MTR 港鐵

Consultancy Agreement No. NEX/1042

Environmental Impact Assessment of South Island Line (East)

Hazard to Life Assessment Final Report

July 2010

ERM

MTR Corporation Limited (MTR)

Environmental Impact Assessment of South Island Line (East):
Hazard to Life Assessment Final Report
Consultancy Agreement No. NEX/1042

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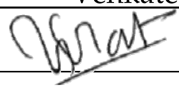
Reference 0086412

For and on behalf of
ERM-Hong Kong, Limited

Approved by: Venkatesh S.

Signed: 

Position: Director

Date: 28 July 2010

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1 INTRODUCTION

1.1 BACKGROUND

MTR Corporation Limited (MTR) is undertaking the design of the seven-kilometre South Island Line eastern SIL(E) section. SIL(E) construction is planned for 2010 to 2015. The proposed SIL(E) is a medium capacity railway with the objective to provide domestic passenger service between Admiralty and South Horizons. The railway extension project consists of an approximately 7 km long electrified railway system with five railway stations at Admiralty (ADM), Ocean Park (OCP), Wong Chuk Hang (WCH), Lei Tung (LET) and South Horizons (SOH).

The selection of construction methods has been optimised to minimise, as far as possible, the use of explosives depending on the type of material to be excavated. However, a significant amount of explosives will be required for the construction of rock caverns, tunnels and adits.

Excavation by blasting will be generally ongoing from November 2011 to August 2013.

To enable a timely delivery of explosives to site and in order to meet the proposed construction work programme, an Overnight Explosives Storage Magazine (Magazine) is required. The purpose of the temporary Magazine is to maintain progress rates for construction activities, i.e. to meet multiple blasts per day and also act as a buffer in case of delivery interruptions by Mines Division (Mines Division) of the Geotechnical Engineering Office (GEO), Civil Engineering and Development Department (CEDD).

Mines Division will deliver explosives and initiation devices (detonators) to the temporary Magazine by the shortest practicable route (but at this stage it is difficult to predict the route). This will be done on a daily basis and explosives and detonators will be withdrawn by the contractors as required. The transportation of explosives by Mines Division either to the temporary Magazine or directly to sites is under Mines Division's responsibility and falls outside the scope of this Environmental Impact Assessment (EIA).

The appointed contractors of MTR will transport explosives, in Mines Division licensed trucks, from the temporary Magazine to a particular construction site for daily or twice-daily blasts depending on the requirements for construction. Generally, the quantity of explosives that can be transported in any 3rd party contractor's truck is limited by the Mines Division to a maximum of 200 kg.

The explosives to be stored and transported from the temporary magazine to the construction sites will include detonators, detonating cord and cartridged emulsion.

ERM-Hong Kong, Limited (ERM) was commissioned by MTR to undertake the Hazard to Life Assessment (also referred as Quantitative Risk Assessment (QRA)) for the storage and transport of explosives during the Project Construction Stage and propose risk mitigation measures if necessary. The criteria and guidelines applicable for the Hazard to Life Assessment are stated in Annexes 4 and 22 of the Technical Memorandum (EIAO-TM Criteria).

Under Section 5(7) of the Environmental Impact Assessment (EIA) Ordinance (Cap. 499) (EIAO), the Director of Environmental Protection (Director) from the Environmental Protection Department (EPD) has issued a Study Brief No. ESB-181/2008 for this project (EIA Study Brief). *Section 3.4.5* of the EIA Study Brief specifies that a Hazard to Life assessment should be conducted for the Project. The relevant EIA Study Brief requirements for this study are quoted in *Table 1.1*.

Table 1.1 EIA Study Brief – Hazard to Life Requirements

3.4.5	**Hazard to Life**
3.4.5.1	If the Project will use explosives, the Applicant shall describe the statutory/licensing requirements with respect to explosives under the Dangerous Goods Ordinance (Cap. 295). The Applicant shall also document any guidelines and/or advice obtained from relevant departments/ authorities on the proposed transport and storage of explosives for the blasting activities.
3.4.5.2	If the proposed use of explosives for rock blasting is required and the location of overnight storage of explosives magazine is in close vicinity to populated areas and/or Potentially Hazardous Installation site (e.g. LPG Transit Depot at Lee Nam Road, Ap Lei Chau), the Applicant shall carry out hazard assessment as follows: (i) Identify hazardous scenarios associated with the storage and transport of explosives and then determine a set of relevant scenarios to be included in a Quantitative Risk Assessment (QRA); (ii) Execute a QRA of the set of hazardous scenarios determined in (i), expressing population risks in both individual and societal terms; (iii) Compare individual and societal risks with the criteria for evaluating hazard to life stipulated in Annex 4 of the TM; and (iv) Identify and assess practicable and cost-effective risk mitigation measures. (e.g. selection of the shortest practicable road transport routes to and from the magazine)
	The methodology to be used in the hazard assessment should be consistent with previous studies having similar issues.

3.4.5.3 The Applicant shall carry out hazard assessment to evaluate potential hazard to life due to the construction and operation of those parts of the Project which fall within the Consultation Zone of the LPG Transit Depot/Bulk Domestic Supply at Lee Nam Road.

The hazard assessment shall include the following:

(i) Identify hazardous scenarios associated with the facilities/activities of the LPG Transit Depot/Bulk Domestic Supply at Lee Nam Road and then determine a set of relevant scenarios to be included in a Quantitative Risk Assessment (QRA);

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

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

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

The methodology of the hazard assessment shall be agreed and approved by the Director.

This Appendix addresses the EIA Study Brief requirements (*Sections 3.4.5.1* and *3.4.5.2*) dealing with hazards to life posed by the storage and transport of explosives as part of this project.

This section of the EIA presents:

- The basis for the assessment;
- Description of the detailed methodology;
- The results for each QRA step; and
- The assessment of the risk against the EIAO-TM Risk Criteria.

The details of the methodology are elaborated further in various sections of this report.

1.2 *SCOPE OF HAZARD TO LIFE ASSESSMENT FOR THE STORAGE AND TRANSPORT OF EXPLOSIVES*

The Hazard to Life Assessment under this section of the EIA, addresses, in particular, the following:

- Storage of explosives at the proposed temporary Magazine (cartridged emulsion, detonating cord and detonators) including handling of explosives within the temporary magazine site; and
- Transport of Explosives to the delivery points.

The scope of the study concerns the transport of explosives (cartridged emulsion, detonating cord and detonators) from the temporary magazine to the construction sites.

Detonators are used in relatively small quantities and transported separately. Bulk emulsion and/or Ammonium nitrate – fuel oil (ANFO) will be used in

this project as the blasting explosives. Cartridged emulsion will be used to initiate the blasting explosives.

Bulk emulsion (unsensitised) is not classified as an explosive substance (i.e. Category 1 Dangerous Good) in Hong Kong (it is classified as Category 7 Dangerous Good, i.e. strong supporters of combustion) until sensitized within the blast holes at the excavation face, and hence is out of the scope of this study. ANFO, if used in this project, will be produced at the construction site by mixing an oxidizing substance i.e. Ammonium nitrate, classified as Category 7 Dangerous Good, with fuel oil. Although ANFO is classified as an explosive (Class HD 1.1D under United Nation Classification), it will not be transported to the construction site as such and hence falls outside the scope of this study.

To be consistent with West Island Line Project (ERM, 2008) and Express Rail Link Project (ERM, 2009), the risks associated with transport of explosives are limited to the delivery by contractor trucks up to the blasting sites boundaries and exclude the manual transportation from trucks.

The Hazard to Life Assessment presented in this section relates to the storage and transport of explosives during the construction phase of the project. There will be no explosives handled during the operational phase of the project.

1.3 *HAZARD TO LIFE ASSESSMENT OBJECTIVES AND RISK CRITERIA*

The main objective of this Hazard to Life Assessment is to demonstrate that the EIAO-TM Criteria will be met during the Project Construction Phase and to identify, where applicable, practical mitigation measures to ensure the EIAO-TM Criteria are met.

The study will particularly focus on the following:

- Identification of hazardous scenarios associated with the transport and storage of explosives for blasting operations;
- Preparation of a Quantitative Risk Assessment (QRA) to estimate risks to the surrounding population in both individual and societal terms;
- Comparison of individual and societal risks with the EIAO-TM Criteria to determine the acceptability of the assessed risk (i.e. the Hong Kong Risk Guideline (HKRG)); and
- Identification and assessment of practicable and cost effective risk mitigation.

1.3.1 *EIAO-TM RISK CRITERIA*

The individual risk guidelines and societal risk guidelines specified in Annex 4 of the EIAO-TM are shown below.

Individual Risk (IR)

Individual risk is defined as the frequency of fatality per year to a specific individual due to the realisation of specified hazards, with account taken of presence factors.

The maximum level of off site individual risk should not exceed 1 in 100,000 per year, i.e. $1x10^{-5}$ per year.

Societal risk

Societal risk is defined as the risk to a group of people due to all hazards arising from a hazardous operation. The simplest measure of societal risk is the Rate of Death or Potential Loss of Life (PLL), which are the predicted equivalent fatalities per year.

Societal risk is also expressed in the form of an F-N curve, which represents the cumulative frequency (F) of all event outcomes leading to N or more fatalities. This representation of societal risk highlights the potential for accidents involving large numbers of fatalities.

The societal risk guidelines expressed in the form of F-N curve is shown in *Figure 1.1*. There are three regions identified:

- Unacceptable region where risk is so high that it should be reduced regardless of the cost of mitigation or the hazardous activity should not proceed;
- ALARP region where risk is tolerable providing it has been reduced to a level As Low As Reasonably Practicable (ALARP);
- Acceptable region where risk is broadly acceptable and does not require further risk reduction.

The risk guidelines incorporate a special requirement (as seen in *Figure 1.1*), that no hazardous scenario shall cause more than 1,000 fatalities. If so, the risks are deemed 'unacceptable' and need to be reduced regardless of the cost.

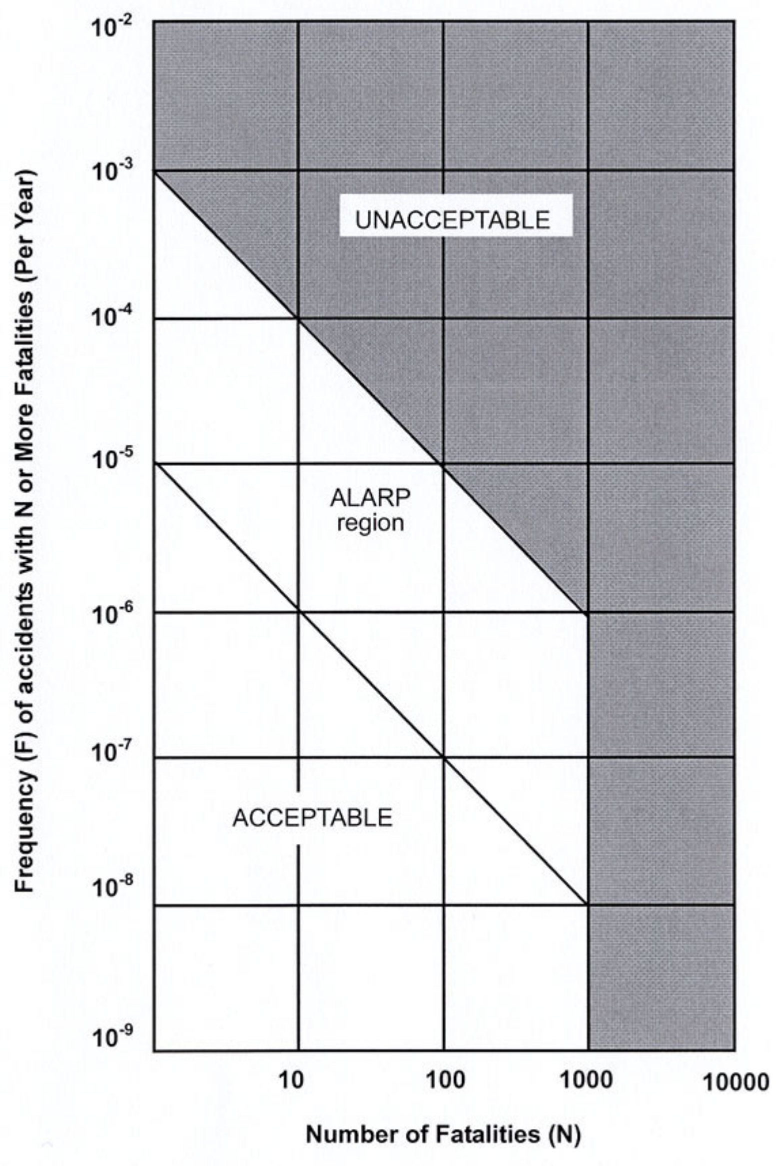
Application of Criteria

Making reference to other studies which involved the transportation of explosives in Hong Kong (ERM 2009, ERM 2008 , Maunsell 2006), the risk guidelines specified in the EIAO-TM Criteria have been applied to the combined risk of fatality associated with the storage and transport of explosives. Injures are not considered in the assessment and similarly, hazards due to operations within the construction site and magazine operation other than those involving explosives are also not considered.

The risk guidelines have been generally applied for public outside the boundary of the hazardous installation. In the context of this study, the risk guidelines are applied to the public outside the construction site and

temporary magazine. Risk to workers on the project construction site, MTR staff or its contractors have not been included in the assessment.

Figure 1.1 ***Societal Risk Criteria in Hong Kong***



2 PROJECT DESCRIPTION AND BASIS FOR THE ASSESSMENT

2.1 PROJECT OVERVIEW

The proposed SIL(E) is a medium capacity railway with the objective to provide domestic passenger service between Admiralty and South Horizons. The railway extension project consists of an approximately 7 km long electrified railway system with five railway stations at Admiralty (ADM), Ocean Park (OCP), Wong Chuk Hang (WCH), Lei Tung (LET) and South Horizons (SOH). Construction is planned for the period 2010 to 2015.

The Project mainly includes the following construction works outlined below as relevant for this QRA:

- Approximately 3.3 km long underground tunnel connecting the proposed underground station at Admiralty and the tunnel portal / box structure near Nam Fung Road (Nam Fung Portal);
- Approximately 2 km long railway viaduct including the railway bridge across the Aberdeen Channel from the Nam Fung Portal to the proposed tunnel portal near Sham Wan Towers (SWT portal), including two elevated railway stations at Wong Chuk Hang and Ocean Park;
- Approximately 1.6 km long underground tunnel connecting the proposed tunnel portal near Sham Wan Towers, the proposed underground railway stations near Lei Tung and at South Horizons;
- An at-grade railway depot at Wong Chuk Hang;
- A ventilation and electrical and mechanical plant building at Hong Kong Park adjacent to the British Council;
- A ventilation and electrical and mechanical plant building at Nam Fung Road adjacent to St. Paul's Co-educational Primary School;
- A ventilation and electrical and mechanical plant building with associated access adit at Lee Wing Street, Ap Lei Chau; and
- Construction of a temporary above ground explosives magazine site at Chung Hom Shan.

The proposed SIL(E) alignment and work areas are shown in *Figure 2.1*.

It is recognised that, from a risk point of view, blasting is not a desirable construction method; however, due to impracticability in using other techniques, blasting is required for some sections of the alignment. The selection of construction methods for the tunnels is detailed in VE01 – Options Report (MTR 1, 2008) and MN14 – Preliminary Design Final Report (Rev. A) (MTR 2, 2009). Details of the construction method, including the location and production rate are provided in Deliverable 3.13B Works Contract 902

Blasting Submissions (MTR 3, 2009) and Working Paper on Magazine Site Options Report (April 2010) (MTR 4, 2010).

The selection of construction methods has been optimised to minimise, as far as possible, the use of explosives depending on the type of material to be excavated. However, a significant amount of explosives will be required for the construction of rock caverns, tunnels and adits. It is envisaged that the following items of works for SIL(E) development will involve blasting.

- Rock excavation for Admiralty Station;
- Approximately 3.3 km long tunnel between Admiralty and Nam Fung Portal;
- A ventilation shaft located in Hong Kong Park;
- Site formation of Wong Chuk Hang Depot; and
- Station cavern for LET and the approach tunnels, access tunnels and shafts.

Excavation by blasting will be generally ongoing from November 2011 to August 2013.

The excavation works requiring the use of Drill and Blast Construction Method are summarised below:

Admiralty:

The blasting at Admiralty will consist of top heading and bench blasting within the station cavern. Access to the ADM station cavern will be from a large open excavation located at Harcourt Garden.

Hong Kong Park:

The blasting at Hong Kong Park includes the ventilation shaft and connecting adits. The ventilation shaft is located at the entrance to Hong Kong Park, adjacent to Supreme Court Drive.

Nam Fung Tunnel:

The Nam Fung Tunnel commences from the headwall of the Admiralty station cavern, located beneath Queensway, passes beneath One Pacific Place, the service road to One Pacific Place, the Island Shangri-La and Conrad Hotels, beneath the podium structure linking the two main hotel structures, then passes beneath Supreme Court Drive, the British Council, beneath Borrett Road, Carmel School, and then beneath Mount Cameron to the portal at Nam Fung. Most of the Nam Fung Tunnel will be excavated from the Nam Fung Portal.

Wong Chuk Hang Depot:

The proposed Wong Chuk Hang Depot is located at the site of the former public housing estate. Rock is anticipated to be encountered in the centre and northern edge, with soft ground at the southern side. Blasting is anticipated in order to excavate the rock.

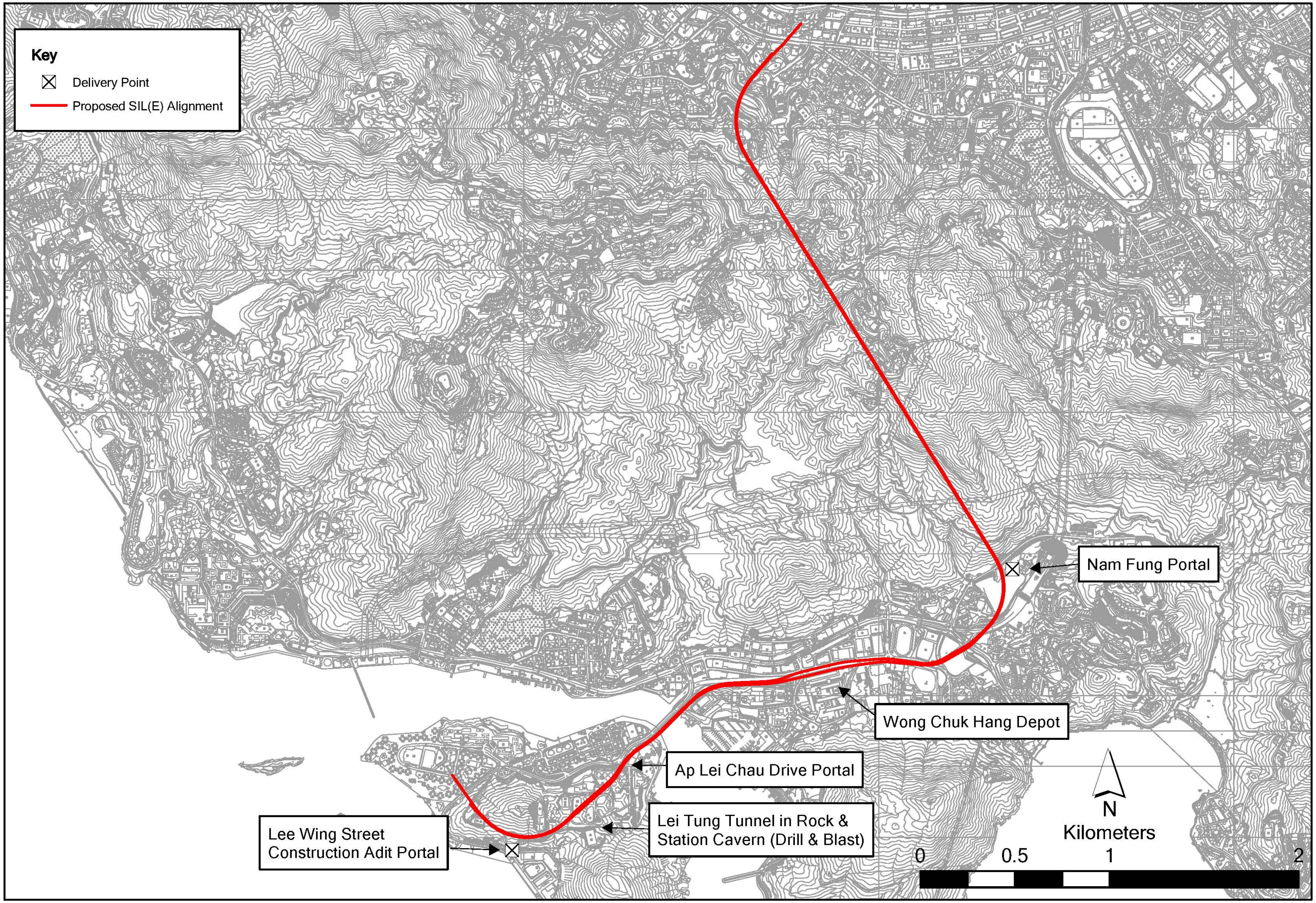
Lei Tung (LET):

The construction will be carried out from a construction adit with portal located at Lee Wing Street, on the southern side of Ap Lei Chau, close to South Horizons Industrial Estate. The LET station cavern commences beneath Tung Mau House, and extends beneath Lei Tung Estate Road and up to Yue On Court. The tunnel alignment then runs from the LET cavern to the Lei Tung portal. The access passage to Entrance B extends northwards from the station cavern to Wah Ting Street on the northern side of Ap Lei Chau.

South Horizon (SOH):

This construction will also be carried out from the construction adit at Lee Wing Street. The tunnel will pass underneath Yuk Kwai Shan service reservoir up to the SOH plant building. The SOH plant building extends beneath the hillside, passes the access road to the Yuk Kwai Shan service reservoir and extends up to Lee Nam Road.

Figure 2.1 SIL(E) Proposed Alignment and Work Areas



Four separate work contracts are envisaged for the construction of the SIL(E). Drill and Blast method will be used for rock blasting activities for a number of tunnel, cavern and adit sections. Mines Division will deliver explosives directly to ADM and WCH work areas. Explosives required for other work areas will be delivered by the appointed contractors to the designated work areas. The work areas and the associated contracts requiring explosives delivery by contractors are shown in *Table 2.1* below.

Table 2.1 SIL(E) Contracts and Works Areas Requiring Delivery by Contractors

Contract No.	Magazine Storage Requirement per contract	Works Area	Blast Faces	Delivery Point
902	300 kg	Nam Fung Tunnel	- Nam Fung Portal - Nam Fung Tunnel to ADM	Nam Fung Portal (Delivery Point 1b)
904	500 kg	Ap Lei Chau	- Construction adit - Running tunnel to LET - LET cavern top and bottom bench - Tunnel from LET to Lei Tung Portal - LET entrance adit B - LET Adit A - Running tunnel to SOH	Lee Wing Street Construction Adit Portal (Delivery Point 1a)

To enable a timely delivery of explosives to site and in order to meet the proposed construction work programme and allow for a buffer in the event of delays to replenishment of the temporary magazine, one explosive storage magazine is required. Several magazine locations have been investigated and the most suitable magazine site location has been identified at the south of Chung Hom Shan (CHS) (MTRC 4, 2009). The proposed temporary magazine will have two stores. Contract 902 will have an allocated explosive store with an explosive storage capacity of 300 kg. Contract 904 will have an allocated store with a capacity of 500 kg. These quantities of explosives are represented in gross weight, unless they are clearly specified as TNT eqv kg. No store will be shared between contractors. Detonators will be stored in a separate chamber within each store. Mines Division will deliver explosives and detonators to the temporary Magazine on a daily basis.

The appointed contractors of MTR will transport explosives in licensed trucks (licensed by Mines Division) to be operated by the contractors, from the temporary Magazine store to a particular construction site for the daily or twice-daily blasts depending on requirements for construction. Generally, the quantity of explosives that can be transported in any 3rd party contractor's truck is limited by the Mines Division to a maximum of 200 kg.

The explosives to be stored and transported from the temporary Magazine to the construction sites will include detonators, detonating cord and cartridged emulsion. Detonators will be stored in dedicated chambers and transported separately on dedicated trucks.

Drill and Blast will be used for a range of tunnel profiles, adits and caverns. Bulk emulsion will be used as far as practicable; however, in close proximity to sensitive receivers, Mines Division generally does not recommend the use of bulk emulsion where the Maximum Instant Charge (MIC) envisaged for a particular blast is below 2 kg. This prevents the occurrence of excessive vibrations due to potential bulk emulsion dosing inaccuracy (refer to the WIL QRA for the "use" of explosives (ERM, 2008)).

The main tunnel at Nam Fung will require an average full face excavation area of approximately 80 m^2. Each blast would require, on average 75 production holes and 40 perimeter holes. If a pull length of 4 m per blast is assumed, then each blast would need approximately:

- 13 kg of detonating cord with a Pentaerythritol Tetranitrate (PETN) load density of 40 g/m;
- 14 kg of cartridged emulsion (assuming the use of 125 g cartridged emulsion);
- ~500 kg bulk emulsion (sensitised on site) or ANFO (produced at site); and
- 115 detonators (Electronic detonators or Non-Electric detonators (1 g/ detonator)).

The other main blasting area where cartridged emulsion explosives will be used is the Ap Lei Chau area. Bulk emulsion will be used wherever possible such as for the excavation of the running tunnel towards SOH and the tunnels towards LET. Blasting of LET cavern will require an excavation area of 140 m^2 for top heading and bottom bench. Due to proximity to sensitive receiver, it is anticipated that bulk emulsion cannot be used for the top heading blasts. The cartridged emulsion requirement for a typical top bench blast at LET will be around 230 kg; while detonating cords requirements will be around 6 kg.

For all the construction work areas of SIL(E), the excavation advance rate will be limited by the proximity of sensitive receivers. For this reason, to achieve the required progress rates, the SIL(E) construction will generally follow a two blast cycle per day for most of the works areas.

2.2 EXPLOSIVE TYPES FOR SIL(E)

2.2.1 PROPOSED EXPLOSIVES

Two types of explosives will be used for the construction of SIL(E) by Drill and Blast methods. These are:

- Initiating explosives: cartridged emulsion explosives, detonating cord and detonators; and
- Blasting explosives: site-sensitised bulk emulsion explosives or site mixed ANFO.

In proximity to sensitive receivers (MIC lower than 2 kg), cartridged emulsion explosives will be used as the main blasting explosives.

Both the cartridged and bulk emulsions contain an oxidising agent mainly ammonium nitrate (single salt), water, and a hydrocarbon such as fuel oil. Cartridged emulsion contains 2-3% aluminium powder, which has been added at manufacture to increase the explosion temperature and hence its power. ANFO has similar composition but has no water or aluminium content.

Cartridged emulsion will be delivered from the temporary Explosives Magazine to the various construction sites by the appointed contractors using Mines Division licensed trucks.

Bulk emulsion precursor will be transported to the blast sites within the Adits/Tunnels by the appointed third party supplier. It only becomes classified as an explosive after being sensitized at the blast location or working face, by the addition of a gassing agent as it is pumped into the blastholes at the excavation face.

ANFO, if used, will also be prepared at the construction site.

