanker Collision • Vehicle Impact with Tanker during Unloading • Storage Vessel Overfilling
Escalation	• LPG Road Tanker Boiling Liquid Expanding Vapour Explosion (BLEVE) due to fire in petrol filling facilities • LPG Road Tanker BLEVE due to jet fire from above ground LPG facilities

11.5.38 The above are the events which could result in LPG release. **Table 11.5.6** summaries the identified LPG release scenarios, which are consistent with the previous approved EIA studies.

Table 11.5.6 Summary of Scenario for LPG Release

Release Scenarios
Catastrophic Failure of a Storage Vessel
Catastrophic Failure of a Road Tanker
Partial Failure of a Storage Vessel
Partial Failure of a Road Tanker
Guillotine Failure of Liquid Filling Line to Storage Vessel
Guillotine Failure of Liquid Filling Line to Dispenser
Failure of Dispenser
Guillotine Failure of Hose during Unloading from Tanker to Storage Vessel, LPG Released from Tanker
Guillotine Failure of Hose during Unloading from Tanker to Storage Vessel, LPG Released from Vessel
Failure of Flexible Hose during Loading to LPG Vehicles, LPG Released from Dispenser
Failure of Flexible Hose during Loading to LPG Vehicles, LPG Released from Vehicle
Release from Storage Vessel Pump Flange
Release from Storage Vessel Drain Valve
Guillotine Failure of Vapour Return Line
Guillotine Failure of Liquid Line from Tanker to Loading Hose
BLEVE of Road Tanker

For Petrol/Diesel

11.5.39 The hazards associated with petrol were identified with reference to historical data, supported by data obtained from previous relevant studies. The identified hazardous scenarios are listed as follow:

- Spillage from road tanker (hazardous scenario 1)
- Spillage from storage tank (hazardous scenario 2)
- Spillage from delivery pipe (hazardous scenario 3)
- Spillage from dispenser (hazardous scenario 4)

11.5.40 Since ignition of spilled petrol from aboveground road tanker is deemed probable in the current Project, frequency of occurrence of this Scenario 1 is further assessed in **Section 11.5.50**.

11.5.41 As petrol/diesel vapour is heavier than air and does not disperse easily in still air conditions, it tends to sink to the lowest possible level of its surroundings. In view that all petrol storage vessels and pipework of Station 1-5 are underground, their content is therefore not likely to come in contact with potential ignition source. In the event of spillage and loss of containment, only land contamination problems are anticipated. As such, spillage scenario from storage tank and delivery pipe (hazardous scenario 2 and 3) will not cause off-site fatality.

11.5.42 Since petrol/diesel weighs heavier than air, so in the event of petrol/diesel release from aboveground dispenser, only limited quantity of petrol contained in the hose of dispenser will be spilled, while mass inventory of petrol will remain in the underground storage vessel in hazardous scenario 4. It is conservatively assumed that the dispenser could release [6]1.75 m^3 of fuel and the largest possible size of the liquid pool would be limited, with a radius of [7]7.47 m. Further, drainage system with petrol interceptor, which could contain up to [8]1.35m^3 of liquid, should be installed at the site boundary of the petrol cum LPG stations; the petrol/diesel spills would therefore remain confined on site. The spillage scenario from dispenser (hazardous scenario 4) will not cause off-site fatality.

11.5.43 In view of the above, the failure cases associated with petrol/diesel that are considered to have potential off-site impact are summarized below:

- Tanker Rupture
- Tanker Large Liquid Leak (Hole size : 100mm)
- Tanker Medium Liquid Leak (Hole size : 25mm)

11.5.44 With reference to information from EMSD website[9], the chamber of the underground fuel oil storage tank shall be constructed impervious to oil and water (i.e. structure made out of fine concrete). As underground spillage of containment will be confined during leakage incidents, there will be no leakages from underground petrol storage tanks into sewers/ underground pipe. Hence leakages from underground petrol storage tanks into sewers/ underground pipe will not be considered further in the assessment.