Detonators and detonating cord will be used to initiate the blast at the working face. Detonators approved for use in Hong Kong are of the Non-Electric Type, i.e. initiated by shock tube or Electronic type detonator systems.

2.2.2 EXPLOSIVES PROPERTIES AND REGULATIONS

Explosives that are relevant to the SIL(E) project can be classified into two types:

- Blasting explosives; and
- Initiating explosives.

Their properties are shown in *Table 2.2*.

Table 2.2 Explosive Types

Type	Function	Use	Example
Blasting explosives	Explosive used as main blasting explosive	General blasting, Shattering rock/structures	Bulk emulsion, ANFO, Cartridged emulsion in closed proximity to sensitive receivers
Initiating explosives	To initiate the main blasting explosives	Initiation of secondary explosive	Detonators, Cartridged emulsion, Detonating cord

2.2.3 CARTRIDGED EMULSION

The cartridged explosive is designed as a small diameter packaged emulsion, which can be used for both priming and full column applications, particularly in underground mining. It is used for mining, quarrying and general blasting work.

It is packaged in a range of plastic films with the tips clipped at each end to form a cylindrical sausage, or wrapped in waxed paper. It is classified as a UN Class 1.1D explosive and Dangerous Goods (DG) Category 1 explosive under the Hong Kong classification system. It has a TNT equivalence of 0.96, i.e. 0.96 kg of TNT per 1 kg of emulsion.

Like all ammonium nitrate based blasting explosives, cartridged emulsion consists of a mixture of oxidisers and fuel. What makes emulsion unique is the high quantity of water it contains – typically around 10-14%. The oxidisers are typically ammonium nitrate, calcium nitrate or sodium nitrate. For cartridged emulsion used in Hong Kong, there is no perchlorate within the formulation. The fuels are waxes or oils such as diesel fuel. The mixture is complete with small amounts of emulsifiers (less than 1%), which keep the water and oil mixture homogeneous. Cartridged emulsion is detonator sensitive.

2.2.4 BULK EMULSION PRECURSOR

Bulk Emulsion has a similar composition to Cartridged Emulsion, except that it does not contain aluminium and is non-sensitized. The bulk emulsion precursor has a density of 1.38-1.40 gms/cc. Prior to sensitizing, it is not considered as an explosive and is classified as UN 5.1 oxidising agent and Dangerous Goods Ordinance (Cap. 295) Category 7, i.e. Strong Supporters of Combustion. This material is stored in a Category 7 store, which falls under the jurisdiction of the Fire Services Department (FSD), and not Mines Division.

Bulk emulsion precursor is stable under normal conditions and there is no major fire hazard before sensitization. Hazards associated with bulk emulsion precursor are mainly due to its oxidizing properties causing irritation to eyes and skin. Explosion is considered possible only under prolonged fire, supersonic shock or very high energy projectile impact.

Storage and transport of bulk emulsion precursor is not included within the scope of this study.

2.2.5 *BULK ANFO*

Depending on blasting requirements, ANFO may be used in this project. ANFO will be produced on site by using a mixing truck. ANFO consists of an oxidizing substance mixed with 6% by weight of diesel fuel oil. ANFO is classified as UN HD 1.1D.

2.2.6 *BLASTING EXPLOSIVE: BULK EMULSION OR ANFO*

Bulk emulsion or ANFO, depending on project requirements, will be used as the main or 'bulk' blasting explosives to excavate rock by tunnel blasting. Both will be manufactured on site and require the use of initiating explosives.

Bulk emulsion precursor is sensitised at the blast site by the addition of a gassing solution containing sodium nitrite. This is applied at the excavation face underground and is added to the charging hose downstream from delivery pump.

ANFO is manufactured on site by mixing an oxidizing substance with oil.

A delivery pump is used for the loading of the blasting explosives into the blastholes. There are two different types of pump driving mechanisms, which are:-

- Pneumatic; and
- Hydraulic.

Based on explosives expert experience, a hydraulic driven pump has a delivery accuracy of ± 100 g, compared to a pneumatic driven pump with an accuracy of ≥ 200 g.

For emulsion, a gassing solution is injected into the precursor to reduce the density to 0.8 to 1.1 g/cc at the discharge end of the loading hose. This sensitises the emulsion by producing nitrogen gas bubbles that aid the propagation of the detonation wave. Hence, the bulk emulsion does not become an explosive until it is pumped into the blastholes at the working blast face. The sensitised emulsion can then be detonated with the assistance of a small booster (generally, a stick of cartridged emulsion) and a detonator. The bulk emulsion, once it is gassed is classified as UN 1.5D explosives or a Dangerous Goods (DG) Category 1 explosives under the Hong Kong classification system.

Blasting explosives which are pumped into blastholes completely fill the blasthole and thus are 'fully coupled' to the rock. This results in improved explosive performance.

2.2.7 *DETONATING DEVICES (DETONATORS, DETONATING CORD)*

Detonators

Detonators are small devices that are used to safely initiate blasting explosives in a controlled manner. In the past, electric detonators were used. Since these are no longer used, this study focuses on to non-electric, or Shock Tube detonators and electronic detonators. Detonators are classified as either UN 1.1B, 1.4B, or 1.4S, or DG Category 1 explosives under the Hong Kong classification system.

Although detonators contain the most sensitive types of explosives in common use, they are constructed and packaged in a manner such that they can be handled and used with minimal risk. If accidentally initiated, they should have no serious effects outside the package.

Non-electric detonators are manufactured with in-built delays that are of various durations. This is to facilitate effective blasting to allow blast holes to be initiated sequentially one at a time, rather than instantaneously, thereby enhancing the practical effects of the blast and reducing the effects of vibration. The detonators to be used in this project will be either millisecond delay period detonators (MS Series) or half second delay detonators (Long Period or LPD).

The delay time of a Non-electronic detonator is controlled by the burning time of a pyrotechnic ignition mixture pressed into a 6.5 mm diameter steel tube, which is the delay element. This element causes the primary explosive, which is typically a small amount of lead azide, to detonate. This in turn, causes the secondary, or output, explosive to detonate, which is usually PETN (Pentaerythritol Tetranitrate). The quantity of PETN within each detonator is approximately 0.9 g. Each detonator has a delay time that is based upon the length of steel tube and the compaction of the pyrotechnic mixture within it. In designing the blasting of a tunnel face, the general principle is to select the required detonators to ensure that no two blastholes will detonate less than 8 ms apart.

The ignition of the pyrotechnic mixture is achieved by the use of shock tubes. This is a small diameter plastic tube that has a light dusting of explosive powder on the inside surface along its length. When ignited by a hot, high pressure impulse the explosive powder combusts at a rate of over 2000 m/s ± 200 m/s, and causes ignition of the pyrotechnic mixture within the detonator.

Electronic detonators consist of a logic core, a communication interface, storage capacitor(s) and the ignition element. The individual detonator delay times have to be programmed and an electrical digital signal is required to arm and fire. A number of systems are available typically undergoing a sequence of power-up, verification, arming (charging and calibration) and finally firing mechanisms. Generally, electronic detonators are receiving increasing acceptance in the blasting industry as they offer better timing accuracy, field programmability and safety features.

Detonating Cord

Detonating cord is a thin, flexible tube with an explosive core. It detonates continually along its length and is suitable for initiating other explosives that are detonator sensitive, such as cartridged emulsion. Detonating cord along cartridged emulsion is used in perimeter pre-split holes to provide a smooth tunnel profile. It can also be used for synchronising multiple charges to detonate different charges almost simultaneously. It is used to chain together multiple explosive charges. The core of the detonating cord is a compressed powdered explosive, usually PETN, and it is initiated by the use of a detonator.

2.3 STATUTORY/LICENCING REQUIREMENTS AND BEST PRACTICE

The Commissioner of Mines is the authority for the approval of explosives for use in Hong Kong, the transportation, storage and use of explosives, Cat. 1 under Dangerous Goods Ordinance (Cap. 295) or are prepared from Cat. 7 dangerous goods.

Mines Division is responsible for giving approval for the issue of Mine Blasting Certificate, Removal Permits for Explosives, Mode A Explosives Store Licence, Mode B Explosives Store Licence and Blasting Permits. A Mine Blasting Certificate permits the shotfirer to use explosives in blasting. A Removal Permit allows a person to move any explosives by land transport within Hong Kong. Mode A Explosives Store Licence permits the storage of blasting explosives. Mode B Explosives Store Licence permits the storage of certain types of explosives such as safety cartridges for industrial fastening tools, cartridges for small arms and marine distress signals. A Blasting Permit allows the Contractor to use explosives at a work site for carrying out blasting. The Division is responsible for regulating the delivery of explosives to blasting sites and carrying out audit inspections on blasting works at times that match with the works activities of the contractors.

2.3.1 TRANSPORT OF EXPLOSIVES

Supply of Detonators and Cartridged Emulsion Explosives

Detonators are imported into Hong Kong. Destructive product sample tests are conducted by the manufacturer before each order leaves the factory. For Non-electric detonators, these tests record the actual delay firing time of each sample detonator and must fall within the manufacturers upper and lower tolerances as dictated by their quality control and quality assurance (QC /QA) system. In the event that the tested sample falls outside of the delay time control, or tolerance limits the batch will be destroyed. The delay time, detonator shock tube length, batch number and date of manufacture are

printed on each vacuum bag (inner packaging) and the delay time is printed on the aluminium shell and the coil tag of each detonator, where the detonator shock tube length is also shown. Similar QC/QA systems are in place for electronic detonators, however in their case every detonator is tested in terms of communication response and firing voltage. The detonators will be imported into Hong Kong and stored at the Mines Division Kau Shat Wan (KSW) explosives depot. Users will then place orders from Mines Division for delivery to their on-site temporary explosives magazine or to their blasting site as appropriate.

Class 1.1D (Cat. 1) explosives are imported into Hong Kong and stored at the KSW magazine and delivered to end users (magazines or delivery points) by Mines Division on a daily basis as required.

Approved Explosives for Blasting in Hong Kong

Under Dangerous Goods (General) Regulations *Cap. 295B*, conveyance and storage of explosives in Hong Kong shall not be allowed except under and in accordance with a licence or permit granted by the Authority. A permit to convey (Removal Permit) and a licence to store (Mode A or Mode B Store Licence) shall not be granted by the Commissioner of Mines unless suppliers of the explosives have submitted the necessary information related to safety, classification, and labelling and packing for vetting. After vetting by the Commissioner of Mines, the explosives will be included in the approved list. All the explosives to be transported in the project will be in the approved list. The current approved list is available from the Commissioner of Mines via CEDD website (CEDD 1, 2009).

Blast Design

The design of the blast will consider the quantity and type of explosives needed including MIC (maximum instantaneous charge), number of detonators required, as well as the sensitive receivers near the blasting location. The blast design will be produced by the blasting engineer using computer aided tools, checked and approved by the project Registered Engineer (RE), and then endorsed by Mines Division prior to implementation. The blast plan will contain information covering the dimensions of the face to be blasted, MIC, location (generally tunnel chainage), size of blastholes, type and number of delay detonators required and powder factor (kg /m^3), which is defined as the ratio of mass of explosives used to the volume of rock removed by the blast.

Blast Loading and Execution

Based on the blast design, immediately prior to loading, the required and approved amount of explosives, cartridged emulsion, detonating cord and detonators for the blast will be collected by the Registered Shotfirer and delivered to the blasting site by the licensed Contractors' Vehicles. The collection of the correct quantity of blasting explosives and initiating explosives will be checked by the Registered Shotfirer, a representative from the supervising consultant (i.e. Resident Site Engineer, (RSE)), a representative from the Contractor, and sometimes on a spot-check basis, a representative from Mines Division.

Licensing Requirements for Transportation of Explosives from the Magazine to the Work Areas

Application for Removal of Explosives

Under Regulation 4 of the Dangerous Goods (General) Regulations, a Removal Permit is required for any person to move explosives in and out of the explosive stores. Some removals are exempted from this requirement which include:

- the removal of safety cartridges for industrial fastening tools not exceeding 5,000 rounds or 5 kg of explosives content whichever is the less, or
- the removal of safety cartridges and cartridges for small arms not exceeding 1,000 rounds if such removal has already been licensed under the Firearms and Ammunition Ordinance (Cap. 238).

Application for Approval of an Explosives Delivery Vehicle

The explosive vehicle should comply with the safety requirements set in the Requirements for Approval of an Explosives Delivery Vehicle (Guidance Note) issued by Mines Division (CEDD 2, 2010). The Guidance Note includes the following provisions:

Any contractor intending to transport explosives from a magazine to the blast sites on public roads shall submit an application to the Commissioner of Mines. The general conditions for approval are summarised as follows:

(a) The vehicle shall have a valid 'Roads Worthiness Certificate' issued by the Transport Department, with a valid vehicle registration document and a valid licence issued by the Transport Department;

(b) The vehicle shall be tested by a testing body certifying the relevant weights, including the 'Permitted Gross Vehicle Weight' and 'Vehicle Net Weight', in order to determine the 'Permissible Laden Weight' of the approved explosives delivery vehicle;

(c) An emergency procedure appropriate to the explosives being carried shall be approved by Mines Division; and

(d) The driver and attendant shall have documentary evidence that they have acquired the basic knowledge of handling explosives and the properties of explosives being carried; and are conversant with the emergency procedures.

Explosives Delivery Vehicle Design Features and Safety Requirements

The explosive delivery vehicle shall be designed and operated in accordance with the Requirements for Approval of an Explosives Delivery Vehicle (Guidance Note). Any improvements made to these requirements are

permitted subject to approval by Mines Division. The minimum safety requirements are summarised below:

Condition of Vehicle:

(a) The vehicle shall be powered by a diesel engine;

(b) The vehicle's design, construction and strength must comply with the Road Traffic (Construction and Maintenance of Vehicles) Regulations, Chapter 374, Laws of Hong Kong; and

(c) The vehicle shall be kept clean, in sound mechanical condition and roadworthy.

Condition of Cargo Compartment:

(a) The cargo compartment of the vehicle, including the floor, shall be constructed with sheet metal at least 3 mm thick and lined internally with at least 13 mm thick plywood, and there shall be no exposed ferrous metal in the interior of the goods compartment.

(b) The interior of the cargo compartment, including doors, shall be kept in good condition and free from defects or projections which might cause accidental damage to the packages.

(c) Electric wiring or electrical devices shall not be installed inside the cargo compartment.

(d) The door of the cargo compartment shall be capable of being locked.

(e) Proper stowage facilities shall be provided to secure the load in a stable manner during transportation.

Safety Provisions:

(a) The driver's cabin shall be separated by a distance of not less than 150mm from the cargo compartment of the vehicle.

(b) The exhaust system shall be located in front of the cargo compartment of the vehicle.

(c) A quick-action cut-off at an easily accessible position shall be fitted to the fuel feed pipe and shall be clearly identified in Chinese and English languages, by a label prominently and legibly stating –

"EMERGENCY ENGINE STOP 緊急死火掣".

(d) At least two serviceable water or carbon dioxide fire extinguishers with a minimum capacity of 2 kilograms each shall be mounted on the vehicle in an easily accessible position.

(e) All electrical installations shall be designed, constructed and protected so that they cannot cause any ignition or short-circuit under normal conditions of use of the vehicle or its electrical installations, and so that the risk of this occurring will be minimized in the event of an impact or deformation. All electrical wiring and fittings shall be shrouded in fire resisting conduits.

(f) The fuel tank shall be located either to the front or below the cargo compartment of the vehicle. It shall be protected from accidental damage, and designed to prevent accumulation of spilt fuel on any part of the vehicle.

(g) Fire resistant material shall be fitted between the wheel arches and the goods compartment.

(h) Explosives and detonators shall not be carried on the same vehicle.

Signage on Vehicle:

(a) Whenever the vehicle is carrying explosives, there shall be displayed:

(i) on both sides of the cargo compartment a placard (of minimum dimensions 250 mm x 250 mm) showing the label of the highest Hazard Code of explosives (see Specimen Labels of Hazard Code in *Section 2.2* of the document (CEDD 2, 2010), and

(ii) in a prominent position a rectangular red flag of dimensions not less than 230mm x 300mm.

(b) A placard showing "EMPTY 空車" shall be displayed when the vehicle is empty.

(c) The vehicle shall be painted in white with warning words in the Chinese and English languages of at least 150 mm height as follows:

"DANGER – EXPLOSIVES" and "危險 – 爆炸品"

of red colour displayed on both sides and rear face of the goods compartment.

A typical contractor's explosives vehicle within a typical Hong Kong Mode A Explosive Store is shown in *Figure 2.2*. It is to be noted that truck shown on the figure was used on the MTR Penny's Bay Link project in 2003, and at this time the vehicle was not required to be painted white.

Figure 2.2 ***Typical Contractor's Explosives truck and Magazine***

2.3.2 STORAGE AND USE OF EXPLOSIVES

Explosives Magazine

The temporary Magazine will comply with the general requirements from the Commissioner of Mines with respect to the construction of the store and security measures to be adopted. These general requirements are defined in the document "How to Apply for a Mode A Explosives Store Licence" (CEDD 3, 2009). Each magazine will be a single storey detached bunded structure with dimensions as specified on Mines and Quarries Division Drawing MQ1630 "Typical Details of Explosives Magazine – Plan A". All magazine buildings will each be fenced and secured in accordance with the

Commissioner of Mines' requirements and surfaced road access suitable for 11 tonne trucks will be provided for delivery of explosives. The main requirements are summarized below:

The following are the general requirements (CEDD 3, 2009) from the Commissioner of Mines in processing the application:

(a) The maximum storage quantity should normally not exceed 1000 kg.

(b) The safety distances requirements from the UK Manufacture and Storage of Explosives Regulations 2005 for an explosives magazine will be used to assess the suitability of the proposed store location. A store made of substantial brickwork surrounded by earth mound is recommended. If the proposed Mode A store is in a densely populated area, a minimum separation distance of 400 m from buildings is normally required.

(c) No proposed Mode A store shall be located within 45 m and 75 m on plan from any high tension power cables carrying 440 V or 1 KV respectively. Diversion of the cables will be required if there is no alternative location.

(d) Approval from the Commissioner of Police will be required on the security aspects of the Mode A store location and on the security company.

(e) No other materials, likely to cause or communicate fire or explosion, shall be transported in any vehicle carrying explosives and no passengers other than persons assigned to assist in handling explosives shall be permitted on a vehicle transporting explosives. The driver and all workers engaged in the loading, unloading or conveying of explosives shall be trained in fire fighting and precautions for the prevention of accidents by fire or explosion.

The following are the general requirements for the construction of the blasting explosives Mode A store:

(a) The store shall be a single storey detached structure with lightning protection and outer steel Mode A store doors.

(b) All hinges and locks shall be of non-ferrous metal.

(c) No ferrous metal is to be left exposed in the interior of the Mode A store.

(d) The interior and exterior walls of the Mode A store shall be painted white.

(e) The outer steel doors shall be painted red. The words

"DANGEROUS – EXPLOSIVES" and "危險 – 爆炸品"

shall be written in white on the outside of each door. The letters and characters shall be at least 10 cm high.

(f) A security fence surrounding the Mode A store shall be installed and set back at least 6 m from the Mode A store. The fence shall be 2.5 m high, stoutly constructed of chain link fencing having a mesh size not exceeding 50 mm. The fence shall be firmly fixed to metal or concrete posts and topped with a 0.7 m outward overhang of razor-bladed wire. The base of the fence located between the posts shall be secured with pegs to prevent intrusion.

(g) The area between the security fence and the Mode A store shall be cleared of all vegetation. Vegetation clearance should also apply to a minimum distance of 1 m on the exterior of the fence. A uniform cross-fall of at least 1 in 100 away from the Mode A store to a drainage system shall be constructed.

(h) Electric flood lighting, from at least eight light poles spaced along the security fence, shall be provided to illuminate the area between the Mode A store and the security fence and the area directly outside the security fence.

(i) The gate in the security fence shall be fitted with a lock of close shackle design with key-intention feature. A warning notice board with prohibited articles and substances painted in red and black, shown in symbols and in Chinese and English characters shall be posted at the gate. Each symbol shall be at least 10 cm in diameter. A sample of the warning notice board is available upon request from the Mines Division.

(j) A guard house for the Mode A store should be provided. Armed security guards shall be on duty outside the security fence adjacent to the gate. This guard house shall be protected by a separate fence.

(k) Inside the guard house, an arms locker constructed as an integral part of the house and fitted with a lock shall be required.

(l) A telephone shall be provided in the guard house.

(m) A watchdog should normally be provided for the store.

(n) The road leading to the Mode A store shall be surfaced. It shall be constructed and maintained so that it can be used by 11 tonne trucks under all adverse weather conditions. A suitable turning circle or other alternative means for these trucks shall be provided so that the trucks can be driven up to the gate of the security fence.

(o) Fire fighting installations consisting of four fire extinguishers, four buckets of sand to be positioned on two racks within the area between the security fence and the Mode A store and as near as is convenient to the Mode A store doors. In addition, the Fire Services Department (FSD) may require other additional fire fighting installations.

Explosives Produced at Blast Sites

Bulk emulsion explosives and bulk ANFO are commonly manufactured at blast sites and used immediately for rock blasting. Under Regulation 31A of the Dangerous Goods (General) Regulations, *Cap. 295B*, a licence is required to manufacture a nitrate mixture outside a factory as Category 1 dangerous goods. The Commissioner of Mines is the Authority for issuing the licence.

The Manufacturing Unit (MU) shall respect the following requirements:

The owner of an MU should make an application to the Commissioner of Mines in writing for approval of the MU for manufacture of bulk explosives at blast sites. An approval of the MU will be issued, subject to satisfactory compliance with the following documentation requirements:

(a) A manual on operation of the equipment fitted to the MU and on procedures for manufacturing explosives;

(b) Procedures for safe handling and use of the manufactured explosives;

(c) Procedures for disposal of any waste product;

(d) A risk assessment on overheating, building up of high pressure at product pump, etc., and the associated control measures on how to prevent the hazards during the manufacturing process of explosives;

(e) Emergency response plan to deal with hazards of the raw materials being transported, fires on carrying vehicle, etc and an emergency contact list; and

(f) Technical and safety information set out in Annex A of the document (CEDD 4, 2007).

For surface or underground transport by vehicles, the Transport Unit (TU) carrying a Manufacturing Unit (MU) must comply with the following requirements:

(a) It shall have a diesel-powered engine.

(b) The TU carrying an MU shall be roadworthy with a valid vehicle licence issued by the Commissioner for Transport.

(c) The TU shall be equipped with an emergency stop at an easily accessible position.

(d) All cables to rear lights shall be fitted with fire resisting conduits.

(e) The TU shall be equipped with two 9 kg dry chemical powder fire extinguishers.

(f) The TU shall be equipped with personal protective equipment, which shall be worn by all operators appropriate to the products being handled, in accordance with the MSDS.

(g) No explosives, detonators or other dangerous goods shall be carried on the TU.

(h) Where mechanical track haulage is used for underground transport, the electric locomotive shall pull the trailer carrying the MU as close as possible to the blast face. The locomotive shall be equipped with:

(i) Effective headlights and rear lights, and

(ii) Adequate earthing provisions.

Storage of Cat. 7 Dangerous Goods

Ammonium nitrate (AN) is used for manufacturing bulk emulsion explosives and bulk ANFO at blast sites. Under Regulation 3 of the Dangerous Goods (Application and Exemption) Regulations, *Cap. 295A*, AN is classified as Category 7 – Strong Supporters of Combustion. A licence for the storage of Cat. 7 Dangerous Goods (DG) is required. The Fire Services Department is the authority for issuing the licence.

The following are the general requirements from the Fire Services Department (FSD) in processing the application:

(a) The Dangerous Goods store is to be provided in accordance with plans approved by the Director of Fire Services.

(b) High and low level ventilators covered internally with brass wire gauze and externally with non-corrodible metal gratings to be provided to the store.

(c) "NO SMOKING" notices and the names of the Dangerous Goods in 120 mm English and Chinese characters to be painted on the door of the store.

(d) A 'Cat. 7 D.G.' plate, which may be purchased from Fire Protection Command Headquarters, to be provided and fixed at a conspicuous position above the main entrance to the premises.

(e) One 9-litre water type fire extinguisher and two buckets of sand to be provided and allocated outside the Dangerous Goods store near the doorway.

(f) No storage of any articles or goods to be effected in the vicinity of the store tank.

(g) No shades over any open yard to be permitted.

(h) The interior of the Dangerous Goods store and around the premises is to be cleared of rubbish and maintained in a clean and tidy condition.

(i) The ultimate licensee/user must confirm in writing to the Department that he is in fact in receipt of the approved plans and set of FSD requirements.

(j) The actual layout of the installation is to be in accordance with the plans approved by Director of Fire Services.

(k) If mechanical ventilation is provided, details/plans to be submitted to the Ventilation Division of the FSD for approval prior to the commencement of work.

(l) Any proposed alteration to the Fire Service Installation on the premises to be carried out by a registered Fire Service Installation Contractor (appropriate to the class) and amended Fire Service Installation plan are required to be approved by the FSD, prior to the commencement of work. The installation is to be tested to the satisfaction of the FSD.

(m) Lighting rod and earthing connections shall be provided to the store.

Detailed requirements for the storage of Dangerous Goods will be provided upon the owners of the storage units making an application to the Fire Services Department in writing. An approval licence will then be issued, subject to the satisfactory compliance with the requirements.

For outside emulsion matrix Category 7 storage, FSD would typically require compliance with the following requirements:

(a) The compound shall be fenced.

(b) A six metre clearance should be maintained between the tank(s) and the fence in all directions.

(c) Adequate lightning protection shall be provided.

(d) The bund shall be able to contain at least 110 % spill of the largest tank inside the bund.

(e) Sand/water buckets and appropriate fire extinguishers should be made available.

(f) Safety signage should be provided.

(g) There should not be any other combustible material within the compound.

2.4 DESIGN AND LOCATION OF THE EXPLOSIVE MAGAZINE

Most of the deliveries in areas such as Admiralty, Hong Kong Park and the WCH depot will be made directly by Mines Division.

The temporary Magazine is required to serve the delivery points at the Nam Fung Portal (Contract 902) and Ap Lei Chau (Contract 904). Potential magazine site locations in both Hong Kong Island and Lamma Island have been investigated. Based on SIL(E) Magazine Site Selection Report (MTR 4), one site has been identified suitable for locating the temporary Magazine in compliance with the separation requirements of Mines Division. The location of the temporary Magazine is in Chung Hom Shan shown in *Figure 2.5*.

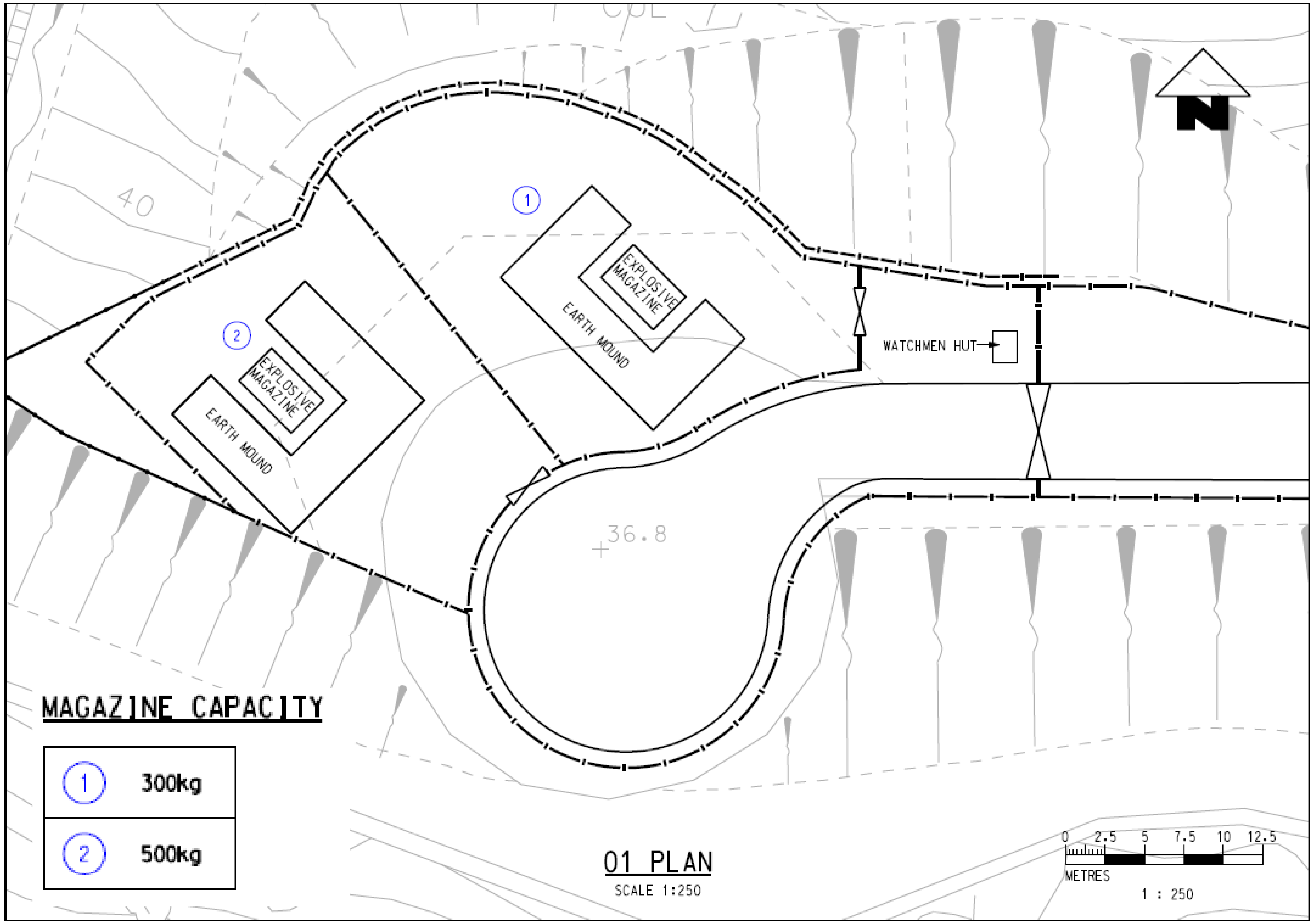
The temporary magazine is generally designed to store sufficient quantities of explosives for two days so as to allow blasting to be carried out 24 hours per day and provide a buffer in the event of delivery interruption to the temporary Magazine by Mines Division. The storage quantity for each magazine structure has been determined with sufficient margin by the design consultant based on estimated project explosives consumption.

The site is located in area of low population density. The only potential sensitive receiver in the area is the PCCW satellite receiving station which is located more than 190 m away from any of the temporary Magazine stores. In order to comply with the Mines separation distance requirements, a configuration has been adopted that comprises 2 magazine stores. A preliminary magazine design plan for this site is provided in *Figure 2.3*. Store 1 is allocated to the Contract 902 and Store 2 is allocated to the Contract 904.

The aerial photo of the temporary magazine site is shown in *Figure 4.1*.

The Natural Terrain Hazard Report and Boulder Assessment Report have formed the basis for the Hazard to Life Assessment for the Temporary Explosives Magazine.

Figure 2.3 Chung Hom Shan Magazine Site Layout



2.5 *CONSTRUCTION CYCLE AND PROGRAMME OF THE SIL(E) TUNNELS, ADITS AND CAVERNS*

2.5.1 *CONSTRUCTION CYCLE*

After commissioning of the temporary Magazine the proposed delivery-storage-blasting cycle will consist of the following elements:

1. Weekday morning deliveries of explosives and initiating systems to each magazine by Mines Division as needed.

2. Storage in the magazine store(s). Each contractor will have one dedicated explosives store.

3. Transfer from the explosives store(s) to the delivery points of the construction areas utilizing public roads via routes as indicated in *Figure 2.5* and *Table 2.10*.

4. Transfer to the working face(s) of the excavation via the tunnels or underground adits.

5. Load and fire the face(s) to be blasted. Blasts in a particular area will be initiated from a common firing point once all personnel are clear and entry routes to each blast site are secured. All blasts are to be carried out underground.

2.5.2 *DRILL AND BLAST INITIATING EXPLOSIVE REQUIREMENTS*

Based on the envisaged SIL(E) construction programme, the Drill and Blast activities together with the required amount of initiating explosives is summarised as shown in *Table 2.3*. The actual amount of initiating explosives is based on the tunnel profiles described in *Table 2.4* and the types of explosives listed in *Table 2.5*.

Table 2.3 *SIL(E) Drill and Blast Explosive Requirements (Summary)*

Works Area	Delivery Point	Blast Face	Approximate No of Blasts	Explosive Load (kg/blast)
Nam Fung Portal (Contract 902)	1b			
		Portal	947	37 - 196
Ap Lei Chau (Contract 904)	1a			
		LET Construction Adit	45	47 – 187
		Main Tunnel to Lei Tung Station	170	48 – 194
		Lei Tung Station Cavern	181	19-156
		Lei Tung Station Entrance B	66	27-119
		Main Tunnel to South Horizons Station	105	45-56

Works Area	Delivery Point	Blast Face	Approximate No of Blasts	Explosive Load (kg/blast)
		Lei Tung Station Cavern – Main Tunnel	109	62-168

Table 2.4 *SIL(E) Drill and Blast – Typical Tunnel Profiles*

Profile Description	Section Area (m²)	No of production holes	No of perimeter holes	Cartridged Emulsion (kg)	Detonating Cord (kg per metre drilled)	Detonators (kg)
Nam Fung Portal (using cartridged emulsion)	80	160	50	193	0.08	0.20
Nam Fung Portal (using bulk explosive)	80	100	50	35	0.08	0.14
LET Construction Adit (using cartridged emulsion)	89	180	50	184	0.08	0.21
LET Construction Adit (using bulk explosive)	89	110	50	39	0.08	0.14
Type B Running Tunnel to LET (using cartridged emulsion)	89	180	50	198	0.08	0.21
Type B Running Tunnel to LET (using bulk explosive)	89	110	50	39	0.08	0.15
Type A Running Tunnel to LET	122	150	60	50	0.08	0.19
Type C Single Tunnels	56	70	40	27	0.08	0.10
LET Cavern Blasting – Top Heading (using cartridged emulsion)	120	240	80	327	0.08	0.28
LET Cavern Blasting – Top Heading (using bulk explosives)	120	145	80	54	0.08	0.20
LET Cavern Blasting – Middle Bench	200	89	0	43	0.08	0.16
LET Cavern Blasting – Bottom Bench	200	89	0	43	0.08	0.16
LET Entrance Adit B	89	110	50	39	0.08	0.15
LET Adit A (using bulk explosives)	27	33	30	14	0.08	0.05
LET Adit A (using cartridged emulsion	27	55	30	65	0.08	0.07
Type C LET-WCH (using cartridged emulsion)	56	115	40	82	0.08	0.14
Type C LET-WCH (using bulk explosive)	56	70	40	27	0.08	0.10
Type B Tunnel to SOH	89	110	50	39	0.08	0.15
Type A Tunnel to SOH	122	150	60	50	0.08	0.19

Table 2.5 *SIL(E) Drill and Blast – Initiating Explosive Types*

Explosive	Quantity per Production/Perimeter Hole
Cartridged emulsion	0.125 kg (125 g per cartridged emulsion) [1]
Detonating Cord	0.080 kg/m based on density of 0.040 kg/m (40 g/m)
Detonator	0.001 kg (0.9 g each)

Note 1: For blast where MIC is lower than 2 kg and bulk emulsion cannot be use; 0.208 kg cartridge types explosives may be used.

2.5.3 EXPLOSIVES TRANSPORT REQUIREMENTS BASED ON BLASTING PROGRAMME

Current Construction Programme

The approach adopted to derive the total number of trips and the total initiating explosives to be transported per trip is as follows:

- As far as practicable, the explosives (cartridged emulsion and detonating cord) required for all the blast faces of a given work area operated by the same contractor will be transported on the same explosive delivery truck when the blasting programmes for the blast faces of the work area overlap (e.g. when the blast programmes of the cavern/ tunnels/ adits/ vent duct for Ap Lei Chau work area overlap, a single explosive delivery will most likely be made). Note that detonators are transported on dedicated trucks.
- Due to potential progress issues during the construction stage, arising from programme delay or change, it may not be possible to adhere strictly to the envisaged construction programme. This will result in blasts carried out at a different time for the various faces and separate deliveries.
- Loads will be limited to a maximum of 200 kg per truck in accordance with the Removal Permit issued by Mines Division.
- The quantity of Category 1 explosives on the roads has been minimised by using bulk emulsion and/or bulk ANFO, which will be manufactured on-site. The on-site manufacture of ANFO and bulk emulsion will require the transportation of Category 7 oxidising substances which falls outside the scope of this study.
- It has been assumed in this report that the project will mostly require a separate explosives delivery from the temporary magazine to each delivery point.
- The actual construction programme will depend on the detailed design and appointed contractors. It may also depend on the actual achievable progress rates which may vary due to site specific conditions (e.g. geology). To consider the uncertainty in the envisaged construction programme, a Base Case, which accounts for expected programme variations, and a Worst Case, which presents the worst programme scenario, have been considered for the assessment.

Base Case for the Hazard to Life Assessment

Based on the envisaged construction programme and sequence of works, the annual travel distance by explosives vehicles, carrying cartridged emulsion and detonating cord, will reach a peak in the period between March 2012 and February 2013, as shown in *Table 2.7*. This period is referred as the peak explosives delivery period which is taken to represent the Base Case scenario

for the Hazard to Life Assessment. Within this period, the annual number of deliveries is 1,156 while the explosives trucks travel distance is around 10,911 km. The delivery frequency has been estimated on the basis that, for a given delivery point, each delivery will be made to each blast face independently of the other blast faces even if the load could be transported on the same truck. This approach, although slightly conservative, accounts for envisaged delivery variations during the peak delivery period, within which, separate deliveries will be generally undertaken. Ap Lei Chau is a major work area in this project and blast will generally be undertaken each morning and each afternoon except on Sundays and general public holidays. Since it is a major work area, load will be combined in the same truck whenever possible. The total number of trips has been estimated based on the typical licensing limit of 200 kg explosives per truck.

The explosive load has been estimated on the basis that, for a particular delivery point, when the blast time for various excavation faces coincides in the construction programme within the peak delivery period, explosives will be transported on the same truck. This applies, for instance, when the blast programme for various work areas at Ap Lei Chau.

In the Base Case, it was considered that blasting could be carried out at predetermined times during the day as given in the envisaged construction programme. A distribution of delivery times has thus been considered based on the envisaged construction programme.

It was generally assumed that explosives will not be returned to the temporary Explosives Magazine.

The travel distance from magazine site to each delivery point is provided in *Table 2.6*. The corresponding explosive load transported in the peak 12-month delivery period is shown in *Table 2.8* for each work area.

Table 2.6 *Travel Distance from Chung Hom Shan Magazine Site to Each Delivery Point*

Delivery Points	Nam Fung Portal	Ap Lei Chau
Travel distance (km) from Magazine Site to Delivery Point	7.9	11.2

Table 2.7 *Explosives Deliveries for Every 12-Month Period During Construction for Each Work Area*

12-Month Delivery Period	Total Explosives Delivery Trips within the 12-Month Period		Total Number of trips	Total Distance Travelled (km)
	Nam Fung Portal	Ap Lei Chau		
Nov 2011 - Oct 2012	459	547	1006	9753
Dec 2011 - Nov 2012	511	547	1058	10163
Jan 2012 - Dec 2012	563	552	1115	10630
Feb 2012 - Jan 2013	594	553	1147	10886
Mar 2012 - Feb 2013 (1)	617	539	1156	10911
Apr 2012 - Mar 2013	624	496	1120	10485
May 2012 – Apr 2013	626	446	1072	9941
June 2012 - May 2013	626	414	1040	9582

	Total Explosives Delivery Trips within the 12-Month Period		Total Number of trips	Total Distance Travelled (km)
July 2012 - June 2013	626	365	991	9033
Aug 2012 - July 2013	626	313	939	8451
Sept 2012 - Aug 2013	592	259	851	7578

Note: (1) Peak delivery period selected for the Base Case based on total travel distance within the 12-Month Period

Table 2.8 *Explosives Load Transported in the Peak 12-Month Delivery Period*

Works Area	Explosive Load Transported (kg/trip)
Nam Fung Portal	41*
Ap Lei Chau	200

Note: * 41 kg will be delivered for 11months, with 179 kg delivered for 1 month

Worst Case

The Hazard to Life Assessment also covers the Worst Case scenario. It addresses the possibility that, due to construction uncertainties or contractors' methods of working, the contractors propose an actual construction programme which differs from the envisaged construction programme. Such a case may result in a higher number of delivery trips. Return trips loaded with explosives will generally be avoided, however, due to some construction uncertainties, a number of return trips could be made. Overall, in the worst case, a 20% increase in the number of deliveries compared to the base case scenario may result based on previous project experience.

For Ap Lei Chau area, it is possible that the explosives load required for each delivery will be higher than what is indicated in the envisaged programme due to particular site conditions and blasting requirements. Since, the explosives load to be transported will be 200 kg (licensing limit), any additional quantities may result in additional trips. This additional number of trips is addressed by the 20% increase in deliveries described above. The delivery load, in the Worst Case Scenario, has been selected as the maximum load that could be transported as per the Licensing limit.

For the Nam Fung Portal, the maximum explosives load to be transported corresponds to the initial blasting period with a worst case scenario as shown in *Table 2.9*.

In this Worst Case, blasting could still be carried out at predetermined times during the day as given in the envisaged construction programme based on a 24 h or 12h blast cycle; however, it is possible that explosives be delivered at peak day times.

The explosive loads which will be transported in this Worst Case are given in *Table 2.9* for each delivery route.

Table 2.9 *Worst Case Explosives Loads to be Transported for Each Work Area*

Works Area	Explosive Load Transported (kg/trip)	Length of Period Considered
Nam Fung Portal	41	9 months
	196	3 months (considering this quantity of explosive load is used for initial blasting within this period
Ap Lei Chau	200	12 months

2.6 TRANSPORT OF BLASTING EXPLOSIVES AND INITIATION SYSTEMS

2.6.1 OVERVIEW

Blasting explosives (Bulk emulsion or ANFO) will be manufactured on-site while the explosives required as part of the initiating system required for a particular Drill and Blast project will be delivered by Mines Division, stored within the contractor's site temporary Magazine and transported to the construction sites by the contractor. Mines Division requires that blast hole loading is commenced immediately, as far as practical, upon receiving the explosives (it may take 2 to 4 hours to transport the explosives from the surface to the blast face, charge the face, evacuate the area and execute the blast). Storage of explosives at the work site is not permitted.

Where no dedicated explosives magazine exists, explosives will be delivered by Mines Division on a daily basis, arriving at the designated site at around 12 noon to 1:00 pm. This means that blasts can only be fired mid-late afternoon, and limits the project to one blast per day for any face.

When approved by Mines Division, one or more dedicated temporary magazines can be constructed to service the particular needs of a project. This enables more than one blast per day.

Mines Division generally limits the amount of explosives that a Contractor can transport from the temporary magazine to the blast site to 200 kg per explosives delivery truck. In some circumstances, this limit may necessitate more than one trip to deliver the required volume of explosives for a blast taking into account the Removal Permit licensing limit. This is particularly applicable to the construction of Ap Lei Chau tunnels which may require more than 200 kg of explosives to be delivered at a time.

Detonators shall be transported in a separate licensed vehicle and are never to be carried together with explosives.

Mines Division allows any unused explosives or detonators from a blast to be returned to their magazine store. However, in practice, any unused cartridged emulsion explosives is generally destroyed by burning in a controlled manner, and excess initiating systems (detonators) is also destroyed by linking them into the blast. Unused explosives may also result if a particular blast is delayed and hence the load needs to be returned to the magazine.

2.6.2 *TRANSPORT STRATEGY*

Bulk emulsion or ANFO will be manufactured on site by an appointed third party supplier.

Explosives will be transferred from the relevant store by the relevant contractor. Two licensed explosives trucks will be required for each delivery - one will only transport detonators while the other will transport a cargo of cartridged emulsion and detonating cord. The explosives transport strategy is shown in *Figure 2.4*.

No more than one truck convoy loaded with explosives (made up of the truck carrying the cartridged emulsion and the detonating cord and the truck carrying the detonators) is generally expected within the magazine complex at any one time. In any event, explosives trucks will maintain a separation headway of about 10 min.

2.6.3 *TRANSPORT TO SITE*

Explosives and detonators will be transported separately but in convoy from the temporary magazine to the designated access shafts / blasting sites by the contractors' licensed delivery vehicles under the escort of armed security guards.

To minimise the transport risk, the following principles have been observed in planning delivery routes between the magazine and the various sites:

- Routes have been planned to avoid areas of high population density and Potentially Hazardous Installations (PHIs) wherever possible.
- Explosives truck convoys for each work area will maintain, as far as possible, separation headway of around 10 min.
- The quantity of Category 1 explosives on the roads has been minimised by using bulk emulsion and/or bulk ANFO wherever possible, which will be manufactured on-site. The manufacture of ANFO and bulk emulsion will require the transportation of Category 7 oxidizing substances, which fall outside the scope of this study.

2.6.4 *SAFETY FEATURES OF TRANSPORT VEHICLES*

The contactors' pick up trucks (LGV pick up truck) for delivery of explosives from the temporary Magazine to the blast faces will be licensed by Mines Division and will meet all regulatory requirements for that transport.

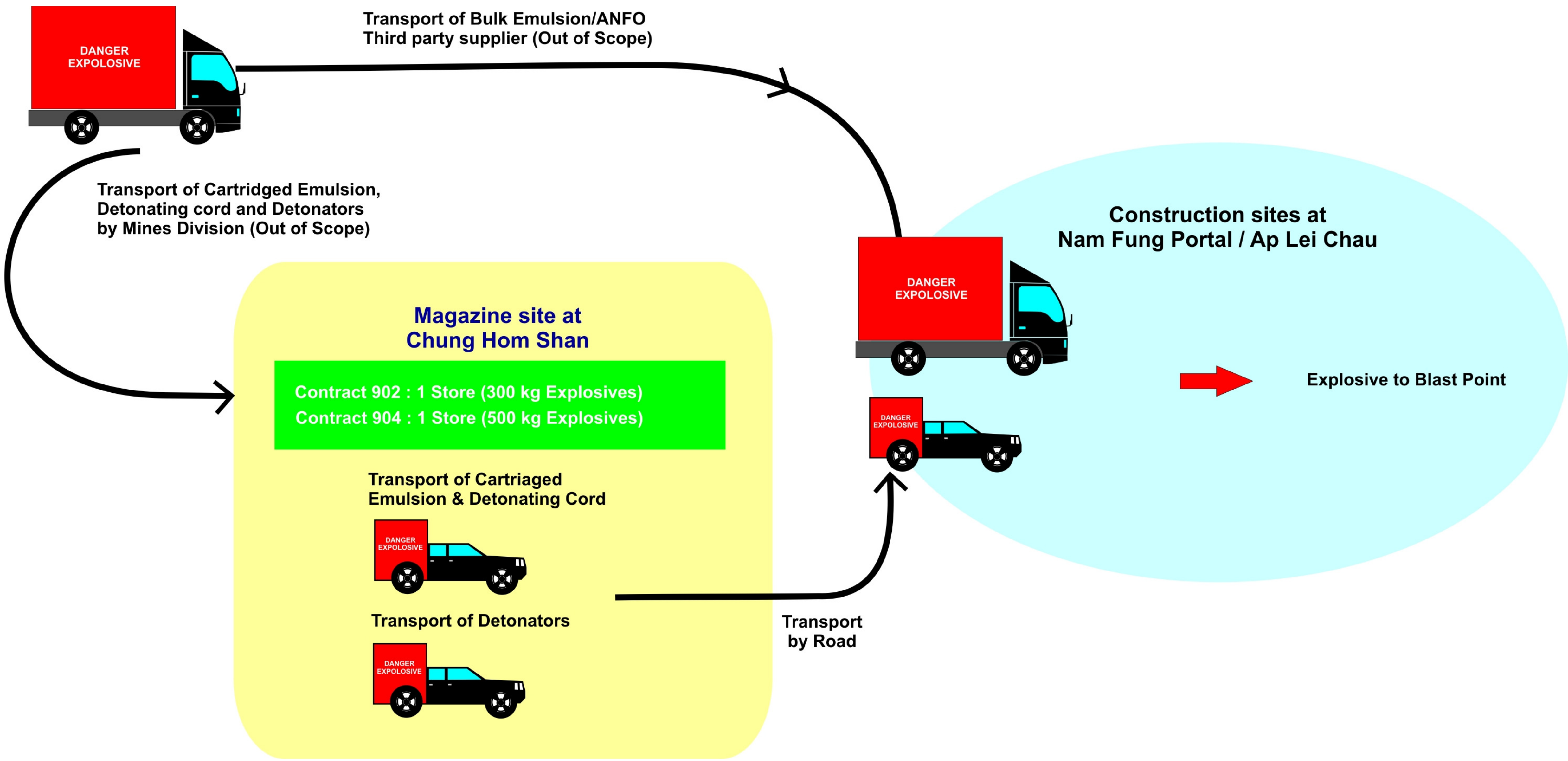
The proposed contractors' explosives delivery vehicle design, used as the basis for the QRA, will have the following safety features:

- Diesel powered;
- Manual fuel isolation switch;

- Forward mounted exhaust with spark arrestor;
- Electric wiring or electrical devices will not be installed inside the cargo compartment;
- All electrical wiring and fittings will be shrouded in fire resisting conduits;
- The fuel tank will be protected from accidental damage, and designed to prevent accumulation of spilt fuel on any part of the vehicle;
- Two serviceable water or carbon dioxide fire extinguishers with a minimum capacity of 2 kilograms each will be mounted on the vehicle in an easily accessible position;
- Fire resistant material shall be fitted between the wheel arches and the goods compartment.;
- Lockable wood lined steel or aluminium receptacles mounted on the vehicle tray; and
- Fold down / up explosives warning signs and rotating flashing light.

In addition to the minimum requirements, a fire screen will be fitted between the cab and the load compartment, both between the cab and the load compartment and underneath the load compartment. The fire screen shall be 3 mm; extend to 150 mm above [all sides of] and run completely under the load compartment; to at least 100 mm behind the cab of the vehicle.

Figure 2.4 Transport Strategy for the Explosives



2.6.5 *DETAILS OF EXPLOSIVES DELIVERY ROUTES*

The explosives will be delivered from the temporary Magazine to the two work areas using the public roads as shown in *Figure 2.5*.

To ensure that the transport risk has been minimised, the shortest delivery routes from the Chung Hom Shan magazine have been selected.

The explosives delivery routes from the magazine to the work sites (Nam Fung Portal and Ap Lei Chau) will involve transportation on roads such as Chung Hom Kok Road, Repulse Bay Road, Island Road and Wong Chuk Hang Road passing through mainly residential areas and various areas of interest which can be occasionally crowded (e.g. Repulse Bay and Deep Water Bay) in the southern part of the Island.

Following the current work programme, both delivery points are expected to be in operation simultaneously during the 15-month period from January 2012 to March 2013.

Since the explosives transport from the temporary Magazine to the delivery points will cover around 10 kilometres of road with varying characteristics, each delivery route was broken down into sub-sections for the assessment. Route sectionalisation allows a more accurate determination of the population and of the risk.

The explosives delivery routes are listed in *Table 2.10*.

Figure 2.5 SIL(E) Alignment, Magazine Location and Explosives Transport Routes

Table 2.10 Delivery Routes from Chung Hom Shan Magazine

Section ID	Description
Route 1a (Chung Hom Shan Magazine - Ap Lei Chau)	
Road 1a1	Chung Hom Kok Magazine site track
Road 1a2	Chung Hom Kok Road
Road 1a3	Repulse Bay Road - Tai Tam
Road 1a3a	Repulse Bay Road - Tai Tam - 2nd section
Road 1a4	Repulse Bay Road - South Bay
Road 1a5	Island Road - Repulse Road
Road 1a5a	Island Road - Repulse Road 2nd section
Road 1a6	Island Road - Deep Water Bay
Road 1a7	Wong Chuk Hung Road - Island
Road 1a7a	Wong Chuk Hung Road - Island sec-a
Road 1a8a	Wong Chuk Hung Road - Nam Fung
Road 1a8b	Wong Chuk Hung Road - Ocean Park
Road 1a9	Wong Chuk Hung Road - Nam Long Shan
Road 1a10	Ap Lei Chau Bridge Road
Road 1a11	Lee Nam Road
Road 1a11a	Lee Nam Road - sec-a
Route 1b (Chung Hom Shan Magazine - Nam Fung Portal)	
Road 1b1	Chung Hom Kok Magazine site track
Road 1b2	Chung Hom Kok Road
Road 1b3	Repulse Bay Road - Tai Tam
Road 1b3a	Repulse Bay Road - Tai Tam - 2nd section
Road 1b4	Repulse Bay Road - South Bay
Road 1b5	Island Road - Repulse Road
Road 1b5a	Island Road - Repulse Road 2nd section
Road 1b6	Island Road - Deep Water Bay
Road 1b7	Wong Chuk Hang Road - Island
Road 1b7a	Wong Chuk Hang Road - Island sec-a
Road 1b8	Nam Fung Road

2.7. DESIGN DOCUMENTATION USED AS THE BASIS FOR THE HAZARD TO LIFE ASSESSMENT

The following preliminary design documentation for SIL(E) forms the basis for this assessment:

- MN14 Preliminary Design Final Report (Rev. A) (MTR 2, 2009);
- VE01 – Options Report (9-5-2008, Rev. A) (MTR 1, 2008);
- Deliverable 3.13B Works Contract 902 Blasting Submissions (MTR 3, 2009);
- GE07 Site Impact Assessment Report (Rev. A) (MTR 5, 2008);
- GE12 Preliminary Natural Terrain Hazard Review Report (Rev. A) (MTR 6, 2008);
- SIL(E) Working Paper on Magazine Site Options (April 2010) (MTR 4, 2010);
- GE06 Ground Movement Report (Rev. A) (MTR 7, 2008); and

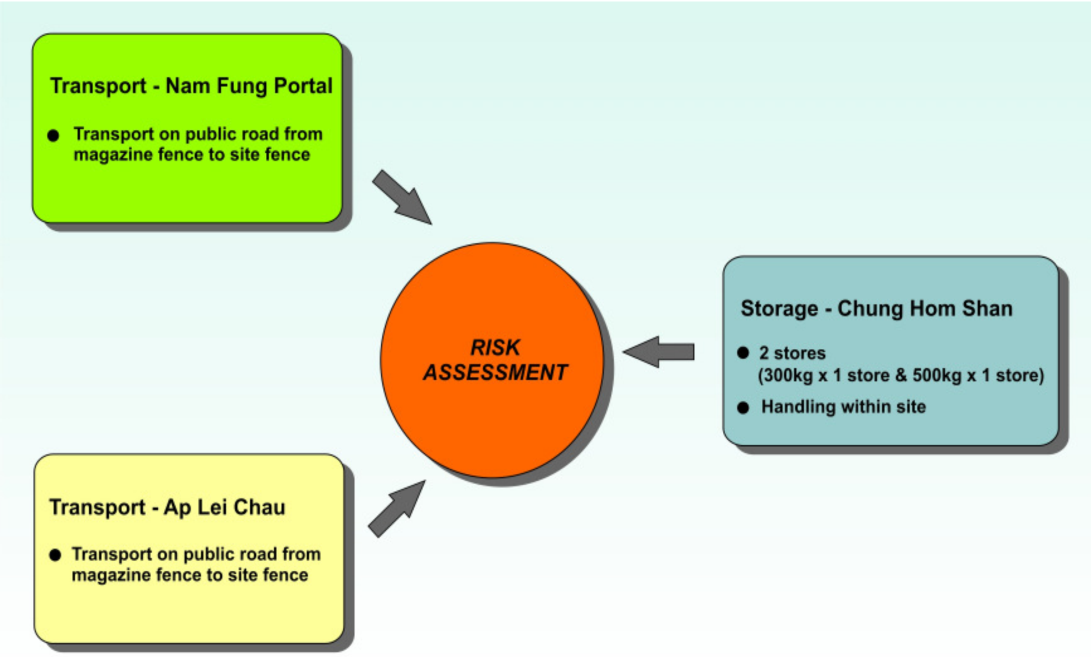
- Blasting schedule: *SIL Explosive consumption_20091103.xls* provided on 5 Nov 2009.