[6] 1.75 m^3 = 1.28m (Width of a standard dispenser) x 0.63m (Depth of s standard fuel dispenser) x 2.175 (Height of a standard fuel dispenser)
[7] According to USEPA (1999) "Risk Management Program Guidance for Offsite Consequence Analysis", the spilled chemical can be assumed to spread instantaneously to a depth of 10mm in an undiked area. Therefore, the 1.75m^3 of petrol from dispenser, if spilled and allowed to spread freely in undiked area, the radius of the spilled pool =$\sqrt{}$(1.75m^3/π 0.01m) = 7.47m.
[8] According to EPD website http://www.epd.gov.hk/epd/english/environmentinhk/eia_planning/guide_ref/rpi_ann2.html, the volume of a petrol interceptor for one compartment is 750 mm x 750 mm x 800 mm = 0.45 m^3. As there are 3 compartments in series, the total volume is 3 x 0.45 = 1.35 m^3
[9] With reference to EMSD website http://www.emsd.gov.hk/emsd/eng/about/gp_tcs_sd.shtml, General Specification of 5000 – 60000 Liter Underground Fuel Oil Storage Tank (drawing no. P-10243-014-A)

11.5.45 Fire and explosions during cleansing and maintenance of petrol storage tanks must be carefully controlled and planned. A permit-to-work system[10] should be established to make sure these activities are done safely covering all foreseeable events. According to HSE [7], the hazardous area in normal operation has a nominal 1m radius from the tank fill point. Due to the fact that it is a relatively small scale of effect zones and fire-rated wall should be erected between the filling area and the public area off-site, it is expected that this scenario will not contribute to the off-site risk. It is therefore not considered further in the assessment.

11.5.46 For external events of plane crash, the frequency for aircraft crash has been addressed for the MTKGWNP in section 11.2.39, the calculated accident rates are much smaller than order of 10^{-9}, aircraft crash causing failure within petrol cum LPG filling stations / dedicated LPG filling stations are therefore not considered in this study.

11.5.47 In view that there is at least 6m distance between the LPG stations site boundary and the locations of LPG / petrol facilities, as well as there is fire fighting equipments on site, external fire will not lead to the failure of petrol / LPG filling facilities. Therefore, external fire will not lead to any disastrous outcome (i.e. external fire leading to failure of petrol/LPG filling facilities and causing offsite fatality).

11.5.48 In addition, traffic accidents associated with the vehicles for refilling could lead to spillage scenario and it will be considered further in the assessment.

Frequency Estimation and Consequence Analysis

Frequency Estimation

11.5.49 In line with CFA ruling, the methodology of frequencies estimation are based on historical data and followed the approach of previous QRA studies approved by EMSD and previous EIA reports approved by EPD.

11.5.50 A review of historical data was carried out for LPG storage vessels and various LPG equipment failures in "Quantitative Risk Assessment for LPG Installations" [Ref 6]. The failure frequencies adopted throughout this QRA study are quoted from this Ref 6.

11.5.51 Release frequencies are derived from generic data on LPG release events [Ref 6]. Fault Tree Analysis (FTA) is employed to determine the occurrence frequency of the LPG release scenarios. In some LPG release scenarios, there are more than one hazard initiating event which would lead to LPG release, and the frequency would depend on the station-specific circumstances (e.g. number of LPG tanker visit). FTA permits the LPG release scenario occurrence frequency to be estimated from a logical model considering the applicable hazard initiating events and station specific circumstances.

11.5.52 FTA is the use of a combination of simple logic gates, "AND" and "OR" gates, to synthesize a failure model of the hazardous installation. The LPG release scenario frequency is calculated from failure data of more simple events (e.g. spontaneous equipment failure), which is based on the review of historical data.

11.5.53 It is assumed that the vessel inventories would be nominally full (85% maximum capacity of vessel) in 20% of time and there is nominal 60% vessel inventory in 80% of time[11]. Besides, based on the information provided by EMSD, LPG tankers will generally stay in the LPG station for 90 minutes per delivery, in which the first and last 5 minutes are used as setting up the equipment. As such, inventories of the road tankers are assumed to be full in 5.6% of time, 50% in 88.8% of time and 0% in 5.6% of time.

[10] As required by West Yorkshire Fire & Rescue Service, "Petrol Filling Stations Guidance on Managing the Risk of Fire & Explosion". (2003). In addition, clause 3.5 of Chapter 12 in HKPSG also stated similar work system.