3 HAZARD TO LIFE ASSESSMENT METHODOLOGY

3.1. OVERVIEW OF THE METHODOLOGY

The overall methodology for the Hazard to Life Assessment addresses the risk associated with the storage and transport of explosives for the SIL(E) construction (see *Figure 3.1*).

Figure 3.1 Components of the Risk Assessment



The potential hazards considered to pose a risk to the general population include overpressure and other effects such as projectiles.

The elements of the QRA are shown schematically in *Figure 3.2*. It includes the following steps.

- Collection and review of relevant data for the proposed temporary Magazine, the transport from the temporary Magazine, as well as population and vulnerable receptors, such as slopes, retaining walls etc., in the vicinity of the tunnel construction and proposed transport routes;
- Hazard identification. A review of literature and accident databases was undertaken and updated. These formed the basis for identifying all the hazardous scenarios for the QRA study;
- Frequency estimation. The frequencies, or the likelihood, of the various outcomes that result from the hazards associated with the storage and transport of explosives was taken primarily from previous EIA QRAs that have been accepted by the relevant authorities. Where necessary, to consider specific factors applicable for the SIL(E) project and to reflect the

current knowledge on the explosives' properties, these frequencies were modified or updated making reference, as far as possible to published references; such as the previous Hong Kong studies, UK HSE, US DoD, Dutch TNO (TNO Purple Book, 1999), latest accident statistics from the Transport Department and Fire Services Department, etc.;

- For all identified hazards, the frequency assessment has been documented and the consequences of the event were modelled;
- The consequence model employed in this study is the ESTC model (ESTC, 2000) developed by the UK Health and Safety Commission (HSC). Although, there have been a number of recent studies suggesting that the ESTC model (ESTC, 2000) models should be reviewed for applicability to explosive stores and transport, these models are still the recommended models in the UK and have been adopted in previous Hong Kong EIAs;
- The same frequency model was adopted in this study as that of XRL study (ERM, 2009), which has been derived to reflect the current Transport Department statistics, Fire Services Department statistics, specific design features as applicable for the SIL(E) project and current knowledge of explosives;
- The consequence and frequency data were subsequently combined using ERM's in-house Explosives transport GIS Risk Assessment tool (E-TRA), which has been developed to account for three-dimensional blast effects on buildings and the effect of accidental explosions on elevated roads. It also accounts for traffic jam scenarios which could occur in some accidental scenarios as reported in the DNV study (DNV, 1997). The model is summarised in the next section and has been validated against ERM in-house proprietary software Riskplot ™. This risk assessment tool has been employed in the XRL study (ERM, 2009); and
- Finally, the results from the risk assessment were compared to the EIAO-TM Criteria. Recommendations have been made where required to ensure compliance with EIAO-TM Criteria, relevant best practice, and to reduce the overall risk levels.

Making reference to other relevant Hong Kong QRA studies, this Hazard to Life Assessment has performed an update of the QRA parameters considered in other studies and reviewed their applicability to the transport and storage elements of the QRA as applicable for the SIL(E) construction. Although, some QRA parameters may differ from previous studies, as required by the EIA Study Brief, the methodology adopted is consistent with the following studies:

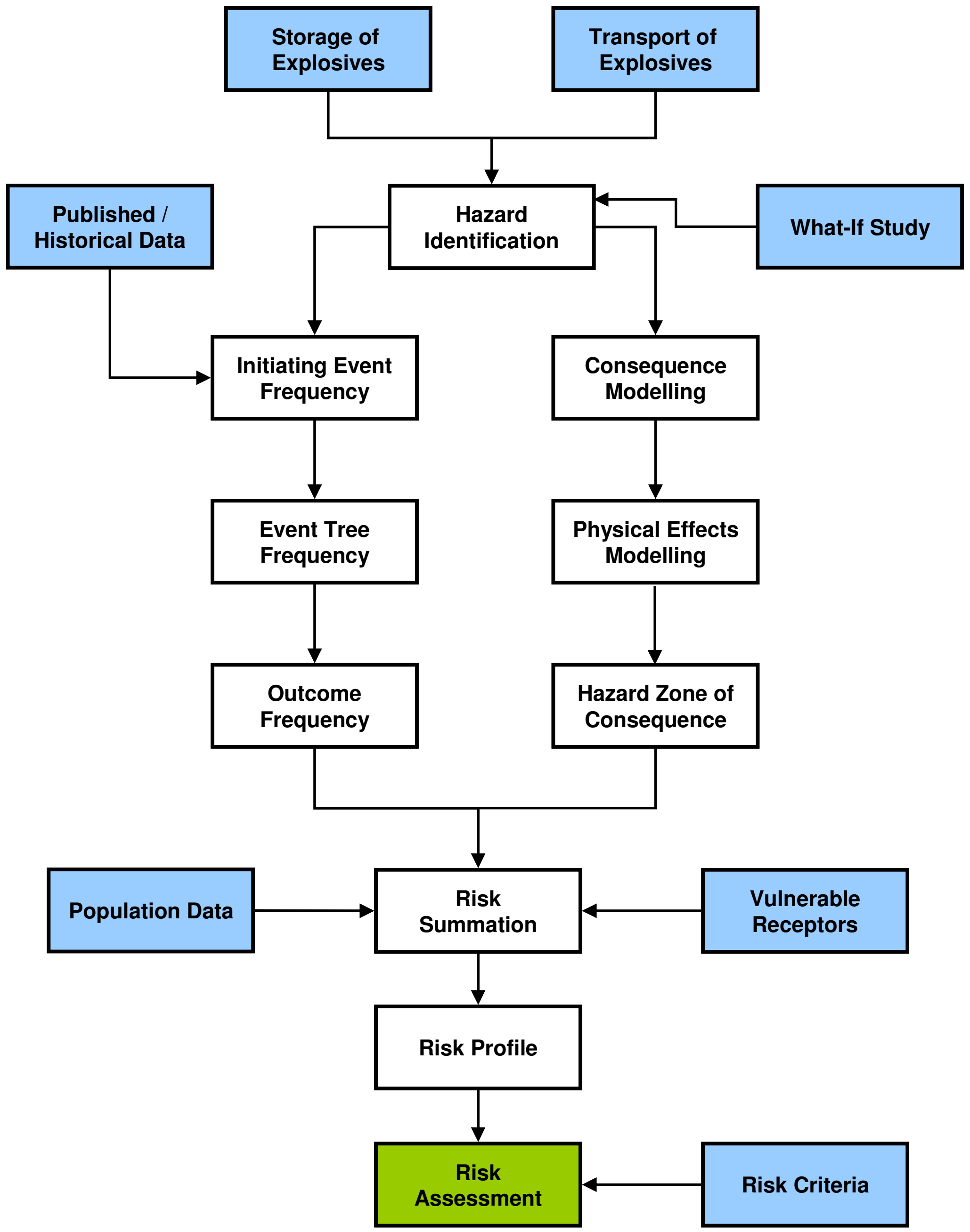
- Express Rail Link (XRL) study (ERM, 2009);
- West Island Line (WIL) study (ERM, 2008);
- Hazard to Life Assessment section of the Ocean Park Development Study (Maunsell, 2006);

- The territory wide study for the transport of explosives (DNV, 1997); which was the basis for the WIL study (ERM, 2008), and the ACDS study (ACDS, 1995) which was the basis for the DNV study (DNV, 1997). The basis for the frequency assessment data and methodology for the DNV study (DNV, 1997), as well as the ACDS study (ACDS, 1995), has been reported separately in Moreton's study (Moreton, 1993).

- Hazard to Life Assessment section of the Penny's Bay Rail Link EIA, (ERM, 2001).

The QRA study for the Express Rail Link (ERM, 2009) is the latest QRA on the transport of explosives in Hong Kong and has formed the primary reference for the SIL(E) Hazard to Life Methodology.

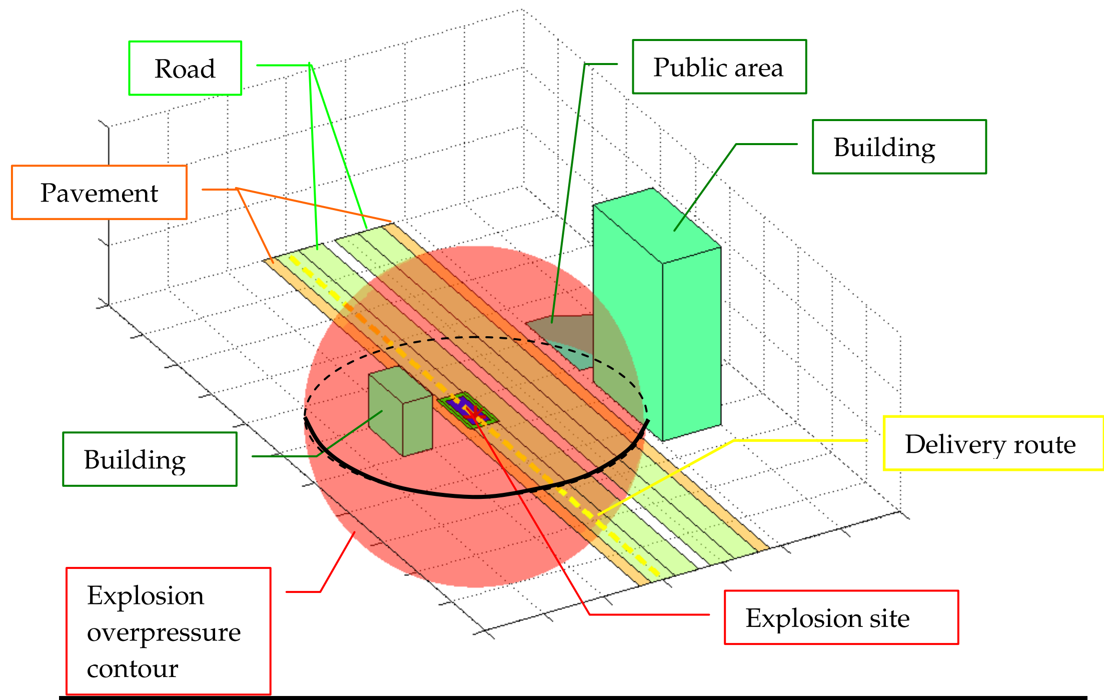
Figure 3.2 *Schematic Diagram of QRA Process*



3.2. *OVERVIEW OF THE EXPLOSIVES TRANSPORT RISK ASSESSMENT TOOL AND METHODOLOGY*

The approach to modelling the risks for the transport of explosives is that developed for the XRL QRA (ERM, 2009) and is fully 3-dimensional and GIS based. It accounts for the potential increased risk when the explosives truck travels on elevated roads. The route from the magazine to each work site is divided into sections for analysis, according to road characteristics. If initiation of the explosives on a delivery truck occurs, spherical blast waves and fragmentation may be produced which may impact on surrounding population such as other road users, buildings, as well as outdoor population on pavements and in public areas (*Figure 3.3*). The number of fatalities from an explosion at a particular location is determined by calculating the degree of overlap between explosion overpressure contours and populated areas.

Figure 3.3 *Explosion Impact on Surrounding Population*



2-Dimensional Calculations

In order to describe the 3-dimensional procedure, the 2-dimensional case at ground level is described first for illustration purposes (*Figure 3.4*). Polygons are used to define population areas for traffic lanes, pavement areas, buildings and public areas. A number of explosion effect levels are calculated to determine the hazard footprint and fatality probability at various distances from the explosives truck. These hazard footprints are then overlaid on the population polygons to determine overlap areas and the number of fatalities resulting from an explosion.

To improve accuracy and be ensured that the risk is not underpredicted, several explosion effect contours are generally used to describe different fatality probabilities (90%, 50%, 10%, 3% and 1%) at different distances from the truck. Geometric means have been applied in the model. Although the geometric means have no physical meaning, the levels calculated with the geometric means using the fatality probabilities listed above closely match the true average explosive effect distances.

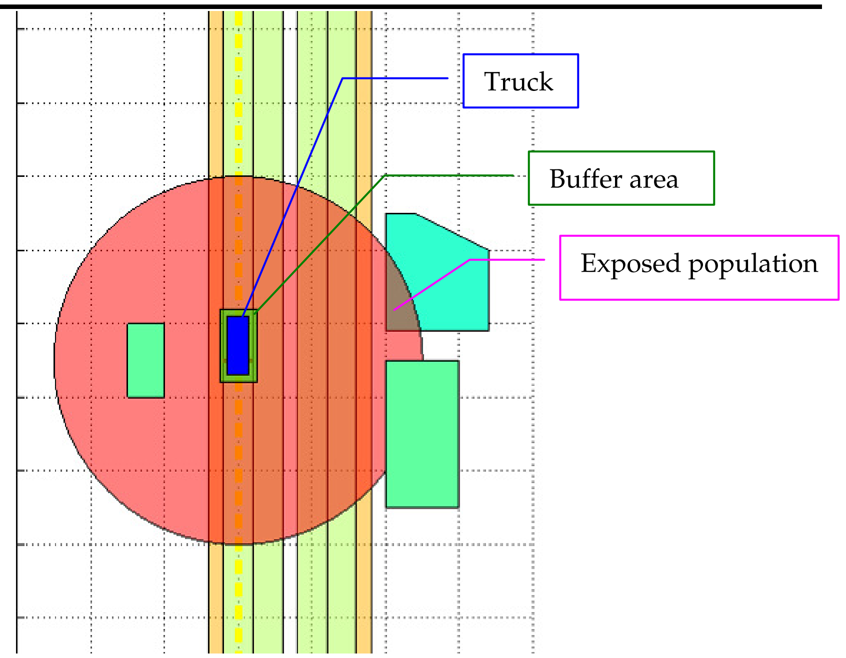
To define the population polygons, each section of a route is characterised in terms of the number of traffic lanes on the nearside and the far side, the widths of the traffic lanes, the width of the centre divides and the widths of the nearside and the far side pavements. Polygons describing buildings and public areas on each side of the road were obtained from a GIS database. The building types, such as high rise residential, low rise industrial, commercial etc., are used to estimate building population and a distinction is made between population indoors and outdoors. Road population densities are estimated for two traffic conditions: flowing traffic and traffic jam. Road traffic is based on the 2011-Base District Traffic Model (BDTM) and 2007-Annual Average Daily Traffic data (AADT), both available from the Transport Department. Further details of the population can be found in *Section 4*.

Although an initiation of an explosives truck could occur anywhere along the delivery routes, it is necessary to consider discrete locations in the modelling. Explosion sites are therefore considered with a spacing of about 10 m. This gives 100 potential explosion sites for each kilometre of the transport route.

Other assumptions made in the model include:

- The explosives trucks are assumed to be located in the slow lane of multilane roads and hence the explosion site is assumed to be centred on the slow lane;
- The explosives trucks present a hazard only during delivery of explosives from the magazine to the work area. The return journey to the magazine presents no risk since the truck is empty. Partial deliveries of explosives i.e. delivery of partial load to work site A, followed by direct routing to work site B etc. are not considered in the model;
- The explosives trucks are expected to be a light truck e.g. a LGV pick-up truck. There will not be any member of the public located within the area occupied by the truck itself. Also, there will not be any other road vehicles within a couple of metres of the truck because of natural separation of vehicles and width of lanes. A buffer area (*Figure 3.4*) is therefore defined as 5 m × 10 m in which the population is taken to be zero.

Figure 3.4 Explosion Overpressure Footprint at Ground Level



Extension to 3-Dimensional Modelling

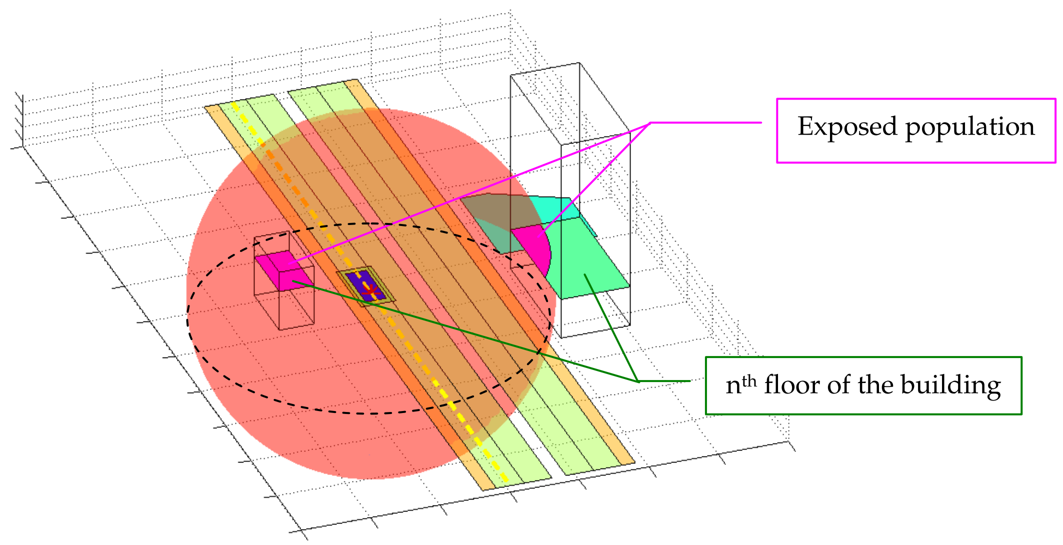
Buildings are modelled in 3-dimensions. This is achieved in essentially the same manner as the 2-D calculations, but the overlap areas between explosion overpressure contours and building polygons are calculated floor by floor (*Figure 3.5*). Since the explosion effects are spherical, the extent of the overpressure contours varies with height above the road. This is taken into account in the model. It is therefore possible that only a few floors of a building may be affected. Any elevation difference between the road and building is also allowed for since a fully 3-dimensional coordinate system is used to define roads and population polygons.

The GIS database of buildings includes details such as podiums on lower levels. These variations in building geometry are therefore captured by the model.

Buildings, in general, have multiple accommodation units, only half of which on average will overlook the road. The calculation of overlap areas therefore has a prescribed upper limit of 0.5 to reflect that at most half of each floor will be affected by a blast. The shielding provided by other buildings is not taken into account in the modelling, however, with explosion effect contours extending to a maximum of only about 60 m, there will be very few instances of impacts reaching the second line of buildings from the road. In any case, neglect of shielding by buildings is a conservative simplification.

Elevation differences between the explosion site on the road and surrounding areas such as parks and playgrounds is also taken into account in the modelling.

Figure 3.5 *3-Dimensional Treatment of Buildings*



The number of fatalities from an explosion is calculated by summing the fatalities in buildings with those outdoors and those on the road before pairing them to the *f* value in an f-N pair. The frequency of an explosion is calculated based on the number of trips for a particular route section and the probability of initiation per kilometre and the separation between explosion sites (about 10 m). This combination of number of fatalities *N*, and frequency *f* form one dataset pair for the explosion event. Summing over all explosion sites along the transport route gives the societal risk, calculated as either Potential Loss of Life (PLL) or presented as F-N curves.

$$PLL = \sum_i f_i N_i$$

F-N curves plot the frequency *F*, of *N* or more fatalities against *N*. The frequency *F* is therefore a cumulative frequency calculated from:

$$F_j = \sum_{N_i > N_j} f_i \ .$$

Individual risk is also calculated and presented as contours overlaid on transport routes.

4 POPULATION ESTIMATES

4.1 POPULATION ESTIMATE NEAR THE EXPLOSIVES MAGAZINE

One temporary Magazine is required in order to enable efficient delivery of explosives to work areas (see *Figure 2.5*). The temporary Magazine will be located at Chung Hom Shan, south of Hong Kong Island, and will supply explosives to work areas at the Nam Fung Portal and Ap Lei Chau.

The temporary Magazine site has been selected based on consideration of separation distances from public areas and buildings and on practicality grounds for their proximity to works areas and transport routes.

Population within the vicinity of this site is based on surveys conducted by ERM in March and April 2009. Additional information was gathered from GIS tools and aerial maps. From these, potential sensitive receivers in the vicinity of the site were identified and their population estimated.

The consequence analysis (*Section 7*) demonstrated that the maximum effect radius from a blast at a temporary Magazine which could produce 1% fatality is about 73m. All population within 73 m radius from the site was therefore estimated.

4.1.1 CHUNG HOM SHAN SITE

The Chung Hom Shan site is located on a disused quarry at the southern edge of Chung Hom Shan. The site is a relatively remote location surrounded by woodland and is currently unoccupied (*Figure 4.1*). There are no public roads or footpaths nearby and no inhabited buildings within sight. The site sits next to an Ocean Park Nursery Site. The only substantial structure in the vicinity of the temporary magazine site is the satellite receiving station located about 147 m to the east of the temporary Magazine entrance. There are about 5 workers within the telecommunication facility.

The access road to the temporary magazine site is a private road, which is blocked by two security gates. Therefore, there is no known (current or future) permanent, temporary or transient population within the hazard zones of the Chung Hom Shan magazine site.

Figure 4.1 Aerial Photo of the Chung Hom Shan Magazine Site

4.2 POPULATION ALONG EXPLOSIVES DELIVERY ROUTES

Three types of population have been considered:

- Pedestrian population on footpaths and pavements next to delivery routes;
- Road population; and
- Building population.

For areas not supported by surveys or where information is not available from other pertinent sources of information, the assumptions in *Table 4.1* have been used, consistent with the XRL study (ERM, 2009).

Table 4.1 Population Assumptions

Type of Population	Assumption	Remarks
Residential Building	3 persons / flat	Government Territorial Population and Employment Data Matrices (TPEDM) indicate current Persons Per Unit (PPU) in the transport area of slightly less than 3. A value of 3 has been adopted as a conservative assumption.
Commercial Building	9 m^2/person	Code of Practice for the Provision of Means of Escape in Case of Fire indicates 9m^2/person as a minimum requirement. For buildings considered to bear an impact on the risk results, a specific survey has been conducted.
Footpath	0.5 persons /m^2	Density figure of 0.5 persons/m^2 is defined as footpath Level Of Service (LOS) in the Highway Capacity Manual. This is considered as a reasonable conservative density for the footpaths in the study area and will be used unless specific surveys indicate lower values.
Education Institute	500 persons / hall	
Passenger Car Unit (PCU)	3 persons per PCU	This is only applicable to the BDTM model

The methodology followed in establishing the population was, to a large degree, consistent with previously approved EIAs including the XRL study (ERM, 2009), WIL study (ERM, 2008) study and the LNG Receiving Terminal EIA (ERM, 2006), which included a detailed population survey for most parts of the explosives transportation route.

Population on the roads was estimated from a combination of:

- Base District Traffic Model (BDTM) 2011;
- Annual Traffic Census 2007 (ATC, 2007); and
- Road Traffic Accident Statistics 2007 (TD, 2007a).

Population in buildings adjacent to transport routes was estimated from data obtained from:

- Centamap (2009); and
- Geographic Information System (GIS) database (2005 data).

Accounting for the maximum licensing limit of 200 kg for the transport of explosives, all buildings within a 100 m corridor each side of the transport routes were included in the assessment. This corridor width is more than sufficient to describe the building population that may be affected by explosion from even the largest transport loads. The 1 % fatality effects from initiation of 200 kg of explosives, for example, does not extend as far as 100 m and all transport loads considered in this project are less than or equal to 200kg.

All of the buildings along each delivery route have been entered individually into the E-TRA model, so as to accurately represent the population. Particular attention has been paid considering the effects of accidental explosion on buildings where the vehicle is located on an elevated road.

A population density approach has been adopted for modelling the presence of pedestrians and road users.

Road users have been considered depending on the explosion scenarios as equally distributed, or under a slow/congested traffic. Referring to the frequency components of the transport QRA (see frequency section), an accidental explosion due to vehicle collision or transport of unsafe explosives will be spontaneous and can only impact on free flowing traffic. Explosives initiation following a vehicle fire (following a traffic accident or otherwise) could impact on queuing traffic conservatively assumed to occur within each lane on either side of the road in day or night conditions. Half jams are assumed in the analysis, whereby a traffic jam occurs behind the incident vehicle with a clear road in front. For such fire scenarios, traffic jam (half jam) is conservatively assumed to develop in 50% of the cases as, under low traffic conditions, such as during night time or day time at non-peak hours, road users may use alternative lanes or reverse which would not give rise to traffic jam.

In addition to road and building populations, the outdoor population on pavements was also estimated, based on a survey undertaken by ERM in March and April 2009.

The following sections present the approach taken, for the base case scenario, where the deliveries could be scheduled at predetermined times during the blast cycles. For the Worst Case, it was considered that deliveries could take place at peak day time during the construction stage.

4.2.1 *ROUTE SECTIONALISATION*

The explosives delivery routes from the Chung Hom Shan magazine to the work sites (Nam Fung Portal and Ap Lei Chau) have been broken down into sub-sections for the assessment as described in *Section 2.6.5*.

4.2.2 *ROAD POPULATION*

The traffic density information used in this study is based on the latest 2007 Annual Traffic Census and the 2011-Base District Traffic Model (BDTM). A growth of 1% per year to the year of completion of the blasting work (2013) has been assumed in the analysis for delivery to various points.

A population density approach was adopted for estimating the population within vehicles on the road. Vehicle occupants were conservatively estimated as indoor with regards to consequence models (i.e. subject to glass debris impact). The traffic density information used in this study was based on the latest 2007 Annual Traffic Census, supplemented by data from the 2011-Base District Traffic Model (BDTM) developed by the Transport Department. A growth of 1% per year was assumed to extrapolate current data to the end year of construction, 2013.

The BDTM data mainly represents peak traffic conditions and has therefore been used for modelling uncongested peak traffic conditions (free flowing traffic). AADT data gives daily average traffic conditions and, for some stations, data are available at different times of the day. AADT data therefore appropriately represents normal traffic flows at non-peak hours.

Flowing Traffic Population

The traffic density information used in this study was based on the latest 2007 Annual Traffic Census (ATC, 2007), supplemented by data from the Base District Traffic Model (BDTM) developed by the Transport Department. A growth of 1% per year was assumed to extrapolate current data to the year of construction, 2013.

Road population density was calculated using the following expressions:

Annual Average Daily Traffic (AADT)

Population Density (persons/m^2) = AADT × P / 1000 / 24 / V / W

where:
P is the average number of persons per vehicle
W is the road width in metre, based on actual road width data
V is the vehicle speed in km/hr

Based on average vehicle occupancy reported in the Traffic Census for the relevant transportation route, the average vehicle occupancy is around 5 persons per vehicle. This includes buses and trucks as well as taxis and private cars.

V has been selected as 60 km/h for highways and 50 km/h for non-highway route sections, consistent with previous Hong Kong studies.

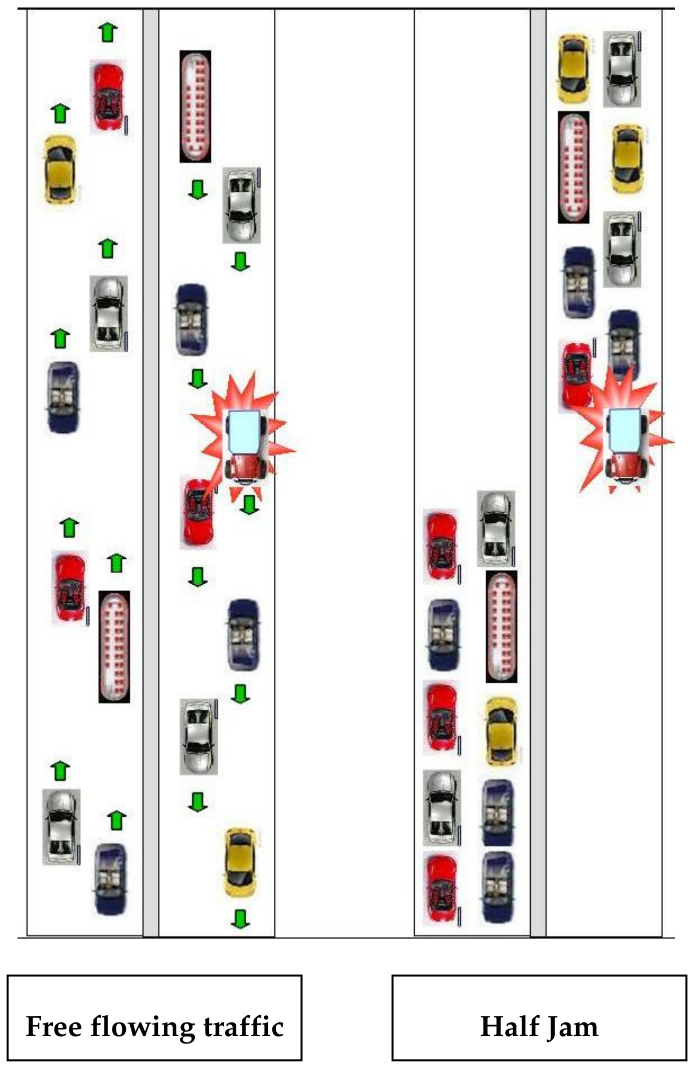
BDTM Model

Population Density (persons/m^2) = PCU / V / W /1000
where:
PCU is passenger car unit per hour
W is the road width in metre, based on actual road width data
V is the vehicle speed in km/hr

The number of vehicle occupants within a PCU has been taken to be 3 consistent with previous studies (ERM, 2009).

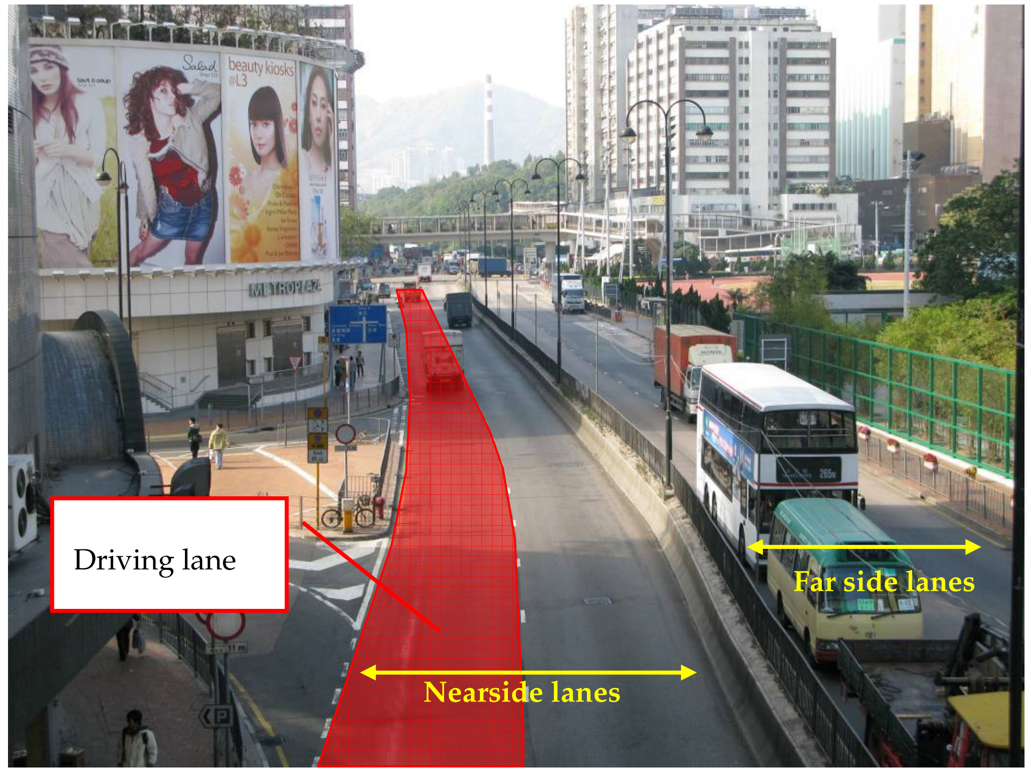
The above formulae based on AADT and BDTM provide population information for average and peak flowing traffic conditions respectively. There is a possibility of a traffic jam when explosive initiation occurs. For example, if the explosives truck catches fire either due to an accident or due to other causes, the incident could disrupt traffic flow and lead to a traffic jam before initiation occurs (*Figure 4.2*).

Figure 4.2 ***Road Traffic Conditions and Scenarios Considered***



The road population estimates take into consideration the number of lanes and distinguishes between traffic on the nearside lanes and traffic flowing in the opposite direction to the explosives truck (the far side lanes) (*Figure 4.3*).

Figure 4.3 ***Road Population Model***



Traffic Jam Population

It is possible that the traffic flow will be disrupted when an explosion initiation occurs on the delivery truck. If a traffic accident is severe enough to lead to a vehicle fire, for example, a traffic jam could develop before the fire spreads to the explosives load causing initiation. The transport model includes scenarios with traffic jam conditions which will in general have higher population densities compared to flowing traffic due to the reduced separation between vehicles.

The traffic jam population density depends only on vehicle mix and not on traffic volume. The length of road occupied by vehicles of different type is estimated as follows:

- Private cars, taxis and motorcycles – 5 m
- Public light buses – 10 m
- Goods vehicles – 20 m
- Buses – 20 m

The occupancies for each type of vehicle were taken from the Annual Traffic Census (ATC) for 2007. The 'Hong Kong External Cordon' was selected as representative of the transport routes from the temporary magazine site. As a conservative measure, the peak occupancy numbers from the 'Hong Kong External Cordon' were used in the assessment (*Table 4.2*).

Table 4.2 ***Vehicle Occupancy for Different Types of Vehicle for Hong Kong External Cordon***

Vehicle Type	Average Occupancy of vehicles
Motorcycle	1.3
Private car	1.7
Taxi	2.1
Public light bus	14.2
Goods vehicle	1.9
Bus	59.8

The vehicle mix was estimated from the vehicle kilometres travelled (TD, 2007a) (VKT) by each type of vehicle in 2007 (*Table 4.3*). This approach gives the average vehicle mix for the whole territory and was used as an estimate of the vehicle mix along the transport routes. Combining the vehicle mix with vehicle occupancies from *Table 4.2* gives an average population density within vehicles of 0.507 persons per metre of road. For sections of the transport routes with multiple traffic lanes, a population density of 0.507 persons/m per lane was used. Road populations were further converted to a density per square metre using the lane width.

Table 4.3 ***Road Population Density***

Vehicle Type	VKT in 2007 (million)	Fraction of VKT	Occupants	Length of road per vehicle (m)	Population (persons/m)
Motorcycle	319	0.0269	1.3	5	0.007
Private car	4442	0.3749	1.7	5	0.127
Taxi	2102	0.1774	2.1	5	0.075
Public light bus	387	0.0327	14.2	10	0.046
Goods vehicle	3719	0.3139	1.9	20	0.030
Bus	878	0.0741	59.8	20	0.222
Total	11847	1			0.507

4.2.3 PEDESTRIAN POPULATION

Pedestrian flow on the pavement was assessed along the explosives delivery routes by site survey carried out in March and April 2009. The site survey also aimed to collect site specific information such as the width of pavement, surrounding conditions of the roads etc. The results from the survey were then analysed and used to calculate population densities for all the pavements along the delivery routes following the steps below:

- All roads along the delivery routes were selected for the survey (*Table 4.4*);
- Pavement population was collected and the population density calculated from:

$$\text{Pavement population (persons/m}^2) = P \,/\, 1000 \,/\, Q \,/\, W$$

where:

P is the number of pedestrians passing a given point
W is the pavement width (m)
Q is the pedestrian speed (km/hr)

- Consistent with the XRL study (ERM, 2009), the calculated population density was further increased by 10% as a conservative measure and applied to the time periods applicable. The results are shown in *Table 4.4*; and
- As with the road population in vehicles, a distinction is made between population on the nearside pavement and population on the far side pavement.

Table 4.4 ***Pavement Population Density on Roads Covered in Site Survey***

Roads	Pavement Population Density (person/m²) (1)
Delivery from Chung Hom Shan Magazine Site to Ap Lei Chau (Route 1a)	
Chung Hom Kok Magazine site track	0 - 0.001
Chung Hom Kok Road	0.002 – 0.003
Repulse Bay Road - Tai Tam	0 - 0.001
Repulse Bay Road - Tai Tam - 2nd section	0 – 0.024
Repulse Bay Road - South Bay	0.074 – 0.092
Island Road - Repulse Road	0 – 0.002
Island Road - Repulse Road 2nd section	0 – 0.08
Island Road - Deep Water Bay	0 – 0.001
Wong Chuk Hung Road - Island	0.007 – 0.031
Wong Chuk Hung Road - Island sec-a	0.004 – 0.082
Wong Chuk Hung Road - Nam Fung	0 – 0.007
Wong Chuk Hung Road - Ocean Park	0 – 0.011
Wong Chuk Hung Road - Nam Long Shan	0
Ap Lei Chau Bridge Road	0.003 – 0.017
Lee Nam Road	0.002 – 0.009
Lee Nam Road - sec-a	0.002 – 0.008
Delivery from Chung Hom Shan Magazine Site to Nam Fung Portal (Route 1b)	
Chung Hom Kok Magazine site track	0 - 0.001
Chung Hom Kok Road	0.002 – 0.003
Repulse Bay Road - Tai Tam	0 - 0.001
Repulse Bay Road - Tai Tam - 2nd section	0 – 0.024
Repulse Bay Road - South Bay	0.074 – 0.092
Island Road - Repulse Road	0 – 0.002
Island Road - Repulse Road 2nd section	0 – 0.08
Island Road - Deep Water Bay	0 – 0.001
Wong Chuk Hung Road - Island	0.007 – 0.031
Wong Chuk Hung Road - Island sec-a	0.004 – 0.082
Nam Fung Road	0.002 – 0.003

Note 1: Growth factor of 1% per year is taken into account in above data

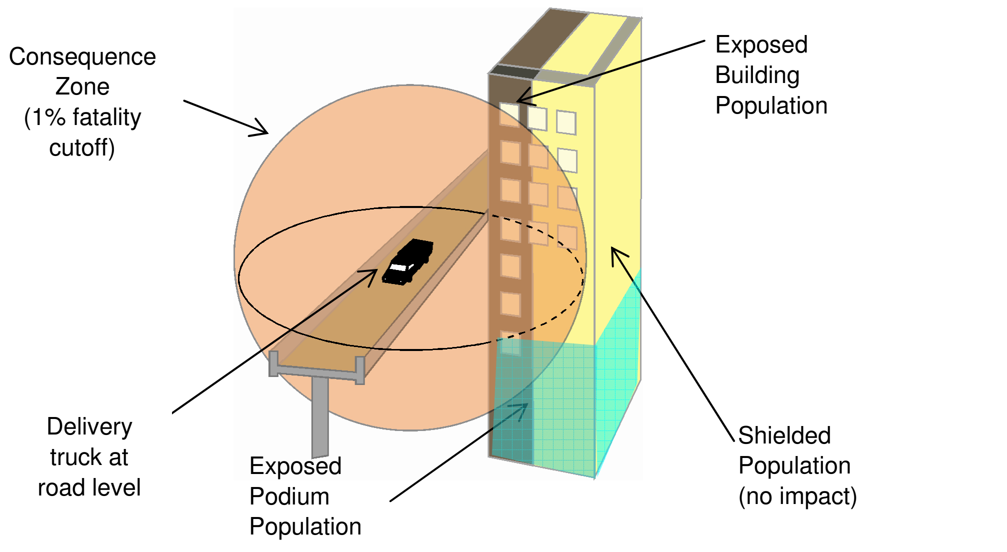
4.2.4 *LAND AND BUILDING POPULATION*

Buildings within a 200 m corridor (100 m either side) of each transport route were included in the assessment, to encompass the effects radius of all explosives transport loads. Buildings that extended only partly into this corridor were also included. Rather than considering density based averages of population, the analysis is based on individual buildings. This involves estimating the population for over 400 buildings along the routes. The task of assessing population building-by-building is substantial but is necessary to accurately model the F-N pairs with high N values. Building populations are then extrapolated to Year 2013.

The hazards due to an explosion during the transport of explosives are principally overpressure and flying debris. For the purpose of this study, it is considered that people at the rear of the building will not be impacted by blast effects.

The hazard footprint was overlaid on the population polygons (road lanes, pavement areas and building areas) considering relative elevations to establish overlap area for each floor of the building impacted from which the number of fatalities could be estimated. A spherical vulnerability model was adopted.

Figure 4.4 Consideration of Population Inside Building



A systematic methodology was employed to allow the estimation of present and future population of individual buildings along the transport routes. The methodology involves 4 steps:

- Step 1: Identify existing buildings within the study area
- Step 2: Identify buildings' attributes and usage, and estimate their population
- Step 3: Project the present population to the assessment year (2013) and distribute predicted future residential population data among identified residential buildings based on a uniform population growth factor of 1% per year.
- Step 4: Adjust future population numbers of non-residential buildings

Following steps 3 and 4, the occupancy of building populations was then determined for different time periods.

4.2.5 *STEP 1: IDENTIFY EXISTING BUILDINGS THAT LIE WITHIN THE STUDY AREA*

The Lands Department of the HKSAR Government maintains a Geographic Information System (GIS) database of buildings in Hong Kong. To identify buildings within the study area, ERM obtained a recent GIS map layer containing all buildings (LD, 2005). Additionally, the GIS building height information for most of the buildings (but usually not podiums or other similar structures) were available from the same source. The buildings at least partly within 100 m of the defined explosives transport routes were selected for further processing. Each of the buildings was assigned a unique label and its grid coordinates were also recorded.

4.2.6 *STEP 2: IDENTIFY BUILDING ATTRIBUTES, USAGE AND POPULATION*

There is no publicly available data on the population of individual buildings in Hong Kong. Therefore, to provide a basis for estimating the number of people in a building, it was necessary to identify each building's attributes and usage.

The buildings and structures in the GIS database are classified as: regular building (BP), building under elevated structure (BUP), open-sided structure (OSP), proposed building (PBP), podium (PD), podium under elevated structure (PDU), ruin (RU) and temporary structure (TSP). Using the above information, the information from property developers' websites as well as aerial photographs, the actual or likely usage category of buildings identified in *Step 1* was determined and each building was assigned to one of the following building usage categories:

- Abandoned/Unpopulated Building;
- Administrative/Commercial;
- Car Park;
- Clinic;
- College;
- Fire Station;
- Hospital;
- Industrial Building;

- Kindergarten;
- Leisure;
- MTR station/Bus terminus
- Petrol Station;
- Podium;
- Police Station;
- Residential Building;
- School;
- Station such as sewage treatment, electrical substation, pump house etc;
- Storage; and
- Temple/Church/Chapel.

Note that unless their usage could be determined from other available sources, the GIS categories OSP, TSP and RU, were assumed to be unpopulated.

Following this, the same information sources were used to sub-categorize buildings by other attributes, such as the number of floors. Details on the building attributes and categories and associated assumptions are presented below.

Number of floors

Building height data was available from the GIS database for most buildings and the number of floors was estimated from these data, assuming 3 m height per floor. For most of the high-rise residential buildings (excluding the housing estates) the floor number information, considered more accurate, was also available from the property developers' websites.

Residential Buildings

Generally a population of 3 persons per unit was assumed. For most of the high-rise residential buildings, the total number of units was available from the property developer website. For all the remaining buildings, including the village houses and estate high-rises, the number of units per floor was estimated from the floor area, assuming 1 unit per about 78 m^2 (700 square feet). Based on this assumption, small structures in village setting of area less than about 30 m^2 were assumed to be unpopulated.

Other Buildings

While residential type buildings are well defined, less information is available for other types of buildings such as commercial, industrial etc. The approach to estimate other building population generally follows that adopted in the

EIA for the Liquefied Natural Gas (LNG) Receiving Terminal (EIA 125/2006), and is based on typical Hong Kong building structure, usage, height, and typical capacity of public facilities. The details are presented in *Table 4.5.* In the application of typical values from *Table 4.5*, further refinements were made based on building height and area and taking into account the maximum density of people in most non-residential building as one person per 9 m^2 (the Code of Practice for the Provision of Means of Escape in Case of Fire).

Table 4.5 Building Population Assumptions

Category	**Building Height /Size[(1)]**	**Assumption**	**Total**
Car Park		Basic assumptions are listed below. In some cases the car park population was adjusted based on the building area. For car parks located in podiums of residential, commercial or industrial buildings, the podium population was assumed as 1% of the population of associated buildings.	
		Parking Levels / **Parking Spaces** / **People/Parking Space**	
	H	5 / 40 / 0.2	40
	L	1 / 20 / 0.2	4
Police Station		About 27750 Policemen are employed in Hong Kong. Assumed that they are evenly spread over 55 branches. It is also assumed that they will roster on 2 shifts each day and about 50% will be out for patrol.	125
Petrol Station		It is assumed that, there are 2 staff stationed in the convenience shop, 4 stationed in fuel area for filling, and 4 vehicles each with 3 people, parked into the Petrol Station for petrol filling	18
Fire Station & Ambulance Depots		About 8600 uniformed staff are employed in Hong Kong. It is assumed that members of fire stream are evenly spread over 76 fire stations and members of ambulance stream are over 33 ambulance depots. It is also assumed that members of fire stream will roster on 24 hours (on-duty) and 48 hours (off-duty) and members of ambulance stream will roster on 12 hours, 2 shifts each day.	30
Station	H	5 people in Refuse disposals, and Mortuaries	5
	M	2 people in Traffic Control Stations	2
	L	No people will stay in Sewage treatment works, Toilet, Electric substation, or pump house	0
Kindergarten		10 students per class, 4 classes for each grade, 3 grades in Kindergarten Total 10 staff employed by each kindergarten	130
College - Secondary School		For Form 1 – Form 5, 45 students per class, 4 classes per form. For Form 6 – Form 7, 30 students per class, 2 classes per form, Total 60 staff employed by a school	1080
School - Primary School	H	Same as College – Secondary School	
	L	30 students for each class, 2 classes per grade, 6 grades in primary school Total 30 staff employed by a school	390
Hospital		Assumed that the population for hospitals for each building height category is as follows:	

Category	Building Height /Size(1)	Assumption			Total
		Floors	**Unit**	**People/Unit**	
	H	10	15	7	1050
	M	5	10	5	250
	L	3	10	5	150
Clinic		Assumed that the population for Clinic for each building height category is as follows:			
		Floors	**Unit**	**People/Unit**	
	H	3	20	3	180
	M	2	10	2	40
	L	1	1	10	10
Temple	H	100 people for large sized temple			100
	M	50 people for medium sized temple			50
	L	10 people for small sized temple			10
MTR Station/Bus Terminus		Based on the building area			
Storage Building		Same as Car Park			
Industrial Building		**Floors**	**Units**	**People/unit**	
	H	25	8	8	1600
	M	15	6	8	720
	L	8	6	6	288
Administrative / Commercial		**Floors**	**Unit**	**People/Unit**	
	H	10	20	2	400
	M	5	20	2	200
	L	2	10	2	40
Leisure	H	200 people for large sized leisure facility			200
	M	100 people for medium sized leisure facility			100
	L	50 people for small sized leisure facility			50
	LL	10 people for very small sized leisure facility			10

Note:
(1) Legend for Building Height/Size
- H for Tall/Large,
- M for Medium,
- L for Low/Small
- LL for Very Low/Very Small

Using the above approach, a database providing characterization of each building by their broad attributes including population was developed.

4.2.7 *STEP 3: DISTRIBUTE PREDICTED FUTURE RESIDENTIAL POPULATION DATA AMONG IDENTIFIED RESIDENTIAL BUILDINGS*

A uniform population growth factor of 1% per year was assumed for the study area in line with the XRL study (ERM, 2009).

While the exact distribution of the future population between the existing and future buildings is unknown, it was assumed that the distribution of the new building population will be similar to that for the existing buildings. Thus, the population estimates of Step 2 for the existing residential buildings identified

in Step 1 have been scaled up according to the population growth factor. In this way, while the locations of any new residential buildings are unknown, the population growth is taken into account and distributed according to the present building locations.

4.2.8 *STEP 4: ADJUST FUTURE POPULATION NUMBERS FOR NON-RESIDENTIAL BUILDINGS*

In the absence of information for non-residential population trends, it was assumed that population in non-residential buildings would follow trends of the residential population. In this way, an approach was adopted whereby the population of non-residential buildings was adjusted to be in line with residential population trends.

4.3 *TIME PERIODS AND OCCUPANCY*

Since population can vary during different time periods, the analysis considers 3 day categories (weekdays, Saturdays and Sundays) with 4 time periods for each day. These are summarized in *Table 4.6*.

Table 4.6 Population Time Periods

Day Category	Time Period	Description
Weekdays	AM Peak	7:00am to 9:00am
	Daytime	9:00am to 6:00pm
	PM Peak	6:00pm to 8:00pm
	Night	8:00pm to 7:00am
Saturdays	AM Peak	7:00am to 9:00am
	Daytime	9:00am to 6:00pm
	PM Peak	6:00pm to 8:00pm
	Night	8:00pm to 7:00am
Sundays	AM Peak	7:00am to 9:00am
	Daytime	9:00am to 6:00pm
	PM Peak	6:00pm to 8:00pm
	Night	8:00pm to 7:00am

The occupancy of buildings during each time period is based on assumptions as listed in *Table 4.7*. These are based on extensive surveys conducted in the ERM's LNG study (ERM, 2006). For vehicle and pavement populations, distribution across time periods were based on data provided in AADT / BDTM and site surveys.

Table 4.7 *Population Distribution (Based on extensive site survey conducted as part of the ERM's LNG EIA (ERM, 2006)*

Type	Occupancy					
	Night (Weekdays / Saturdays / Sundays)	AM Peak (Weekdays / Saturdays / Sundays)	PM Peak (Weekdays / Saturdays / Sundays)	Weekday Daytime	Saturday Daytime*	Sunday Daytime
Administrative/ Commercial (H)	10%	10%	10%	100%	100%	100%
Administrative/ Commercial (L)	10%	10%	10%	100%	100%	100%
Administrative/ Commercial (M)	10%	10%	10%	100%	100%	100%
Car Park/Podium - residential	10%	100%	100%	70%	70%	70%
Car Park/Podium – Commercial/Industrial	0%	100%	100%	70%	45%	20%
Car Park/Podium – MTR	10%	100%	100%	70%	60%	50%
Clinic (H)	0%	10%	10%	100%	100%	100%
Clinic (L)	0%	10%	10%	100%	100%	100%
Clinic (M)	0%	10%	10%	100%	100%	100%
College	0%	10%	10%	100%	55%	10%
Fire Station/Ambulance Depot	100%	100%	100%	100%	100%	100%
Hospital (H)	80%	80%	80%	100%	90%	80%
Hospital (L)	80%	80%	80%	100%	90%	80%
Hospital (M)	80%	80%	80%	100%	90%	80%
Hotel	90%	50%	50%	20%	50%	80%
Industrial Building (H)	10%	10%	10%	100%	55%	10%
Industrial Building (L)	10%	10%	10%	100%	55%	10%
Industrial Building (M)	10%	10%	10%	100%	55%	10%
Industrial/Warehouse	0%	1%	1%	100%	51%	1%
Kindergarten	0%	10%	10%	100%	55%	10%
Leisure (H)	0%	10%	10%	70%	85%	100%
Leisure (L)	0%	10%	10%	70%	85%	100%
Leisure (LL)	0%	10%	10%	70%	85%	100%
Leisure (M)	0%	10%	10%	70%	85%	100%
MTR/bus terminus	10%	100%	100%	70%	60%	50%
Petrol Station	1%	100%	100%	50%	50%	50%
Police Station	30%	30%	30%	100%	65%	30%
Power Station	10%	10%	10%	100%	55%	10%
Residential Building (H)	100%	50%	50%	20%	50%	80%
Residential Building (L)	100%	50%	50%	20%	50%	80%
Residential Building (LL)	100%	50%	50%	20%	50%	80%
Residential Building (M)	100%	50%	50%	20%	50%	80%
School (H)	0%	10%	10%	100%	55%	10%
School (L)	0%	10%	10%	100%	55%	10%
Station (H)	10%	10%	10%	100%	55%	10%
Station (L)	10%	10%	10%	100%	55%	10%
Station (M)	10%	10%	10%	100%	55%	10%
Storage Building (L)	0%	1%	1%	100%	51%	1%
Temple/ Church/ Chapel (H)	0%	10%	10%	50%	75%	100%
Temple/ Church/ Chapel (L)	0%	10%	10%	50%	75%	100%
University	90%	30%	30%	70%	60%	50%
Highway	20%	100%	100%	100%	100%	100%

* Estimated as average of Weekday daytime and Sunday daytime

4.4 *FEATURES CONSIDERED IN THIS STUDY*

A number of manmade slopes and retaining walls were identified in the vicinity of Chung Hom Shan magazine site as shown in *Table 4.8*. These have been considered in the Hazard to Life Assessment.