[11] Site specific information for the LPG storage vessel inventories of Station 7 was obtained from EMSD on 18 April 2008. The average inventories of the two LPG storage vessels are 6.58 tonnes. With reference to the previous QRA studies carried out by Housing Authority (HA) and EMSD, the contents under pressure will equilibrate with atmospheric conditions, thus cause part of the liquid to flash instantaneously to vapour. As such, an instantaneous release mass of twice the flash fraction, 66.2% (2 x 33.1%) is adopted for cold catastrophic failure events of underground vessels for Station 7 and this mass are considered in addressing the consequences either as fireball or in a vapour cloud explosion for Station 7.

11.5.54 Sets of fault tree diagrams are attached in **Appendix 11.5.4**. Event failure frequencies are modified to account for the knock-on effect due to petrol fire and fireball explosion, as illustrated in **Appendix 11.5.8**. The estimated likelihoods of different release of LPG are summarized in **Table 11.5.8**.

Table 11.5.8 Estimated Frequencies of significant release of LPG

Release cases	Appendix	Station No.	Likelihoods (per year)	
			Full Inventory	60% Inventory (Vessel) / 50% Inventory (Tanker)
Catastrophic Failure of a Storage Vessel	11.5.4-1	1	7.48E-08	2.99E-07
		2	3.76E-08	1.50E-07
		3	3.84E-08	1.54E-07
		4	3.83E-08	1.53E-07
		5	4.02E-08	1.61E-07
		6	9.20E-08	3.68E-07
		7#	4.05E-07	
Catastrophic Failure of Road Tanker	11.5.4-2	1	3.54E-08	5.62E-07
		2	2.13E-08	3.39E-07
		3	3.11E-08	4.93E-07
		4	2.94E-08	4.67E-07
		5	5.36E-08	8.50E-07
		6	2.58E-07	4.10E-06
		7	1.16E-07	1.84E-06
Partial Failure of a Storage Vessel	11.5.4-3	1	2.02E-06	8.08E-06
		2	1.02E-06	4.09E-06
		3	1.02E-06	4.09E-06
		4	1.02E-06	4.09E-06
		5	1.02E-06	4.10E-06
		6	2.04E-06	8.16E-06
		7#	1.01E-05	
Partial Failure of Road Tanker	11.5.4-4	1	2.61E-06	4.14E-05
		2	1.57E-06	2.50E-05
		3	2.29E-06	3.64E-05
		4	2.17E-06	3.44E-05
		5	3.95E-06	6.27E-05
		6	1.90E-05	3.02E-04
		7	8.53E-06	1.35E-04
Guillotine Failure of Liquid Filling Line to Storage Vessel	11.5.4-5	1	2.58E-12	4.10E-11
		2	6.11E-12	9.70E-11
		3	3.61E-12	5.73E-11
		4	6.55E-12	1.04E-10
		5	6.68E-12	1.06E-10
		6	9.01E-12	1.43E-10
		7	5.22E-12	8.29E-11
Guillotine Failure of Liquid Filling Line to Dispenser	11.5.4-6	1	3.48E-08	1.39E-07
		2	8.21E-08	3.29E-07
		3	4.86E-08	1.94E-07
		4	8.78E-08	3.51E-07
		5	8.84E-08	3.53E-07
		6	1.24E-07	4.95E-07
		7#	3.59E-07	