Table 4.8 *Slopes Identified*

Slopes	Site	Distance from explosive store (m)	Population
15NE-C/C210	Chung Hom Shan site	8.3	Adjacent to the magazine store(s)
15NE-C/C211	Chung Hom Shan site	8.3	Adjacent to the access road of the magazine store(s)
15NE-C/F65	Chung Hom Shan site	3.0	Adjacent to the magazine store(s)
15NE-C/R90	Chung Hom Shan site	29.1	No road or population nearby
15NE-C/F88(2)	Chung Hom Shan site	16.7	Adjacent to the access road

5 HAZARD IDENTIFICATION

5.1 OVERVIEW

Hazard identification consisted of a review of:

- explosive properties;
- scenarios presented in previous relevant studies;
- historical accidents; and
- discussions with explosives and blasting specialists.

5.2 ACCIDENTAL INITIATION DUE TO HAZARD PROPERTIES OF EXPLOSIVES

5.2.1 EXPLOSIVE TYPE AND PHYSICAL PROPERTIES

The physical properties for the explosives to be stored and transported as part of this project are shown in *Table 5.1*.

Table 5.1 *Explosive Types and Properties*

Explosive Type	TNT Equivalency	Melting Point (°C) @ 1 atm	Bullet Test Sensitivity	Autoignition Point (°C) @ 1atm	UN Hazard Division
Emulsion (packaged in cartridges)	0.96	170 *	>500 m/s	230-265**	1.1D
PETN (as provided for detonating cord)	1.4	135-145	> 450 m/s	190	1.1D
PETN (as provided within detonators)	1.4	120	> 450 m/s	190	1.4B 1.4S

* This refers to the melting point of Ammonium Nitrate: Ammonium nitrate undergoes phase changes at 32-83 °C and starts to melt at 170° C.

** Depends of type of oil used

Explosives are considered 'initiated' when a self sustaining exothermic reaction is induced. Such a reaction results in either a violent burning with no progression to explosion, a deflagration or a detonation. A deflagration may transit to detonation. The mechanism of transition from deflagration to detonation is still a subject of research. However, both modes of explosion can lead to significant injuries and fatalities and are considered in the Hazard to Life Assessment. The main difference between a deflagration and detonation is that a detonation produces a reaction front travelling at greater than sonic velocity, whereas a deflagration has a subsonic flame front. Both explosion types can cause extensive injury and damage.

Where explosives are stored under controlled conditions in purpose built and operated temporary Magazine or stores, the likelihood of accidental initiation

in situ is remote. This is because the storage environment is unlikely to experience extremes of heat, shock, impact, or vibration of sufficient intensity to initiate detonation. The most common means of accidental initiation is principally the introduction of fire. Other means of initiation include severe impact and friction.

Generally, for an event to cause casualty concerns, a deflagration has to propagate. For a deflagration to occur, the explosive should be, at least but not only, subject to a stimulus which could be:

- Local stimulus: such as to generate a 'hot spot' (e.g. sparks, friction, impact, electrostatic discharge etc);
- Shock stimulus: Subject to shock or high velocity impact: (e.g. bullet impact, detonation of other explosives, etc.); or
- Thermal stimulus: Subject to mass heating leading to exothermic reaction (e.g. subject to intense heat or fire). For all systems, it can be envisaged that there can be no significant event until the medium becomes molten (and in the case of the emulsion, much of the water is lost).

For the types of explosives used in this project, not all of these causes necessarily lead to a deflagration or detonation.

In this study, accidental initiation of explosives has been categorised as either fire or non-fire induced.

The following sections briefly describe the initiation mechanisms and events applicable for this Hazard to Life Assessment.

5.2.2 HAZARDOUS PROPERTIES OF EMULSION TYPE EXPLOSIVES

The family of emulsion explosives typically contains over 78% AN, which is a powerful oxidising agent. Emulsion based explosives will not explode due to friction or impact found in normal handling. However, it can explode under heat and confinement or severe shock, such as that from an explosion. The sensitivity of AN based explosives to deflagration or detonation is increased at elevated temperatures.

There are two broad categories of emulsions:

- Packaged emulsion (sensitized); and
- Bulk emulsion precursor (void-free liquid).

Cartridged emulsions are sensitised to fulfil their intended function (the emulsion is sensitised by either adding gassing solution or plastic microspheres) at the point of manufacture, they are then transported in a sensitized state. Bulk emulsions are sensitized at the point of use on sites. The chemical properties for these two categories of emulsion mainly differ due to the presence of sensitizer.

Matrix or bulk emulsion (no voids) is not sensitive to shock as there is no known mechanism for the shock front to propagate. Also, a very high pressure would be required to heat a void free liquid.

In normal atmospheric conditions, a local stimulus generating 'hot spots' including sparks, friction, impact, electrostatic discharge, extremes of ambient air temperature, etc., does not cause packaged emulsions (sensitized) to readily deflagrate. A pressure in excess of 5 bar above atmospheric pressure, is additionally required in the "deflagrating mass" to generate a deflagration which may subsequently transit to a detonation.

The behaviour of packaged emulsion following a shock or thermal stimulus is discussed below.

5.2.3 *ACCIDENTAL PACKAGED EMULSION INITIATION BY FIRE*

In a fire, pools of molten AN may be formed, and may explode, particularly if they become contaminated with other materials e.g. copper. In a fire, AN may also melt and decompose with the release of toxic fumes (mainly oxides of nitrogen). Beyond 140 °C (ERP, 2009) or in its molten form, its sensitivity to local stimuli increases.

A number of tests indicate that, when subjected to fire engulfment, many explosives ignite and burn, deflagrate, and in some cases detonate. The time for an explosive to ignite is dependent upon its physical characteristics and chemical composition.

It is generally considered that cartridged emulsions are generally less sensitive to fire engulfment as a means of initiation due to the high water content. However, when exposed to heat or fire, the water content of the emulsion will be driven off, leading to possible initiation if the energy levels are high enough, long duration and confinement pressure increases.

A fire surrounding the explosive load will clearly raise the temperature of any reactive media and enable evaporation of components e.g. water. The rate at which this occurs is dependent on the fire (extent) and the heat transfer considering the cargo container wall design. The external part of the container wall will heat by direct contact with the flame and heat will be eventually transferred to the explosive load.

Transport accident statistics for ANFO, another type of ammonium nitrate based explosive, indicate a minimum time to deflagration of about 30 minutes. Emulsion is considered more difficult to initiate than ANFO due to its water content.

The consequences of an accidental explosion due to thermal stimulus could be a thermal explosion (cook-off) or detonation or some combination of the two.

5.2.4 *ACCIDENTAL PACKAGED EMULSION INITIATION BY MEANS OTHER THAN FIRE*

Non-fire initiation mechanisms are commonly divided into two distinct groups; mechanical and electrical energy. The term 'mechanical' encompasses both shock and friction initiation, because in most accidental situations, it is difficult to distinguish between them. It has been recorded that some explosives (not emulsion type) can initiate (in the absence of piercing) mechanically at an impact velocity as low as 15 m/s. If the explosives are pierced, for example by a sharp metal object, then it is likely that the required velocity will be far less than 15 m/s. This is due to localised heat generation resulting from frictional rubbing between layers of explosive, and is referred to as 'stab-initiation'.

However, cartridged emulsion is insensitive to initiation via impact, as demonstrated by the bullet impact test from a high velocity projectile. Based on bullet impact test, it requires at least 10 times the energy level of that required to detonate a nitroglycerine based explosive.

All explosives have a minimum ignition energy level, above which initiation will occur. Typically, minimum ignition energy levels range between 0.015 J and 1.26 J.

For the vast majority of explosives, including cartridged emulsions, the required ignition energy level is far exceeded by contact with mains electricity. In comparison, the energy levels possible from batteries or alternators fitted to motor vehicles, or that due to static build-up on clothing, is typically much less than that required to initiate most commercial explosives (e.g. 0.02 J or less). Hence, only very sensitive explosives are likely to ignite from these electrical energy sources. Therefore, electrical energy is not a possible energy source for the types of explosives intended to be used in this project.

Possible degradation of cartridged emulsion is from water loss and prolonged temperature cycling above and below 34 °C, which leads to potential caking or a change in ammonium nitrate crystalline state and increase in volume. Both modes of degradation do not lead to the detonation of the cartridged emulsion by means other than fire.

5.2.5 *HAZARDOUS PROPERTIES OF DETONATING DEVICES*

These detonating devices may detonate when exposed to heat or flame, or with friction, impact, heat, low-level electrical current or electrostatic energy. Detonation produces shrapnel. Hazardous gases/vapours produced in fire could be lead fumes, nitrogen oxides and carbon monoxide. However, these gases depend on the type of material used in the detonators.

The main explosive contained in detonating devices including detonating cord and detonators is PETN. Detonators also contain a primary explosive substance, e.g. lead azide, which is very sensitive to initiation.

In the case of detonating cord, PETN has similar sensitivities (somewhat less sensitive) than nitroglycerine (NG) based explosives. It is generally more sensitive than emulsions.

PETN has the potential to deflagrate at ambient pressure following a local stimulus. Local initiation can lead to a deflagration (ambient pressure or higher) and from this to a detonation. As an explosive, it has a comparatively small critical diameter (i.e. the smallest physical size of a charge of an explosive that can sustain its own detonation wave) for detonation. When compared to emulsion, PETN can readily initiate by shock but its shock sensitivity is still low compared to NG based explosives. Based on the bullet impact test, it requires at least 10 times the energy level of that required to detonate an NG based explosive (ERP, 2009).

5.3 *ACCIDENTAL INITIATION ASSOCIATED WITH STORAGE AT MAGAZINE*

For the proposed temporary Magazine, the possible means of accidental initiation of the explosives by fire are as follows:

- Inadequately controlled maintenance work (e.g. hot work);
- Poor housekeeping (e.g. ignition of combustible waste from smoking materials);
- Inappropriate methods of work (e.g. operators may not follow strictly the adopted work control system such as the procedures in the operating manual during the operation of the magazine);
- Electrical fault within the store, which ignites surrounding combustible material resulting in a fire; or
- Arson.

Possible means of accidental initiation of the explosives by means other than fire are as follows:

- Dropping of explosives during handling (for the detonators only);
- Crushing of explosives under the wheels of vehicles during loading or off-loading (for detonators and detonating cord only).

The detonators supplied are packaged within plastic separating strips, such that the initiation of a single detonator will not propagate to the adjacent detonator. Packaged in this manner the detonators are classified as Class 1.4B explosives. The total mass of detonators is negligible in terms of explosive mass.

5.4 *ACCIDENTAL INITIATION ASSOCIATED WITH TRANSPORTATION FROM MAGAZINE*

Both cartridged emulsion and detonating cord will be transported within the same truck in the same compartment.

In accordance with the vehicle cargo specifications, the cargo will be designed to minimise all sources of local stimulus and as such will require a significant crash impact and/or a fire to cause a concern to the explosive load. As reported in the ACDS study (ACDS, 1995), a low speed traffic accident is not likely to cause a concern to the explosive load. Conservatively, such an event is still considered possible in this study but with a lower probability (ERP, 2009). Based on the review with explosives experts, the energy required to detonate PETN or emulsion based explosives is one order of magnitude higher (based on bullet tests) than NG. Since NG was considered as the basis for determining the probability of imitation under impact conditions in previous studies (assessed at 0.001), this probability can be reduced by one order of magnitude based on impact energy consideration (ERP, 2009).

The response of the explosive load to an accidental fire would depend on the time and possibility to full fire development on the vehicle (typically 5-10 minutes) and the amount of heat transferred to the load. In the case of emulsion, if isolated from the detonating cord, based on accident statistics, it may take at least another 30 minutes for the explosive to reach critical conditions. This time may be considerably reduced for mixed loads of cartridged emulsion and detonating cord; however, no accurate time could be predicted from detonating cord transport accident data (ERP, 2009).

In this project, the behaviour of explosives as transported was considered to be similar to the XRL study (ERM, 2009), for which, the explosive properties were reviewed with assistance from experts in the explosives industry (ERP, 2009). The review was based on the current knowledge on the explosive properties taking into account recent knowledge on explosive behaviour under thermal stimulus as well as worldwide accident experience. The expert panel has considered in detail what might happen in situations where an emulsion explosive load suffers a thermal stimulus (which could be via heat transfer or direct fire impingement). The main findings for emulsion based explosives are quoted below.

"The radical change in explosive properties at higher temperatures compared to the original emulsion must be taken into account. At high temperatures (> melting point), emulsion explosives would lose water content which may result in a refined explosive (small droplet/ crystal size Ammonium Nitrate (AN)). This could lead to a thermal explosion, deflagration or detonation and the probability of 0.1 may not therefore be applicable to emulsion. Also, some limited accident statistics have some bearing on this hazard scenario: these accidents may include a combination of both thermal and mechanical stimuli, which would likely have resulted in explosion or detonation. The consensus was that the probability of an explosion for the case of an emulsion was less than 0.5 but further refinement of this upper estimate would require additional data and more detailed analysis." (ERP, 2009).

This is consistent with recent accident experience as described in the next section.

On the subject of detonating cord (PETN based), there is no accident data directly relevant for PETN. The properties of detonating cord (PETN based) was reviewed by experts (ERP, 2009) by comparison with other commercial explosives such as NG-based blasting explosives, Plastic Explosives, etc. taking particularly care to exclude mixed load where the load was mixed with significantly more sensitive items such as detonators and safety fuse to offer a valid comparison for PETN. The review was based on accident events reported in the EIDAS which had an explosion confirmed to be caused by a fire event. The review showed that for the incidents involving explosives with properties comparable to detonating cord (PETN based), a fire resulted in explosion in roughly 50% of the cases. Most of the cases involved dynamite known to be more sensitive than detonating cord (PETN based). The data set reviewed contained a number of uncertainties. In particular, for incidents which did not result in explosion, the degree of explosive involvement in fire is uncertain in a few cases. There could also be the presence of other factors which could have contributed to the explosion. On the other hand, it is likely that a number of fire incidents which did not result in explosion do not appear in the database. The panel concluded that a probability of 0.5 would be more appropriate for PETN based explosives.

5.5 *REVIEW OF INCIDENTS*

This section presents a review of reported safety incidents involving explosives (in industrial/commercial applications). Records were retrieved mainly from the UK Health and Safety Executive's (UK HSE)'s Explosives Incidents Database Advisory Service (EIDAS), US Mine Safety and Health Administration (MHSA) and Western Australia's Department of Consumer and Employment Protection (DOCEP). The records provided are also supplemented with information obtained from various sources. Analyses of accident data are provided in the following sections.

For the purpose of this study, incidents were sorted according to the following categories to highlight causative factors to the incidents:

- Incidents involving storage of explosives; and
- Explosives transport incidents.

Further analysis has been performed for other types of explosives (e.g. NG based explosives, ANFO, Plastic (C4), etc.) as relevant for the Frequency Assessment part of this Hazard to Life Assessment.

5.5.1 *EXPLOSIVES STORAGE INCIDENTS*

In the UK a study of the risks associated with explosives manufacture and storage was undertaken based on the 79 major incidents identified during the period from 1950 to 1997 (Merrifield, 1998). A total of 16 major incidents were attributed to the storage of explosives. Thirteen (13) incidents related to the storage of gunpowder, ammunition, nitroglycerine, and fireworks. A further incident, occurring in 1970, involved the storage of detonators and was attributed to corrosion of the detonators themselves. The remaining two (2) incidents related to the storage of blasting explosives in 1954 and 1964. One of

these incidents involving blasting explosives was attributed to malicious activity, whilst the cause of the remaining incident in 1954 was not identified.

Based on the above study, and on the hazards of the explosive materials, it is apparent that the protection of explosives from malicious human activity, and the elimination of possible ignition sources are critical to maintaining storage facilities. From a review of the above records, some of the identified initiating causes of accidents in storage facilities are listed below:

- Impact;
- Friction;
- Overheating;
- Electrical effects (lightning/static discharges);
- Sparks;
- Spontaneous reactions; and
- Malicious action/mishandling.

Avoidance of incidents in the storage area can only be assured by maintaining good housekeeping practice, eliminating potential ignition sources and allocating safe and secure storage space for explosives.

However, not all of these causes are applicable to the types of explosives used in the SIL(E) project. These are further discussed in *Section 6.1.2*.

5.5.2 *EXPLOSIVES TRANSPORT INCIDENTS*

In Hong Kong, there has not been any road transport related incidents on vehicles carrying explosives. The international experience of incidents involving the transport of explosives on the road has therefore been reviewed in detail.

A review of international incident databases indicates that the EIDAS database contains most of the worldwide incidents associated with the transport of commercial explosives. The incidents which were reported from 1950 to 2008 were scrutinised.

The EIDAS database identified one emulsion related transport incident in which a tyre fire on a truck spread to the emulsion load, which eventually detonated producing a substantial crater. However, there were no casualties as the truck crew had time to evacuate to a safe distance before the explosion occurred. Other than this incident, there have been a number of other incidents involving mixed cargoes of emulsion or watergel carried with other types of explosives. One such event was the 1989 '*Peterborough* incident', involving a vehicle carrying Cerium fuseheads, detonators, NG-based explosives and watergel (Peterborough, 1989). The explosion was initiated by fire and explosion from a box of Cerium fusehead combs destined for a local fireworks manufacturer. The combs were in unauthorised and unsafe packages. This incident initiated enactment of more stringent safety guidelines in the UK, specifically the Road Transport (Carriage of Explosives) Regulations of 1989, which came into force just 3-months after the incident.

Australia is a significant user and transporter of explosives, consuming approximately 900,000 tonnes of explosives per year (approximately 8% of the world's consumption of explosives). Of this total, approximately 3,000 tonnes (0.3%) is non-bulk explosives (boosters or cartridged emulsion) based on industry estimates. Western Australia consumes approximately 30% of Australia's explosives and publishes accident data (DOCEP). Within the data recorded by DOCEP, there was one accident reported: a vehicle carrying blasting explosive and detonators overturned (DOCEP, 2001). No ignition (i.e., no fire or explosion) occurred. In the 1990s, there were several accidents in Western Australia involving ammonium nitrate or Ammonium Nitrate Emulsion (UN3375) (UN Class 5 dangerous goods, used as a precursor for manufacturing explosives). All three incidents involved articulated vehicles overturning with no fire or explosion. None of these incidents are directly comparable to the situation in Hong Kong where explosives vehicles are not articulated. In the EIDAS database, two fire incidents involving explosive delivery trucks were recorded in 1998 and 2007 in Australia, however none of these incidents resulted in fatality or injury.

In the US, explosives transport has a good safety record. In a recent study released by the National Institute of Occupational Safety and Health (NIOSH, 2008), analysis of data from 1998 to 2006 revealed that accidents related to the transport of explosives and ammonium nitrate used in mining and construction have resulted in only 5 major injuries, 11 minor injuries, and no fatalities. The safe history of explosives and ammonium nitrate transport is attributed to diligent efforts by government, labour and industry.

Other pertinent statistics could be summarised below:

- There has not been any known transport related explosions involving purely packaged emulsion, hence, accidents data have been examined for other types of explosives having similar properties like bulk emulsion or ANFO although they may be subject to different explosion mechanisms;

- There have been numerous accidents involving crash impact and, even with more sensitive explosives such as nitroglycerine based explosives, there are no reported instances of explosion following a crash impact for either nitroglycerine based explosives, or less sensitive explosives such as PETN and emulsion. Amongst those incidents, several have resulted in truck overturn or other significant scenarios but no explosion occurred purely due to the shock impact (Oct 2008 (US), Aug 2008 (US), Jul 2008 (US), May 2008 (Spain), etc.).

- There have been only six reported transport related accidents involving emulsion (Jun 2004 in Russia and Mar 2007 in Chile) and bulk ANFO (which would behave like emulsion in a fire condition) (Apr 1959 in USA,

Aug 1998 in Canada, Dec 1998 in Australia and Sept 2007 in Mexico). All of these are reported in the EIDAS database and listed in *Table 5.2* Each of these six accidents was caused by a vehicle fire (50% crash related) and most of them led to explosion. Although a high probability (nearly 100%) exists based on accident statistics, the actual probability is less including the number of potentially unreported incidents and at least four known burning tests in Canada, Sweden and Norway in which burning is known to have occurred instead of explosion.

A summary of transport fire incidents involving unmixed loads of ammonium nitrate based commercial explosives is shown in *Table 5.2*.

Table 5.2 Summary of Transport Fire Incidents Involving Unmixed Loads of Ammonium Nitrate Based Commercial Explosives

Date	Country	Type of Explosives	Type of Event	Cause
Apr 1959	USA	ANFO	Explosion	Vehicle Fire
Aug 1998	Canada	ANFO	Explosion	Vehicle crash/ collision
Dec 1998	Australia	ANFO	Explosion	Vehicle Fire
Jun 2004	Russia	Emulsion	Explosion	Vehicle Fire
Mar 2007	Chile	Emulsion	Fire	Vehicle crash/ collision
Sep 2007	Mexico	ANFO	Explosion	Vehicle crash/ collision

It is also relevant to note the experience of cartridged emulsion disposal, reported in the EIDAS database, in burning grounds in controlled burning grounds conditions (typically involving maintenance of separation distances, controlled fire, and in many cases removal of the explosives from their package), where, although the causes may have potentially included contamination i.e. mixing explosives with other materials e.g. waste copper, five events are known to have led to explosions. It is however difficult to correlate these events to transport or storage conditions under uncontrolled fire conditions with potential confinement. It is also worth noting that a number of explosive packages have been disposed by way of burning in which no explosion occurred. However, the information is scattered and the number of such events could not be determined to estimate a probability of explosion.

It is also worth noting a high number (over 20) of known pumping accidental explosions associated with emulsions or slurries which occurred in combination of overheating and confinement (high pressure) (ISEE, 1996).

5.6 SCENARIOS FOR HAZARD ASSESSMENT

The following hazardous scenarios were identified:

5.6.1 *PROPOSED MAGAZINE*

A magazine site typically contains more than one explosive store. Chung Hom Shan, for example, will have 2 stores (*Figure 2.3*). The store of 300 kg storage capacity (i.e. Store 1) will serve Nam Fung worksite (Contract 902) and the store of 500 kg capacity (i.e. Store 2) will serve worksites at Ap Lei Chau (Contract 904). Within each store, explosives and detonators are stored in segregated compartments.

Different contractor's magazine structures are designed with separation and enclosed walls so that initiation of the contents of one contractor's store(s) will not affect other contractor's store(s). The analysis therefore considers the worst case scenario to be the detonation of the full contents of one contractor's store(s). Further justification for this is provided in *Section 6*. This, together with accidents involving the delivery trucks leads to the following scenarios that were considered in the assessment:

- Detonation of a full load of explosives on a delivery truck within the magazine access road; and
- Detonation of the full quantity of explosives within a contractor's store(s).

The explosives transport within the magazine site has conservatively considered the maximum load and the maximum delivery frequency throughout the project as a simplification. In addition, in cases where the explosives trucks are allowed to load explosives at the same time, it was simplistically and conservatively assumed that an accidental explosion of one truck load can lead to domino effects to the other trucks resulting in a potential 2 fold increase in truck load explosion frequency for a Magazine with 2 stores.

The explosive loads considered are listed in *Table 5.3*. The detonator explosive load has been considered in the total explosive load.

Table 5.3 Explosives Storage Quantities

Storage site	Mass of explosive per store (kg)(1,2)	No. of stores	TNT equivalent per store (kg) (3,4)
Chung Hom Shan –Store 1 (Contract 902)	300	1	313
Chung Hom Shan – Store 2 (Contract 904)	500	1	522

Notes:

1 Assumed the worst storage scenario, in which the store contains 18.7% detonating cord, 81.0% cartridged emulsion and 0.3% detonators based on a typical pull length of 4 m and face area of 91.4 m^2 (extracted from the SIL blasting programme)

2 Detonating cord are made of PETN

3 Each detonator contains about 0.9 g of PETN

4 1kg of cartridged emulsion equals 0.96 kg of TNT, and 1 kg of PETN equals 1.4 kg of TNT

5.6.2 *TRANSPORT OF EXPLOSIVES*

Hazardous scenarios considered for the transport of explosives are:

- Accidents involving explosives delivered and transferred from magazine to each delivery point from the gate of each magazine to the gate of the construction face.

Explosion of the detonator load during transport is not quantified for the following reasons:

- Detonators will be transported on a separate truck within the same convoy; and
- Detonator packages will be classified as HD 1.4B or HD 1.4S (articles which present no significant hazard outside their packaging). Packaged in such a way, the consequences potentially leading to fatalities will be limited to remain within the explosives truck boundaries. The UK HSE has estimated the consequences for small quantities of explosives in workrooms. For a detonator load of less than 200 g per trip to be transported in SIL(E), an accidental explosion will lead to approximately 1% chance of eardrum rupture at a distance of 3.5 metres; approximately 50% chance of eardrum rupture at 1.5 metres. Persons in very close proximity to the explosion (e.g. holding the explosives) would almost certainly be killed (HSE, Explosion of Small Quantities of Explosives).

The drill and blast activities for the SIL(E) project will be carried out over a 2 year period during which the explosive load requirement and delivery frequency is expected to vary (see *Section 2.5*). Risks, however, are defined on a per year basis and represent one year construction programme; the base case scenario for the Hazard to Life Assessment was therefore defined to cover different risk levels and possible construction programme deviations throughout the project period.

5.6.3 *SCENARIOS CONSIDERED IN THE ASSESSMENT*

A Base Case and a Worst Case were considered in the risk assessment; the assessed scenarios are summarised in the following tables.