Release cases	Appendix	Station No.	Likelihoods (per year)	
			Full Inventory	60% Inventory (Vessel) / 50% Inventory (Tanker)
Failure of Dispenser	11.5.4-7	1	2.28E-04	9.12E-04
		2	2.28E-04	9.13E-04
		3	2.28E-04	9.13E-04
		4	2.28E-04	9.13E-04
		5	2.28E-04	9.13E-04
		6	1.37E-03	5.48E-03
		7	5.71E-03	
Guillotine Failure of Hose during Unloading from Tanker to Storage Vessel, LPG Released from Tanker	11.5.4-8a	1	2.95E-07	1.18E-06
		2	1.79E-07	7.14E-07
		3	2.59E-07	1.04E-06
		4	2.45E-07	9.81E-07
		5	4.48E-07	1.79E-06
		6	2.16E-06	8.64E-06
		7	9.66E-07	3.86E-06
Guillotine Failure of Hose during Unloading from Tanker to Storage Vessel, LPG Released from Vessel	11.5.4-8b	1	7.66E-10	3.06E-09
		2	4.64E-10	1.86E-09
		3	6.73E-10	2.69E-09
		4	6.40E-10	2.56E-09
		5	1.16E-09	4.66E-09
		6	5.62E-09	2.25E-08
		7#	1.26E-08	
Failure of Flexible Hose during Loading to LPG vehicles, LPG Released from Dispenser	11.5.4-9a	1	1.11E-02	4.43E-02
		2	9.72E-03	3.89E-02
		3	9.72E-03	3.89E-02
		4	1.30E-02	5.18E-02
		5	1.67E-02	6.70E-02
		6	8.07E-02	3.23E-01
		7#	2.66E-01	
Failure of Flexible Hose during Loading to LPG vehicles, LPG Released from vehicle	11.5.4-9b	1	5.54E-03	
		2	4.86E-03	
		3	4.86E-03	
		4	6.48E-03	
		5	8.37E-03	
		6	4.04E-02	
		7	2.66E-02	
Release from Storage Vessel Pump Flange	11.5.4-11	1	8.72E-05	3.49E-04
		2	4.36E-05	1.74E-04
		3	4.36E-05	1.74E-04
		4	4.36E-05	1.74E-04
		5	4.36E-05	1.74E-04
		6	8.72E-05	3.49E-04
		7#	4.36E-04	
Release from Storage Vessel Drain Valve	11.5.4-12	1	9.60E-05	3.84E-04
		2	4.80E-05	1.92E-04
		3	4.80E-05	1.92E-04
		4	4.80E-05	1.92E-04
		5	4.80E-05	1.92E-04
		6	9.60E-05	3.84E-04
		7#	4.80E-04	

Release cases	Appendix	Station No.	Likelihoods (per year)	
			Full Inventory	60% Inventory (Vessel) / 50% Inventory (Tanker)
Failure of Vapour Return Line	11.5.4-13	1	2.88E-08	1.15E-07
		2	3.04E-08	1.22E-07
		3	3.56E-08	1.42E-07
		4	2.94E-08	1.17E-07
		5	4.50E-08	1.80E-07
		6	6.68E-08	2.67E-07
		7#	1.65E-07	
Guillotine Failure of Liquid Line from Tanker to Loading Hose	11.5.4-14	1	4.64E-06	1.85E-05
		2	2.80E-06	1.12E-05
		3	4.07E-06	1.63E-05
		4	3.85E-06	1.54E-05
		5	7.01E-06	2.81E-05
		6	3.38E-05	1.35E-04
		7	1.52E-05	6.06E-05
BLEVE of Road Tanker	11.5.4.-15	1	3.27E-10	5.19E-09
		2	1.98E-10	3.14E-09
		3	2.87E-10	4.56E-09
		4	2.72E-10	4.32E-09
		5	4.96E-10	7.87E-09
		6	6.17E-10	9.80E-09
		7	2.30E-10	3.66E-09

Noted:
Site specific information for the LPG storage vessel inventories was obtained from EMSD on 18 April 2008. The average inventories of the two LPG storage vessels are assumed to be 6.58 tonnes.

11.5.55 Taking into account the waiting and unloading time, it is assumed each tanker/truck would stop at the station for a maximum of 2 hours. The likelihood of different release of petrol is then calculated based on the approved SEKDCFS EIA study for events likelihood, number of vehicles movement in the station and time at the station. Event failure frequencies are modified to account for the knock-on effect due to LPG explosion, as illustrated in **Appendix 11.5.8**. **Table 11.5.9** summarizes the estimated likelihood of petrol release scenarios.

Table 11.5.9 Estimated Frequencies of Significant Release of Petrol

	Likelihood (per vehicle year)	Release Mass (kg)	Hole Size (mm)	Station No.	No. of Tanker per Year #	Likelihoods (per Year)	
						Without knock-on Effect##	With knock-on Effect###
Tanker Rupture	4.00E-8	9000	n/a	1	313	2.86E-09	9.30E-08
				2	1231	1.12E-08	2.16E-07
				3	543	4.96E-09	1.27E-07
				4	1273	1.16E-08	2.85E-07
				5	1043	9.53E-09	3.86E-07
				6			
				7			
Tanker Large Leak (liquid)	3.60E-8	9000	100	1	313	2.57E-09	9.27E-08
				2	1231	1.01E-08	2.14E-07
				3	543	4.46E-09	1.27E-07
				4	1273	1.05E-08	2.84E-07
				5	1043	8.57E-09	3.85E-07
				6			
				7			

	Likelihood (per vehicle year)	Release Mass (kg)	Hole Size (mm)	Station No.	No. of Tanker per Year #	Likelihoods (per Year)	
						Without knock-on Effect##	With knock-on Effect###
Tanker Medium Leak (liquid)	3.60E-8	9000	25	1	313	2.57E-09	9.27E-08
				2	1231	1.01E-08	2.14E-07
				3	543	4.46E-09	1.27E-07
				4	1273	1.05E-08	2.84E-07
				5	1043	8.57E-09	3.85E-07
				6			
				7			

Notes:
Annual petrol throughputs are estimated based on the site survey data and the assumptions that the average consumption for petrol is estimated to be 40L per vehicle and the density for petrol is 0.75 kg/L.
Frequency = likelihood per vehicle.year x no. of vehicles per year x (no. of hours of tanker at filling station / no. of hours per year).
Detailed calculation refers to Appendix 11.5.8

Consequence Analysis

11.5.56 Consequence analysis is conducted to provide a quantitative estimate of the likelihood and number of deaths associated with the range of possible outcomes (i.e. fireball, jet fire, flash fire) resulted from the identified LPG release scenarios. In this study, SAFETI *micro* is used to evaluate the consequence of both LPG and petrol release scenario.

11.5.57 Failure events which have potential off-site impact listed as follows are input into the model:

- Rupture of storage vessel
- Rupture of road tanker
- Partial failure of storage vessel
- Partial failure/Leak of road tanker
- Guillotine failure of liquid filling line to storage vessel
- Pump flange leak
- BLEVE of road tanker

11.5.58 By extracting the modeling results from SAFETI *micro,* **Appendix 11.5.7** summarize the consequence results of significant LPG and petrol release events.

11.5.59 In order to calculate the risk from flammable materials, information on ignition sources present in the study area needs to be identified. Such data has been input into SAFETI ignition file for the each ignition source. The risk calculation program (MPACT) will then predict the probability of a flammable cloud being ignited (delayed ignition) as it moves downwind over the sources.

11.5.60 Ignition source is an important parameter for determining the consequence due to delayed ignition. Source of ignition is identified to be associated with vehicles using the road carriageways. The following input has been entered into the ignition file to estimate the presence factor of the ignition source and the ignition probability:

- Probability of ignition for a vehicle was taken as 0.4 in seconds
- 68.5% and 31.5% of daily average population are assumed as the day-time road traffic density and the night-time road traffic density

11.5.61 Referencing Britter and MacQuaid, the calculated maximum LPG cloud height was 10 meter using the dense gas dispersion models. In view of this, in continuous release events, only population within the 10 meter cloud height (eg at the lowest 2 storeys or on ground) would be affected. Population in high rise building beyond second storey will be excluded in the continuous risk calculation. Similarly, for elevated road, such as Kwun Tong Bypass, where appropriate, it is reasonable to assume the impact arisen from continuous release to the road population to be negligible.

11.5.62 Consideration is also given to the protection provided by the firewall, which will minimize the offsite population impact of a jet fire release from a point source adjacent to the area protected by the firewall. Therefore, the road population immediately next to a firewall at the LPG station is deducted for the continuous release scenarios.

11.5.63 In instantaneous release events, a fireball will be formed upon immediate ignition. A fireball model of a ground hemisphere and lifted fireball is considered for the effect of fireball radiation. Thus, a fireball height of 1.25 times of the fireball diameter is calculated for the potential fatalities in the immediate vicinity of the petrol cum LPG stations / dedicated LPG stations. Based on a conservative yet realistic consideration, for instance, the fireball radiation effect is predicted to affect the population up to 95m above ground level at station 7.

11.5.64 Referencing "Quantitative Risk Assessment Methodology for LPG Installations" [Ref 6], a shielding factor is applied to allow shielding of buildings by other buildings from fireball effects. Shielding Factors are determined by the proportion of the building within the fireball diameter. For buildings which are partly inside the fireball diameter, that proportion of the building outside the fireball diameter is considered to be shielded.

Risk Summation

11.5.65 By combining the population data, meteorological data, results of frequency estimation and consequence analysis, risk levels due to the operation of petrol cum LPG station / dedicated LPG filling station at 2012, 2016 and 2021 would be characterized in terms of individual risk (presented by individual risk contours) and societal risk (presented by FN curves).