Table 5.4 ***Scenarios Considered in the Base Case Assessment***

Tag	Scenario	Explosives load (TNT eqv. kg)	No. of Trips per year	Remarks
Storage of Explosives				
01	Detonation of full load of explosives in Store 1 in Chung Hom Shan site (Contract 902)	313	-	Store 1 capacity is 300 kg
02	Detonation of full load of explosives in Store 2 in Chung Hom Shan site (Contract 904)	522	-	Store 2 capacity is 500 kg
03	Detonation of full load of explosives in one contractor truck on the access road within Chung Hom Shan magazine site boundary	207	1156	
Transport of Explosives				
04	Detonation of full load of explosives in one contractor truck on public roads – from Chung Hom Shan site to Nam Fung Portal delivery point	42	572	
06	Detonation of full load of explosives in one contractor truck on public roads – from Chung Hom Shan site to Nam Fung Portal delivery point	173	45	
07	Detonation of full load of explosives in one contractor truck on public roads – from Chung Hom Shan site to Ap Lei Chau delivery point	207	539	

Table 5.5 ***Scenarios Considered in the Worst Case Assessment***

Tag	Scenario	Explosives load (TNT eqv. kg)	No. of Trips per year	Remarks
Storage of Explosives				
01	Detonation of full load of explosives in Store 1 in Chung Hom Shan site (Contract 902)	313	-	Store 1 capacity is 300 kg
02	Detonation of full load of explosives in Store 2 in Chung Hom Shan site (Contract 904)	522	-	Store 2 capacity is 500 kg
03	Detonation of full load of explosives in one contractor truck on the access road within Chung Hom Shan magazine site boundary	207	1388	
Transport of Explosives				
04	Detonation of full load of explosives in one contractor truck on public roads – from Chung Hom Shan site to Nam Fung Portal delivery point	42	629	
05	Detonation of full load of explosives in one contractor truck on public roads – from Chung Hom Shan site to Nam Fung Portal delivery point	190	112	
06	Detonation of full load of explosives in one contractor truck on public roads – from Chung Hom Shan site to Ap Lei Chau delivery point	207	647	

6 FREQUENCY ASSESSMENT

6.1 STORAGE OF EXPLOSIVES

6.1.1 EXPLOSION IN CONTRACTOR'S COLLECTION TRUCK WITHIN THE MAGAZINE SITE

The risk associated with accidental explosion during transportation within the temporary magazine site was assessed using the same methodology as described for explosives transport, which will be discussed in detail in *Section 6.2* and is consistent with the approach considered in the XRL study (ERM, 2009). The base frequency for accidental explosion during transport has been taken as 7.69×10^{-10}/km for normal roads, and the same frequency has been assumed while the contractor's truck is onsite at the temporary magazine. For expressways, the base frequency for accidental explosion during transport is 6.87×10^{-10}/km. For cases where, several explosives trucks are allowed to operate within the temporary Magazine site, this frequency has been multiplied by the number of stores to account for potential domino effects (refer to *Section 5.6.1*). This is considered conservative accounting for low speeds, lack of other vehicles and hence low collision probability. The lengths of the magazine access roads and the number of trips considered are provided in *Table 6.1*.

Table 6.1 ***Length of Magazine Access Roads (within the Magazine Sites) and Number of Trips Considered***

Magazine	Route length (km)	Total number of deliveries (/year)
Chung Hom Shan	0.08	1156

6.1.2 EXPLOSIVE MAGAZINE EXPLOSION

In this analysis, the following possible causes of accidental initiation have been considered. Each is discussed in further detail below.

Table 6.2 ***Potential Causes of Accidental Initiation in Magazine***

Generic causes (included in base frequency)
Explosion during manual transfer from store to contractor's collection truck
Lightning strike
Fixed wing aircraft crash onsite
Hill/vegetation fire
Earthquake
Escalation (explosion of one magazine storeroom triggers another)
Other site specific considerations

Generic Causes

A base frequency of 1×10^{-4} /year per magazine site has been taken for generic causes of explosion during storage in the magazine site based on the UK historical records (Merrifield, 1998) as detailed in the WIL study (ERM, 2008). An analysis of the UK explosive storage experience shows that all explosions in UK magazines (other than military stores and ordnance factories) were caused by one of the following:

- unstable explosive material caused by product degradation, corrosion, and contamination;
- escalation of an external incident, e.g. fire; or
- malicious acts, e.g. vandalism or attempted theft.

The explosives types to be used in the SIL(E) project are stable and less likely to undergo initiation due to degradation or impact. However, the explosives stored in this project are detonator sensitive, and hence the detonators are to be stored and transported separately, within a dedicated chamber in the temporary magazine.

The explosives magazine is protected from external fire due to location of explosives inside a concrete or brick wall building and with the provision of fire fighting measures (described in *Section 2.3.2*), and therefore the probability of initiation due to external fire is considered to be lower than that implicit in the UK HSE event frequency.

Hence, it is considered that the most significant causative event that leads to an explosion within the magazine is that posed by malicious activities, such as vandalism or robbery. The proposed temporary Magazine is provided with a comprehensive security system as elaborated in the previous section (*Section 2.3.2*) and thus the possibility of vandalism may be reduced.

The installation of fire fighting measures within each magazine store will reduce the probability of initiation due to fire. The proposed security system will also reduce the frequency of initiation of an explosion due to vandalism or robbery. Nevertheless, this conservative figure of 1 x 10^{-4} per magazine site per year was retained to represent all generic causes of explosion that are common to nearly all magazines. Other causes such as on-site transportation and aircraft impact will vary between sites and have therefore been addressed separately.

Explosion during Manual Transfer from Store to Contractor's Truck

Since transfer of explosive from the store to the truck or vice versa will be carried out manually without involving any tools susceptible to initiate explosives, mishandling is deemed to be the only cause leading to an explosion. There is no significant cause of explosive mishandling identified specific to the project temporary Magazine compared to international practice; hence risks due to manual transfer are taken to be covered in the generic failure causes.

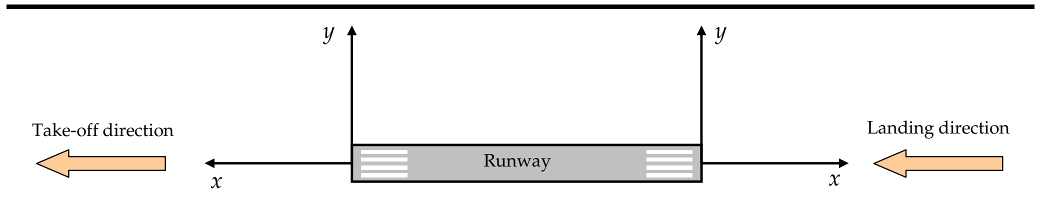
Lightning Strike

The temporary Magazine will be protected with lighting conductors to safely earth direct lightning strikes. The potential for a lighting strike to hit the facility and cause a detonation of explosives is therefore deemed to be unlikely although possible. Given that lightning protection will be provided for each store, lightning strike does not present an additional risk compared to the risk considered as part of the base frequency estimation in the UK. Explosive initiation due to lightning strikes is taken to be covered by the generic failure frequency.

Fixed Wing Aircraft Crash

The probability of a civilian aeroplane crashing onsite can be estimated using the HSE methodology (Byrne, 1997). The same model has been used in previous assessments of aircraft accidents (ERM, 2006). The model takes into account specific factors such as the target area of the proposed site and its longitudinal (*x*) and perpendicular (*y*) distances from the airport runway thresholds of the Hong Kong International Airport (*Figure 6.1*).

Figure 6.1 Aircraft Crash Coordinate System



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

$$g(x, y) = NRF(x, y) \quad (1)$$

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

Landings

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

for $x > -3.275$ km

Take-off

$$F_T(x, y) = \frac{(x+0.6)}{1.44} e^{\frac{-(x+0.65)}{1.2}} \left[\frac{46.25}{\sqrt{2\pi}} e^{-0.5(125y)^2} + 0.9635 e^{-4.1|y|} + 0.08 e^{-|y|} \right] \quad (3)$$

for $x > -0.6$ km

Equations 2 and *3* are valid only for the specified range of *x* values, as defined in *Figure 6.1* for take-offs and landings. If *x* lies outside this range, the impact probability is zero.

National Transportation Safety Board (NTSB) data for fatal accidents in the US involving scheduled airline flights during the period 1986-2005 show a downward trend with recent years showing a rate of about 2×10^{-7} per flight. However, only 13.5% of accidents are associated with the approach to landing, 15.8% are associated with take-off and 4.2% are related to the climb phase of the flight (NTSB, 2001). The accident frequency for the approach to landings hence becomes 2.7×10^{-8} per flight and for take-off/climb 4.0×10^{-8} per flight. The Civil Aviation Department (CAS) reports an annual number of flights at Chek Lap Kok is about 300,000.

Chek Lap Kok has 2 runways, but with take-offs and landings from each direction, the runway designations are 07L, 07R, 25L and 25R. Half the plane movements are taking-offs (150,000 per year) and half are landings (150,000 per year). Assuming each runway is used with equal probability, the frequency of crashes at the magazine sites may be calculated as summarised in *Table 6.3*. The footprint area of each store and associated sand mound is estimated at 120 m^2, suggesting a target area of 240 m^2 for Chung Hom Shan site since it has 2 stores.

From *Table 6.3,* the combined frequencies of all take-off and landing crashes amount to much less than 10^{-9} per year for each of the magazine sites. The risk of aircraft crash is therefore negligible compared to the risks considered in this project.

Table 6.3 Airplane Crash Frequencies

Magazine	Distance from Runway Threshold (km)				Crash Frequency (/km²/yr)*					Magazine Store Area (m²)	Impact Frequency (/yr)
	07L/25R		07R/25L		07L Take-off	25R Landing	07R Take-off	25L Landing	Total		
	x	*y*	*x*	*y*							
Chung Hom Shan	23.6	19	23.6	17.5	1.13×10^{-21}	1.60×10^{-13}	1.14×10^{-19}	3.33×10^{-14}	1.93×10^{-13}	240	4.64×10^{-17}

* Take-offs to the west on runways 25L/R, and landings from the west on runways 07L/R will not contribute to the crash frequencies impacting on the magazine sites

Hill/Vegetation Fires

Hill/vegetation fires are relatively common in Hong Kong, and could potentially occur near a magazine site. Recent statistics for these fires in Hong Kong country parks have been reviewed. Although the temporary Magazine is not actually located in a country park, the surrounding terrain and vegetation are similar to those typically found in country parks. According to Agriculture, Fisheries and Conservation Department (AFCD) statistics, the average number of hill fires is 52 per year during the five years 2003-7 (range: 41 to 66). The area affected by fire each year is available from AFCD annual reports for 2004-2006 (*Table 6.4*). These are compared to the total area of country parks in Hong Kong of 43394 Ha.

Averaging the data for the 3-year period suggests that 1% of vegetation areas are affected by fire each year, or equivalently, the frequency of a hill fire affected a specific site is 0.01 per year.

Table 6.4 ***Hill Fire Data for Hong Kong***

Year	Area Affected (Ha)	% of Total Country Park Affected
2004	371	0.85
2005	144	0.33
2006 (most recent available)	872	2.01

With respect to the explosive magazine design, the land within the compound will be cleared of vegetation to remove combustible materials (see *Section 2.3.2g*). The temporary Magazine, referring to *Section 2.3.2*, will be constructed from fire resistance materials such as bricks, cement rendering and steel doors. The ground surface will be made of either concrete or stone to prevent fire ingress to explosive stores. Since the temporary Magazine will be protected from fire by design, together with other fire-fighting measures in place, the chance of explosive initiation due to hill fire will be much lower than the generic explosion frequency and will be at no greater risk than other explosive magazines worldwide. Thus the generic explosion frequency is considered to include hill fire scenarios.

Earthquake

Studies by the Geotechnical Engineering Office (GEO Report 65, 2002) and Civil Engineering Services Department (GCO, 1991) conducted in the last decades indicate that Hong Kong SAR is a region of low seismicity. The seismicity in Hong Kong is considered similar to that of areas of Central Europe and the Eastern areas of the USA. As Hong Kong is a region of low seismicity, an earthquake is an unlikely event. The generic failure frequencies adopted in this study are based on historical incidents that include earthquakes in their cause of failure. Since Hong Kong is not at disproportionate risk from earthquakes compared to similar explosive magazines worldwide, it is deemed appropriate to use the generic frequencies without adjustment. There is no need to address earthquakes separately as they are already included in the generic failure rates.

Escalation

Referring to the WIL study (ERM, 2008), it is not considered possible that an explosion within one magazine store will directly initiate an explosion within an adjacent store (i.e. leading to mass explosion). This is based on the results obtained from the Ardeer Double Cartridge (ADC) test for cartridged emulsion that show that beyond a separation distance of 2 cartridge diameters the consequence of a detonation are not able to propagate. Therefore the direct propagation by blast pressure wave and thermal radiation effects of an explosion within one store initiating an explosion within the adjacent store is not considered. However, the ground shock induced from an explosion may cause damage within the adjacent stores leading to subsequent explosion.

Explosive stores are made of substantial brickwork surrounded by earth mounds between each store. Referring to a previous assessment (ERM, 2008), a building can withstand a vibration level lower than 229 mm/s without significant structural damage.

Ground vibration distances *R* can be assessed using the formula

$$A = K\, Q^{d}\, R^{-b}$$

where

A is the vibration threshold (mm/s)
Q is the mass of explosive detonated.
$K = 1200$, $d = 0.5$, $b = 1.2$.

The above equation applies to explosives fully coupled with hard rock as typically found in Hong Kong. The temporary Magazine store building will provide some confinement which would result in explosion energy being transmitted through the ground by ground shock effects due to the direct contact of explosives with the ground. The WIL study (ERM, 2008) defines a methodology for assessing the ground shock effects in underground explosive stores. Although the criteria for underground store of the DoD 6055.9-STD will not be reached given the thickness of the walls, the same approach is conservatively adopted to evaluate the ground shock effects in the absence of other relevant correlation. This gives a K value circa 200 ± 10% for the SIL(E) project considering the amount of explosives to be stored in each storeroom at the temporary Magazine site.

Applying the above equation and the ground coupling correlation of the WIL study (ERM, 2008), the maximum ground vibration generated from detonating of 522 kg TNT equivalent explosive (i.e. full load of explosives within Contract 904's magazine complex) is calculated at 133 mm/s for a separation of 19 m (i.e. separation distance between temporary Magazine stores 1 and 2), which is less than 229 mm/s. Hence, this study considers the possibility to initiate other contractor store's explosives due to escalation or domino effect to be negligible compared to the overall explosion frequency.

Conclusion on Accidental Initiation in Magazine

All external hazards make either negligible additional contribution to the risks or are deemed to be already included in the generic frequency of 10^{-4} per year.

6.1.3 *IMPACT ON AIR TRAFFIC NEAR THE CHUNG HOM SHAN SITE*

The proposed Chun Hom Shan magazine site will be located about 9.5 km, 12.5 km, 6.5 km and 40 km away respectively from the regular arrival paths 25L/25R, departure paths 07L/07R (South), 07L/07R (North) and 25L/25R at Hong Kong International Airport (*Figure 6.2* and *Figure 6.3*). These distances are far beyond the maximum impact area of fragments generated in an explosion.

The downwind leg of the approach to 07L/07R and 25L/25R passes over the magazine site (*Figure 6.2*). An aircraft flying along this leg might be stuck by the explosion fragments. The maximum fragment range for an explosion from a magazine is reported to be less than 600 m (Moreton, 2002). Thus, the maximum height that the fragments can reach is less than 600 m considering gravity force in the vertical direction. From an air safety point of view, U.S. National Transport Safety Board recommends a minimum flight altitude of 2000 ft (~ 610 m) above terrain and obstacles in mountainous areas according to Federal Aviation Regulations (FAR) Part 95 (NTSB, 1998). The Civil Aviation Department of Hong Kong adopts a flight altitude of 3000 ft (~ 910m) above hilly terrains based on the obstacle clearance criteria. (LegCo, 1998a and LegCo, 1998b). The actual flight height at the magazine site could be much higher than 3000 ft considering that the site resides at the initial section of arrival paths 07L/07R. A similar site, Sai Kung, a mountainous area located at the initial section of arrival paths 25L/25R, has a flight altitude of approximately 5000 ft (~ 1520 m) (LegCo, 1998a and LegCo, 1998b). Therefore, aircrafts passing the magazine site are at safe distances from the temporary Magazine.

Figure 6.2 ***Arrival Flight Paths of Hong Kong International Airport***

Figure 6.3 ***Departure Flight Paths of Hong Kong International Airport***

6.2 *TRANSPORT OF EXPLOSIVES*

A deflagration or detonation explosion is a possible accidental outcome which may occur during the transportation of explosives from the temporary Magazine to the construction sites. The causes of potential accidental explosion during transportation have been identified in the WIL QRA study (ERM, 2008), which was based on the DNV (1997) study and to a great extent on the ACDS study (ACDS, 1995) study and its associated frequency assessment reported by Moreton's study (Moreton, 1993).

Accidental explosion can be caused by spontaneous fire (non-crash fire), fire after a vehicle crash (crash fire) and impact initiation in crash (crash impact) or spontaneous explosion during the normal condition of transport which may occur if the cargo load contains 'unsafe explosives'.

- **Non-crash fire**:
  This cause category includes any explosion instance where the explosive load has been subject to thermal stimulus which was not the result of a vehicle collision. Events in this category, not only include instances where the explosive load is directly engulfed in the fire but also events where thermal stimulus occurs by ways of heat conduction and convection;

- **Crash fire**:
  This cause category is similar to the non-crash fire category but only concerns fires resulting from a vehicle collision;

- **Crash impact**:
  This cause category includes all instances of vehicle collisions with a sufficient energy to significantly affect the stability of the explosive and which could have the potential to cause an accidental explosion; and

- **Spontaneous explosion ('Unsafe Explosives'):**
  The term 'unsafe explosive' originates from the ACDS study (ACDS, 1995) study. It includes explosions, during conditions of normal transport, resulting from breach of regulations caused by badly packaged, manufactured, and/or 'out-of-specification' explosives.

For crash and non-crash fires, explosive initiation requires a fire to start, the fire to spread to the explosives load and initiation to occur once the load is engulfed by the fire for a period of time.

Based on the Hazard Identification section of this report, explosive initiation due to impact is considered possible but unlikely. It would first require, as demonstrated by bullet impact tests (Holmberg, 2009), a significant mechanical (impact) energy which is unlikely to be encountered in a transport accident scenario. Even in the case of a significant mechanical (impact) energy, as demonstrated by the accident records and drop test data (ACDS, 1995), an explosion would be unlikely. Scenarios in this report include direct initiation events of the explosive load due to impact or secondary events resulting in explosives being spilt onto the road which could subsequently initiate due to indirect impact. For both scenarios, the initiating event requires, as mentioned above, a significant crash impact leading to the loss of integrity of the load compartment and/or a significant mechanical energy affecting the explosive load.

6.2.1 *Explosive Initiation Frequency during Transport as used in Previous Hong Kong Studies*

The basic event frequencies derived in previous Hong Kong studies for road accidents were based on those derived in the ACDS study (ACDS, 1995) for assessing the risks related to the transport of explosives (commercial and non-commercial) in ports. The basic event frequencies were subsequently adjusted in the DNV study (DNV, 1997) to address the risk associated with the transport of commercial explosives by Mines Division Medium/Heavy Goods Vehicle (M/HGV) trucks. Subsequent studies undertaken in Hong Kong including the WIL study (ERM, 2008), Ocean Park Development study (Maunsell, 2006) and Penny's Bay study (ERM, 2001) adopted the frequencies derived for the M/HGV Mines Division trucks based on the DNV study (DNV, 1997) and applied them to the transport of explosives in pick-up truck type Light Goods Vehicles (LGV) operated by contractors from the relevant temporary Magazine to the construction sites.

Accounting for the safer nature of the explosives to be transported nowadays in Hong Kong and the existing regulations in place, the WIL study (ERM, 2008) study proposed a refined approach for the assessment of the explosion frequency associated with the transport of 'unsafe explosives'. Although such events are considered extremely unlikely for the types of explosives used in Hong Kong, it has not been possible to completely rule out their occurrence. As such, the assumption that the assessed frequency of explosion will be doubled as used in the ACDS study (ACDS, 1995) has been dismissed for the particular types of explosives transported in Hong Kong and replaced, instead, by an overall frequency increase by 1% (i.e. a factor of 1.01 was applied to the overall frequency). The details of the approach are presented in the WIL QRA report (ERM, 2008).

The frequency components for transport of explosives has been re-assessed in detail as part of the XRL study (ERM, 2009) given the current knowledge on the explosives' properties, vehicle incident frequencies provided by the Transport Department and Fire Services Department and specific design features applicable for the project such as:

- Light Goods Vehicle (LGV) pick-up type truck for explosive delivery;
- Recent Hong Kong Transport Department statistics;
- Hong Kong specific vehicle fire data;
- Specific Hong Kong explosive delivery truck design feature;
- Specific Hong Kong explosive delivery truck operation; and
- Revised knowledge of explosives properties.

The revised frequency parameters for transport of explosives are summarized in the following sections. The historical background for the derivation of each frequency component are presented in the XRL study (ERM, 2009) report.

Initiation Probability on Significant Impact

Based on the review with explosives experts, the energy required to detonate PETN or emulsion based explosives is one order of magnitude higher (based on bullet tests) than nitroglycerin (NG) based explosives. Since NG was considered as the basis for determining the probability of initiation under impact conditions in the ACDS study (ACDS, 1995) study (assessed at 0.001), a reduction factor of 0.1 was applied based on impact energy consideration (ERP, 2009), giving the overall initiation on impact probability taken as 0.0001.

Probability of Explosive Response to Fire

The initiation of explosives in the DNV study (DNV, 1997) was assessed as 0.1 for any fire involvement. This value was based on the ACDS study (ACDS, 1995), which was derived from an expert judgement for heat insensitive explosive group which included a variety of explosives. In the XRL study (ERM, 2009), the proportion of detonating cord and cartridged emulsion differs from the previous projects. The sensitivity of the explosive load to fire and impact has therefore been reviewed. Based on the experts' knowledge (ERP, 2009) and experience on PETN and sensitized emulsion, the probability that the explosive melts and detonates once the fire impacts on the load is more likely than what was initially assumed in the ACDS study (ACDS, 1995) given the recent transport accident experience and the known properties of mixed explosives used. In the absence of further test data on transported explosives, a probability of 0.5 has been taken in the XRL study (ERM, 2009) to more appropriately represent the mix of explosive loads as applicable in the study. The same probability of 0.5 is used in the current study.

Frequency of Non-crash Fire – Explosives Subject to Thermal Stimulus

Referring to the expert panel review (ERP, 2009), a thermal stimulus is sufficient to cause an explosion of the explosive load based on updated knowledge on explosive properties. The non-crash fire frequency (i.e. 1.30×10^{-9} /km) was then derived specifically for Hong Kong conditions based on goods vehicle data provided by Transport Department in 2007 and Fire Services Department data on causes of fire call incidents in Hong Kong between 2004 and 2008. This update in the XRL study (ERM, 2009) reflects the most common causes of fires occurring on motor vehicles in Hong Kong, giving a lower fire incident rate compared to UK data (1.4×10^{-9}/km).

Vehicle Involvement Rate

In previous studies undertaken in Hong Kong including the XRL study (ERM, 2008), Ocean Park Development study (Maunsell, 2006) and DNV study (DNV, 1997), they adopted the frequencies derived for the M/HGV to account for Hong Kong situation based on the relevant HK HGV to UK HGV reportable vehicle collision involvement. Since specific LGV pick-up type trucks will be used in the project, a review of the Hong Kong accident data and vehicle involvement rate for LGVs was carried out based on the data published by the Transport Department between 2003 and 2007.

Explosive Initiation Frequency for Different Types of Road

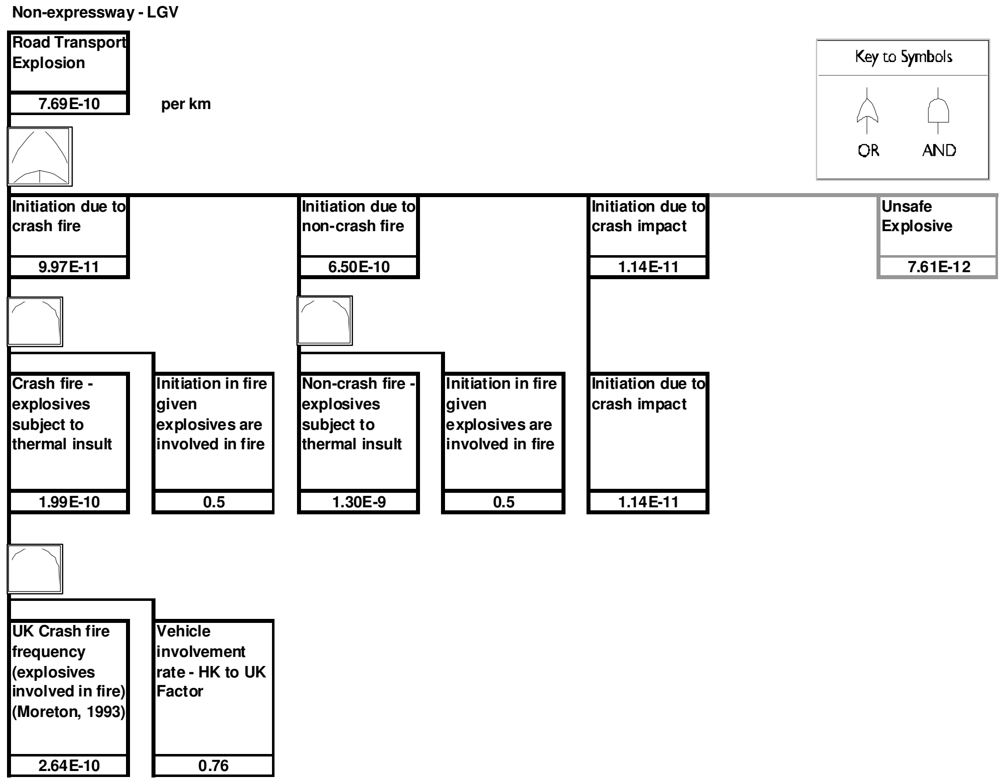
Since the vehicle impact speed and the accident involvement rate on highway/ major roads and non-highway are significantly different, different sets of explosive initiation frequencies for Expressway and Non-expressway have been derived during explosives transport to reflect the road conditions along the transport routes.

The components of the explosive initiation fault tree adopted in the XRL study (ERM, 2009) as well as their individual probabilities are shown in *Table 6.5* and the fault tree models for the road transport explosion are shown in *Figure 6.4* and *Figure 6.5*. The frequencies of explosives initiation during road transport were therefore estimated at 6.87×10^{-10}/km on expressways and 7.69×10^{-10}/km on other road sections considering an additional 1% increase for "unsafe explosives" (i.e. a factor of 1.01), as justified in the WIL QRA (ERM, 2008).