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

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

Individual Risk

11.5.68 The associated risk levels are shown in **Figure 11.5.5 - 11.5.11**. The risk levels are based on 100% occupancy as taken from the user manual of SAFETI *micro*. Risk contours of individual risk level of $1x10^{-6}$, $1x10^{-7}$ and $1x10^{-8}$ per year are shown. As observed in the figures, no off-site location was subjected to a risk greater than $1x\ 10^{-5}$ per year.

Societal Risk

11.5.69 The societal risks were evaluated for the range of incidents with the potential for fatalities in the vicinity and were shown in **Figure 11.5.12 - 11.5.18**. As shown in these figures, the societal risks associated with Station 1 to Station 7 fall within the "acceptable" region. As such, the associated societal risk was considered acceptable.

11.5.70 The total Potential Life Loss (PLL) and top 5 most significant risk contributors for the modeled case at Year 2021 for each petrol cum LPG station / dedicated LPG station are shown in **Appendix 11.5.5.**

Risk Mitigation Measure Identification

11.5.71 If the estimated off-site individual risk level is found to be > 1 x 10^{-5} per year or the societal risk level is found to be at the "ALARP" or "Unacceptable" region, practicable and cost-effective risk mitigation measures should be identified and assessed to reduce the risk level for the compliance of the risk guidelines.

Summary

11.5.72 The individual risk and societal risk associated with the petrol cum LPG filling stations / dedicated LPG stations were found to be "acceptable" in accordance with the criteria stipulated in Annex 4 of the EIAO TM. Therefore, the risk level is considered to be in compliance with the risk guidelines.

Reference

1. Allied Environmental Consultants Ltd., "Proposed Joint User Complex and Wholesale Fish Market at Area 44, Tuen Mun". (2002)

2. Atkins China Ltd., "Route 9 between Tsing Yi and Cheung Sha Wan". (1999)

3. CH2M Hill (China) Ltd., "New World First Bus Permanent Depot at Chai Wan". (1999)

4. HSE, "Dispensing Petrol HSG146 – Assessing and Controlling the Risk of Fire and Explosion at Sties where Petrol is Stored and Dispensed as a Fuel". (1996)

5. HSE, "Hazardous Installations Directorate". SPC/TECH/OSD/24. (2007)

6. Reeves, A.B., Minah, F.CC. and Chow, V.H.K., "Quantitative Risk Assessment Methodology for LPG Installations", Conference on Risk & Safety Management in the Gas Industry, EMSD & HKIE, Hong Kong. (1996)

7. West Yorkshire Fire & Rescue Service, "Petrol Filling Stations Guidance on Managing the Risk of Fire & Explosion". (2003)

8. Whittle, K., "LPG Installation Design and General Risk Assessment Methodology by the Gas Standard Office", Conference on Risk & Safety Management in the Gas Industry, EMSD & HKIE, Hong Kong. (1993)

9. Ove Arup & Partners Hong Kong Ltd., "Agreement No. CE32/99 Comprehensive Feasibility Study for the Revised Scheme of South East Kowloon Development". (2001)

10. Workbook on the dispersion of dense gases, Britter and MacQuaid, 1988

11.6 Conclusions

11.6.1 The combined risks to the Kai Tak Development from all hazardous installation is the sum of the risks to the Kai Tak population from Ma Tau Kok Gas Works North Plant and its facilities, Kerry DG Warehouse (Kowloon Bay), Kwun Tong DG Vehicular Ferry Pier and the existing petrol cum LPG filling stations and dedicated LPG filling stations. **Figure 11.6.1** shows the cumulative individual risk curve for all hazardous installations within Kai Tak Area respectively[12]. This is to fulfill Clause 3.2.2 (ix) of the EIA Study Brief which stated that the hazard to life section should assess the implication that any one or combination(s) of these facilities may have on early stages of the Project development.

11.6.2 For compliance checking, the individual risk and societal risk associated with the examined hazardous installations within or near the Kai Tak Development were found to be "acceptable" in accordance with the criteria stipulated in Annex 4 of the EIAO TM except the risk level for the MTKGWNP. The risk level of MTKGWNP at Year 2012, 2016 and 2021 would fall within "As Low As Reasonably Practicable (ALARP)" region. Given that the MTKGWNP is existing installations and no mitigation measure is practicable, the risk is considered to be in compliance with risk guidelines.

[12] The cumulative individual risk curve is calculated by taking arithmetic sum of IR for each facility.