Table 6.5 Explosives Initiation Fault Tree Inputs After XRL Study (ERM, 2009)

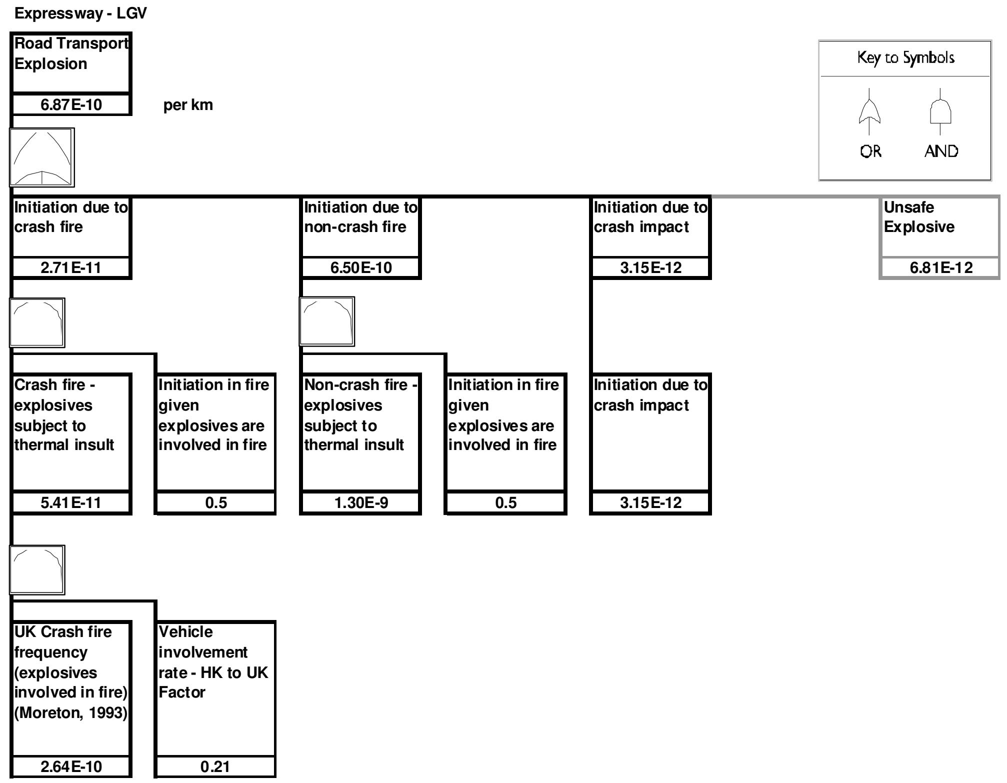
Event	Event type	Value
Vehicle crash (on expressway)	Frequency	1.27×10^{-7} /km
Vehicle crash (on non-expressway)	Frequency	4.68×10^{-7} /km
Crash fire (on expressway)	Frequency	5.41×10^{-11} /km
Crash fire (on non-expressway)	Frequency	1.99×10^{-10} /km
Non-crash fire	Frequency	1.30×10^{-9} /km
Explosives initiation in fire	Probability	0.5
Explosives initiation in impact	Probability	0.0001

Figure 6.4 Explosives Initiation Fault tree for Non-Expressway – Road Transport Events After XRL Study (ERM, 2009)



Note: Vehicle involvement rate – HK to UK factor was calculated by dividing the crash frequency of 4.7E-7 per year by the UK frequency of 6.2E-7 per year (see discussion of *Section 6.2.2* in XRL study (ERM, 2009) study)

Figure 6.5 Explosives Initiation Fault tree for Expressway – Road Transport Events After XRL Study (ERM, 2009)



Note: Vehicle involvement rate – HK to UK factor was calculated by dividing the crash frequency of 1.3E-7 per year by the UK frequency of 6.2E-7 per year (see discussion of *Section 6.2.2* in XRL study (ERM, 2009) study)

6.2.2 *TRANSPORT EXPLOSION FREQUENCY FOR SIL (E)*

The Hazard to Life Assessment study for SIL(E) has been performed based on the explosive initiation frequencies derived in the XRL study (ERM, 2009) for the transport of explosives and the specific explosives transport vehicle design and operation to be used as part of the SIL(E) project. This approach is consistent with previous studies. The explosives initiation fault tree models for the road transport events for non-expressway and expressway are presented in *Figure 6.4* and *Figure 6.5* respectively, although the fault tree for expressways is not needed in this study since there are no expressways along the transport routes.

7 CONSEQUENCE ASSESSMENT

7.1 GENERAL

Explosives present a hazard to both property and people. This hazard manifests itself in the following ways:

- blast and pressure wave;
- flying fragments or missiles;
- thermal radiation; and
- ground shock.

In the case of bulk explosions, the most damage is usually caused by the blast effects. However, for small detonations, fragmentation is the most significant effect and thermal radiation is only of interest in low speed deflagrations.

Two modes of injury can result to people when exposed to blast effects:

- Primary;
- Secondary; and
- Tertiary effects.

Primary effects involve the direct effects of the blast upon sensitive human organs such as the ears and lungs. Compared with secondary and tertiary effects, considerable overpressures are required for fatalities to occur, and consequently people need to be fairly close to the scene of the explosion for primary effects to be significant.

Secondary effects are associated with building collapse or the impact of debris and fragments from damaged building structures and the vehicle or container in which the explosives are held. Predicting injury and fatality levels due to fragments/debris from high explosives is particularly difficult.

Tertiary blast injuries may occur with whole body impacts, when people are displaced or swept away, or due to the violent movement of internal organs within the body. For people outdoors, tertiary effects are dominant.

Thus, for the cartridged emulsion to be transported and stored for this project, the blast effects will be of most concern. Also of interest are the detonators used to initiate these explosives. However, provided these are kept within their original packaging they will only explode 'one-at-a time', and will not present a mass explosion hazard. Packaged in this way, the detonators may be classified as UN Class 1.4 S.

7.2 PHYSICAL EFFECT MODELLING

7.2.1 BLAST AND PRESSURE WAVE FOR EXPLOSION

The consequence models used for the assessment of the probability of fatality due to blast and pressure waves, are based on the most recent UK Explosive Storage and Transport Committee (ESTC) model defined in the HSC publication (ESTC, 2000). This model has been previously used in the XRL study (ERM, 2009) and considers all the effects associated with an above ground explosion including fireball, overpressure, flying debris, broken glass, structural damage, etc.

People Indoors

The ESTC indoor model is based on the analysis of casualty data collated from records of a number of major incidents involving accidental explosion. The data on which the model is constructed does not distinguish between those killed by the blast and those killed by fragments. It is assumed that blast effects were the cause of most of the fatalities recorded in these incidents but the model implicitly makes some allowance for fragment effects. The probability of fatality for persons located inside conventional buildings for various quantities of explosives can be estimated by:

$$\log_{10} P = 1.827 - 3.433\log_{10} S - 0.853(\log_{10} S)^2 + 0.356(\log_{10} S)^3 \qquad \text{for } 3 < S < 55$$

Where $S = R / Q^{1/3}$

P is the probability of death, R is the range in metres, and Q is the explosive charge mass in kg (TNT equivalent mass).

In this study, the indoor consequence model has been assumed to be also applicable to the population present in vehicles.

People Outdoors

The outdoor model is based on a review of the available literature on primary and tertiary blast effects:

$$P = \frac{e^{(-5.785S + 19.047)}}{100} \qquad \text{for } 2.5 < S < 5.3$$

The distance to 1%, 3%, 10%, 50% and 90% fatality contours were used in the modelling.

7.2.2 FLYING FRAGMENTS OR MISSILES

Fatality due to flying fragments or missiles due to explosion is considered in the ESTC model; therefore, no separate model for debris is considered.

7.2.3 *THERMAL RADIATION*

The initiation of an explosion will result in thermal radiation from a fireball as the explosives initiate. There are relatively few published models in the literature for high explosive fireballs, or those that may result from a cartridged emulsion detonation. Models that are available describe the fireball duration and diameter based on TNT or similar explosives e.g. nitroglycerine, PETN, etc. Radiation effects are generally considered to be a concern for explosives classified as HD 1.3. For the purpose of this study, it is assumed that the fireball correlations are applicable to cartridged emulsion containing ammonium nitrate, fuel oil and aluminium powder.

The diameter and duration of a fireball from a high explosive are given in Lees (1996):

$$D = 3.5\, M^{0.333}$$

$$t_d = 0.3\, M^{0.333}$$

where D is the fireball diameter (m)
M is the mass of the explosive (kg), TNT equivalent
t_d is the duration of the fireball (seconds).

For the largest explosive mass of 522 kg (initiation of an entire store contents), a fireball radius of 14.1 m is predicted with a duration of 2.4 seconds.

The surface emissive power (E_f) can then be calculated from the equation:

$$E_f = \frac{f_s M \Delta H_r}{4\pi r_{fireball}^2 t_d}$$

Where ΔH_r is the heat released from the explosive (kJ/kg), which is approximately 4.01 MJ/kg for cartridged emulsion. M is the mass of explosive (kg) and f_s is the fraction of the heat that is radiated, a conservative value of 0.4 is taken. This gives a surface emissive power of the fireball of 140 kW/m^2.

The heat flux received by a receptor at some distance from the fireball is estimated from:

$$q'' = E_f . F_{view} \tau_a$$

Where E_f is the surface emissive power of the fireball, which is either estimated using the previous equation or is an assumed maximum value. F_{view} is the view factor, and τ_a is the atmospheric transmissivity.

For a vertical surface the view factor can be calculated from:

$$F_{view} = \frac{X (r_{fb})^2}{\left(X^2 + r_{fb}^2\right)^{3/2}}$$

Where X is the distance measured along the ground from the object to a point

directly below the centre of the fireball. This distance must be greater than the radius of the fireball, because actual development of the fireball often involves an initial hemispherical shape, which would engulf nearby receptors. Additionally, as the fireball lifts off the ground, the distance to near field receptors changes significantly. This means that the radiation estimates in the near field are of questionable accuracy.

At very large distances, the above equation for the view factor reduces to

$$F_{view} = \left(\frac{r}{X}\right)^2$$

The atmospheric transmissivity, τ_a, reflects the proportion of radiation that is adsorbed by the water vapour and the carbon dioxide present in the atmosphere. A correlation for the estimation of transmissivity was published by F.D. Wayne (1991):

$$\tau_a = 1.006 - 0.01171 \log_{10}(X_{H_2O}) - 0.02368[\log_{10}(X_{H_2O})]^2 - 0.03188 \log_{10}(X_{CO_2}) + 0.001164[\log_{10}(X_{CO_2})]^2$$

where

$$X_{H_2O} = \frac{2.165 P_w^o RHd}{T}$$

$$X_{CO_2} = \frac{273d}{T}$$

RH is the relative humidity and is assumed to be 85% for Hong Kong. P_w^o is the vapour pressure of water at atmospheric temperature T, and d is the distance to the fireball surface, or path length.

The probit equation for fatalities due to thermal radiation is proposed by Eisenberg (Lees, 1996):

$$\Pr = -14.9 + 2.56 \ln L$$

Where L is the thermal dose or load defined as $L = t\, I^{4/3}$, I is the thermal radiation flux (kW/m^2), t is the exposure duration and Pr is the probit that is related to probability of fatality.

The thermal dose units corresponding to 1%, 50%, and 90% fatality levels are 956, 2377, and 3920 s.(kW/m^2)$^{4/3}$ respectively. These broadly match with the 1000, 1800 and 3200 TDU levels reported by the UK HSE Safety Report Assessment Guides (HSE HFLs, 2001) for the same fatality levels. Applying the HSE thermal dose criteria limits for a fireball of duration 2.4 s, indicates that the incident radiation fluxes to cause these fatality levels are estimated as 92, 143, and 221 kW/m^2.

Comparing these with the fireball surface emissive power of 140 kW/m^2, shows that these levels of thermal flux will only be realised when in very close proximity to the fireball. Therefore, it can be concluded that a fireball from the initiation of cartridged emulsion within the storage magazine will not pose an off-site hazard. It is generally the case that the thermal hazards from an explosives detonation event are of less concern than the blast and fragment hazards. Therefore, the hazards from a fireball are not considered further in this assessment.

7.2.4 *GROUND SHOCK*

The detonation of solid phase materials liberates energy by a rapid chemical reaction process, which produces and sustains a shock wave in the material. The high temperatures and pressure associated with the shock wave causes almost instantaneous reaction in the material. This reaction produces high pressures and temperatures in the expanding gas. In the case of rock excavation, it is this pressure that crushes surrounding rock when the explosive material is placed in a drill hole for blasting.

In areas where the explosive material is less confined, the pressure will be reduced due to the increased volume into which the gases can expand. If the degree of confinement is reduced, eventually the pressure will cease to crush the rock, but instead will cause rock fractures or cracking. If the level of confinement is reduced further, the pressure will cease to fracture the rock and the energy will propagate through the rock as an elastic wave causing the rock particles to vibrate. The degree of vibration of the rock particles decreases with increasing distance from the blast. However, the vibration of the rock particles can cause damage and structural failure to buildings if sufficiently strong (USBM 656).

Considering the fact that in this project explosives transport and storage will be carried out aboveground with much less confinement than that of rock excavation, this aspect of consequence should not be of much concern compared to the hazards posed by the overpressure wave and debris generated (modelled by the ESTC model). A comparison of 1% fatality impact distance calculated by ground vibration model and ESTC model are provided in *Table 7.1* and the results show the effect of ground vibration are less significant than that of air shockwave and debris.

Table 7.1 ***Blast Effect Distances for 1% Fatality Probability from Detonation of 522 kg TNT Equivalence of Explosive***

Consequence	Receiver's location	Effect radius (m)
Shockwave and debris - ESTC model	Indoor	72.5
	Outdoor	25.6
Ground shock – Object falling threshold (PPV = 100mm/s)	Indoor / outdoor close by a structure	24.2

In addition, excessive ground vibration may lead to slope failure and create a secondary hazards. Based on the effect thresholds defined in the previous assessment, the weakest slope with factor of safety (FOS) of 1.1 can be damaged in 0.01% chance with a peak particle velocity (PPV) of 90 mm/s.

The effect radius of 90mm/s was calculated as 26.3 m for detonation of 522 kg TNT equivalence of explosives, which correspond to the maximum quantity of explosive (TNT equivalent) to be stored in Contract 904's magazine store 2. Based on the data for slopes nearest to the temporary Magazine supplied by MTR as tabulated in *Table 7.2*, explosion in this magazine store 2 (capacity: 500 kg) could possibly result in collapse of the adjacent slopes (i.e. 15NE-C/C210, 15NE-C/C211, 15NE-C/F88 and 15NE-C/F65 in *Table 4.8*). The estimated PPV

values for slopes C210 and F65 caused by the detonation of 500 kg explosives are 183 mm/s *(<0.01% slope failure)*, 361 mm/s *(<10% slope failure)*, 156 mm/s *(<10% slope failure)* and 107 mm/s *(<0.01% slope failure)* respectively. Failing of slope 15NE-C/F65 may also damage the magazine store 1 and result in a second explosion.

Similarly, an initiation of 300 kg explosives within the magazine store 1 will be sufficient to cause possible slope failure of 15NE-C/C210 *(<0.01% slope failure)* and 15NE-C/F65 (100% *slope failure)* because of the limiting separation distances (8.3m and 3.0m respectively) between the store and nearby slopes.

However, additional significant casualties due to slopes collapse in the above scenarios are not expected because the affected slopes are located at the site boundary and too far away from the offsite population or roads. In addition, there is no known (current or future) permanent, temporary or transient population within the hazard zones of the Chung Hom Shan magazine site.

Table 7.2 ***Particulars of the Slopes Nearest to the Magazine***

Slope Identification	Static Factor of Safety	Slope length, m	Slope depth, m	Slope material	PPVc, mm/s	Slip Volume, m³
15NE-C/C210	1.276	17	4.4	Soil & Rock	71.8	666
15NE-C/C211	1.226	21	8.4	Soil & Rock	81.4	1940
15NE-C/F65	1.209	8	1.4	Fill	20.6	47
15NE-C/F88	1.318	4	0.7	Fill	19.6	6

7.3 *RESULTS OF CONSEQUENCE ASSESSMENT*

The consequence results for each transport and storage scenario are summarized in *Table 7.3* and *Table 7.4*. Consequence distances for the storage scenarios (no. 1 -3) may be compared to the separation distances specified in the magazine designs, as follows: public footpaths must be at least 54 m away (vehicle routes must be further); buildings must be at least 180 m away. Thus, the design separation distances substantially exceed the 1% fatality distance and hence no significant risk of fatality due to explosive storage is expected.

Table 7.3 Summary of Results for Base Case Consequence Scenarios

No.	Scenario	TNT eqv. kg	Fatality Prob.	*Indoor* Impact distance (m)	*Outdoor* Impact distance (m)
	Storage of Explosives				
01	Detonation of full load of explosives in store 1 in Chung Hom Shan site	313	90%	20.9	16.8
			50%	24.2	17.4
			10%	35.6	19.3
			3%	47.4	20.8
			1%	57.3	21.6
02	Detonation of full load of explosives in store 2 in Chung Hom Shan site	522	90%	24.8	19.8
			50%	28.6	20.6
			10%	42.4	22.8
			3%	56.4	24.5
			1%	72.5	25.6
03	Detonation of full load of explosives in one contractor truck on the access road within the Chung Hom Shan magazine site boundary	207	90%	18.2	14.6
			50%	21.1	15.2
			10%	31.3	16.8
			3%	41.7	18.0
			1%	53.6	19.1
	Transport of Explosives				
04	Detonation of full load of explosives in one contractor truck on public roads – from Chung Hom Shan site to Nam Fung Portal delivery point	42	90%	10.8	8.7
			50%	12.5	9.0
			10%	18.5	10.0
			3%	24.8	10.7
			1%	32.1	11.3
05	Detonation of full load of explosives in one contractor truck on public roads – from Chung Hom Shan site to Nam Fung Portal delivery point	173	90%	17.2	13.8
			50%	19.9	14.3
			10%	29.5	15.8
			3%	39.4	17.0
			1%	51.0	18.0
06	Detonation of full load of explosives in one contractor truck on public roads – from Chung Hom Shan site to Ap Lei Chau delivery point	207	90%	18.2	14.6
			50%	21.1	15.2
			10%	31.3	16.8
			3%	41.7	18.0
			1%	53.6	19.1

Table 7.4 Summary of Results for Worst Case Consequence Scenarios

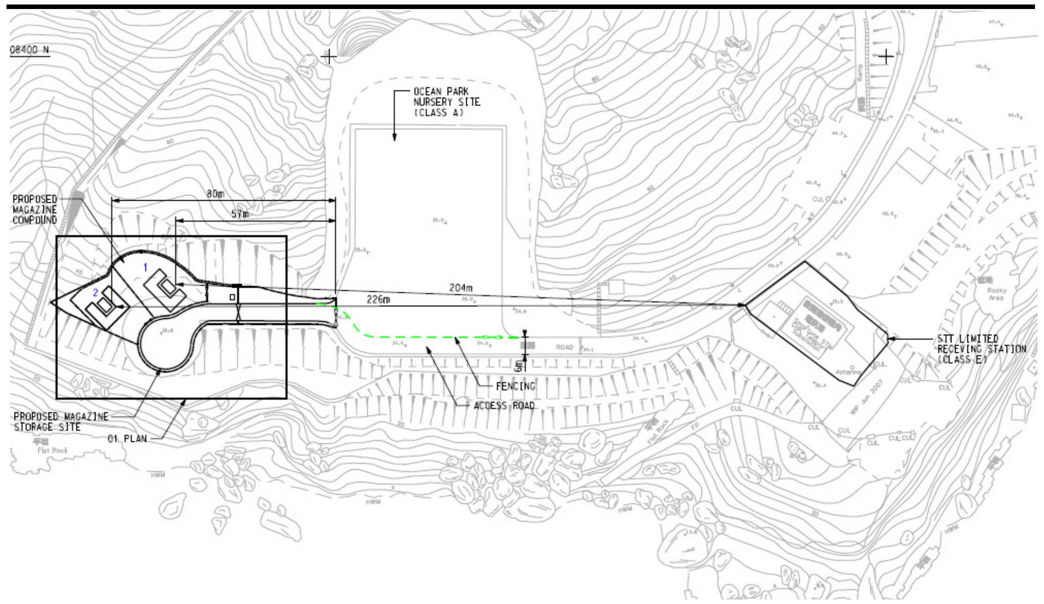
No.	Scenario	TNT eqv. kg)	Fatality Prob.	*Indoor* Impact distance (m)	*Outdoor* Impact distance (m)
	Storage of Explosives				
01	Detonation of full load of explosives in store 1 in Chung Hom Shan site	313	90%	20.9	16.8
			50%	24.2	17.4
			10%	35.6	19.3
			3%	47.4	20.8
			1%	57.3	21.6
02	Detonation of full load of explosives in store 2 in Chung Hom Shan site	522	90%	24.8	19.8
			50%	28.6	20.6
			10%	42.4	22.8
			3%	56.4	24.5
			1%	72.5	25.6
03	Detonation of full load of explosives in one contractor truck on the access road within the Chung Hom Shan magazine site boundary	207	90%	18.2	14.6
			50%	21.1	15.2
			10%	31.3	16.8
			3%	41.7	18.0
			1%	53.6	19.1
	Transport of Explosives				
04	Detonation of full load of explosives in one contractor truck on public roads – from Chung Hom Shan site to Nam Fung Portal delivery point (Period of blasting with bulk emulsion)	42	90%	10.8	8.7
			50%	12.5	9.0
			10%	18.5	10.0
			3%	24.8	10.7
			1%	32.1	11.3
05	Detonation of full load of explosives in one contractor truck on public roads – from Chung Hom Shan site to Nam Fung Portal delivery point (Period of blasting with cartridged emulsion only)	190	90%	17.7	14.2
			50%	20.5	14.8
			10%	30.4	16.3
			3%	40.6	17.5
			1%	52.4	18.5
06	Detonation of full load of explosives in one contractor truck on public roads – from Chung Hom Shan site to Ap Lei Chau delivery point	207	90%	18.2	14.6
			50%	21.1	15.2
			10%	31.3	16.8
			3%	41.7	18.0
			1%	53.6	19.1

7.4 SECONDARY HAZARDS

7.4.1 SATELLITE RECEIVING STATION NEAR THE CHUNG HOM SHAN MAGAZINE SITE

The satellite receiving station is located at about 147 m from the entrance of proposed temporary explosives magazine site Chung Hom Shan (*Figure 7.1*). The shortest distances from the station to the explosive stores are 204 m (Store 1, max capacity of 300 kg) and 226 m (Store 2, max capacity of 500 kg). In previous sections, the fatality consequence model (ESTC model) was used to assess hazard to life and it was concluded that there is no direct risk to staff at the station from the proposed magazine site based on this separation distance. However, if the station is to be damaged, secondary or knock-on effects may lead to additional hazards and loss of life. Potential damage to the station is considered further in this section.

Figure 7.1 ***Location of Chung Hom Shan Magazine in Relation to the Satellite Receiving Station***



Based on the TNT explosion model from the Yellow Book (Yellow Book), explosion in the magazine stores could generate the maximum overpressure of 0.51 psi at the west boundary of the satellite station. This is a conservative upper limit without consideration of the shielding effects of the store barricades.

Some examples of the property damage expected for various levels of overpressure (Lees, 1996) are indicated in *Table 7.5*. An overpressure of 0.51 psi will shatter the glass windows with only minor impacts on the building structures expected.

Table 7.5 ***Damage Effects Produced by a Blast Wave***

Overpressure (psi)	Description
0.4	Limited minor structural damage; 10% window glass broken
0.5 – 1.0	Windows shattered
1.0 – 2.0	Connection failure of corrugated steel/asbestos/wood panelling
2.0	Partial collapse of walls & roofs of houses
2.5	50% destruction of brickwork of houses
3 – 4	Rupture of oil storage tanks
5 – 7	Nearly complete destruction of houses
7 – 8	Brick panels 8-12in. thick, not reinforced, fail by shearing or flexure

In addition to the direct overpressure from the blast, any initiation of the explosives at the temporary magazine would also create ground vibrations that may impact the station. The maximum peak particle velocity (ppv) was calculated to be 6.8 mm/s, assuming an underground explosion. This is considered as a conservative estimation because explosives are actually stored

aboveground in a chamber with air space around the explosives to reduce any coupling between the blast and the surrounding rock. No damage is expected since this level of ground vibration is much lower than 25 mm/s which could cause the cosmetic damage to general buildings and structures.

A few flying fragments/projectiles generated by an explosion may fall on the buildings or impact the outdoor workers in the station. Insignificant damage is expected to the concrete structure of the buildings. Impact on staff is unlikely but is included in the consequence models as described in *Section 7.3*.

7.4.2 *IMPACTS ON SLOPES AND BOULDERS*

Along the transport route, there are some slopes close to the road, in particular along some sections of Chung Hom Kok Road, Repulse Bay Road, Island Road and Lee Nam Road. There is a possibility that an explosion on road vehicle may trigger a landslide or a boulder fall. This is regarded as a secondary hazard. The impact of this hazard in terms of potential consequences was evaluated using the approach adopted in the XRL study (ERM, 2009). It was found that any landslide and boulder fall event will impact the same area along the road that is already affected by the primary explosion consequences. Hence, no additional fatality will occur.

8 RISK SUMMATION

8.1 OVERVIEW

The Consultants' in-house software has been used for risk calculation and summation. This integrates the risks associated with the magazine sites with those from the transport of explosives to the work sites, including the risks to other road users, nearby buildings and outdoor population.

The base case considered a realistic construction scenario. The individual risk and societal risk results are shown below.

A Worst Case was also considered to address potential changes in the construction programme due to construction uncertainties. The societal results for this worst case are also shown for comparison purposes.

8.2 RISK MEASURES

The two types of risk measures considered are societal and individual risks.

8.2.1 SOCIETAL RISK

Societal risk is defined as the risk to a group of people due to all hazards arising from a hazardous installation or activity. The simplest measure of societal risk is the Rate of Death or Potential Loss of Life (PLL), which represents the predicted equivalent fatalities per year:

$$PLL = f_1N_1 + f_2N_2 + f_3N_3 + \ldots + f_nN_n$$

where f_i is the frequency and N_i the number of fatalities for each hazardous outcome event.

Societal risk can also be expressed in the form of an F-N curve, which represents the cumulative frequency (*F*) of all event outcomes leading to *N* or more fatalities. This representation of societal risk highlights the potential for accidents involving large numbers of fatalities.

8.2.2 INDIVIDUAL RISK

Individual risk may be defined as the frequency of fatality per individual per year due to the realisation of specified hazards. Individual Risk may be derived for a hypothetical individual present at a location 100% of the time or a named individual considering the probability of his presence etc. (the latter case being known as Personal Individual Risk).

8.3 SOCIETAL RISK

8.3.1 POTENTIAL LOSS OF LIFE

Table 8.1 and Table 8.2 below show the PLL values for the transport of explosives to the blasting sites. As expected, the Worst Case (PLL = 1.58×10^{-4}/year) imposes a higher risk than the Base Case (PLL = 1.25×10^{-4}/year).

The proposed temporary magazine storage site (Chung Hom Shan) has negligible contribution to the overall risks since it is located in a remote area with very low population density nearby. The delivery to Nam Fung Portal accounts for almost 1/5 of the overall transport risk, with the remaining 4/5 attributed to the delivery to Ap Lei Chau. This can be explained by longer transport distances and higher explosive loads to the latter worksite.

Table 8.1 PLL for Base Case

Case: Base Case	PLL (per year)	Contribution (%)
Storage of Explosives		
Chung Hom Shan Magazine	1.11E-08	0.009%
Transport of Explosives		
Chung Hom Shan Magazine to Ap Lei Chau	9.09E-05	72.83%
Chung Hom Shan Magazine to Nam Fung Portal	3.39E-05	27.16%
Total	1.25E-04	100.00%

Table 8.2 PLL for Worst Case

Case: Worst Case	PLL (per year)	Contribution (%)
Storage of Explosives		
Chung Hom Shan Magazine	1.11E-08	0.007%
Transport of Explosives		
Chung Hom Shan Magazine to Ap Lei Chau	1.14E-04	72.15%
Chung Hom Shan Magazine to Nam Fung Portal	4.40E-05	27.85%
Total	1.58E-04	100.00%

8.3.2 F-N CURVES

Figure 8.1 shows the overall F-N curves for explosives storage and transport combined. These include the Chung Hom Shan magazine site and the associated transport routes to the 2 work sites.

The Base Case represents the risks associated with the expected blasting programme, whereas the worst case has considered a 20% increase in the number of deliveries for both worksites. It can be seen that for both cases the risks lie in the lower ALARP region.

Figure 8.1 *F-N Curve for Storage and Transport of Explosives*

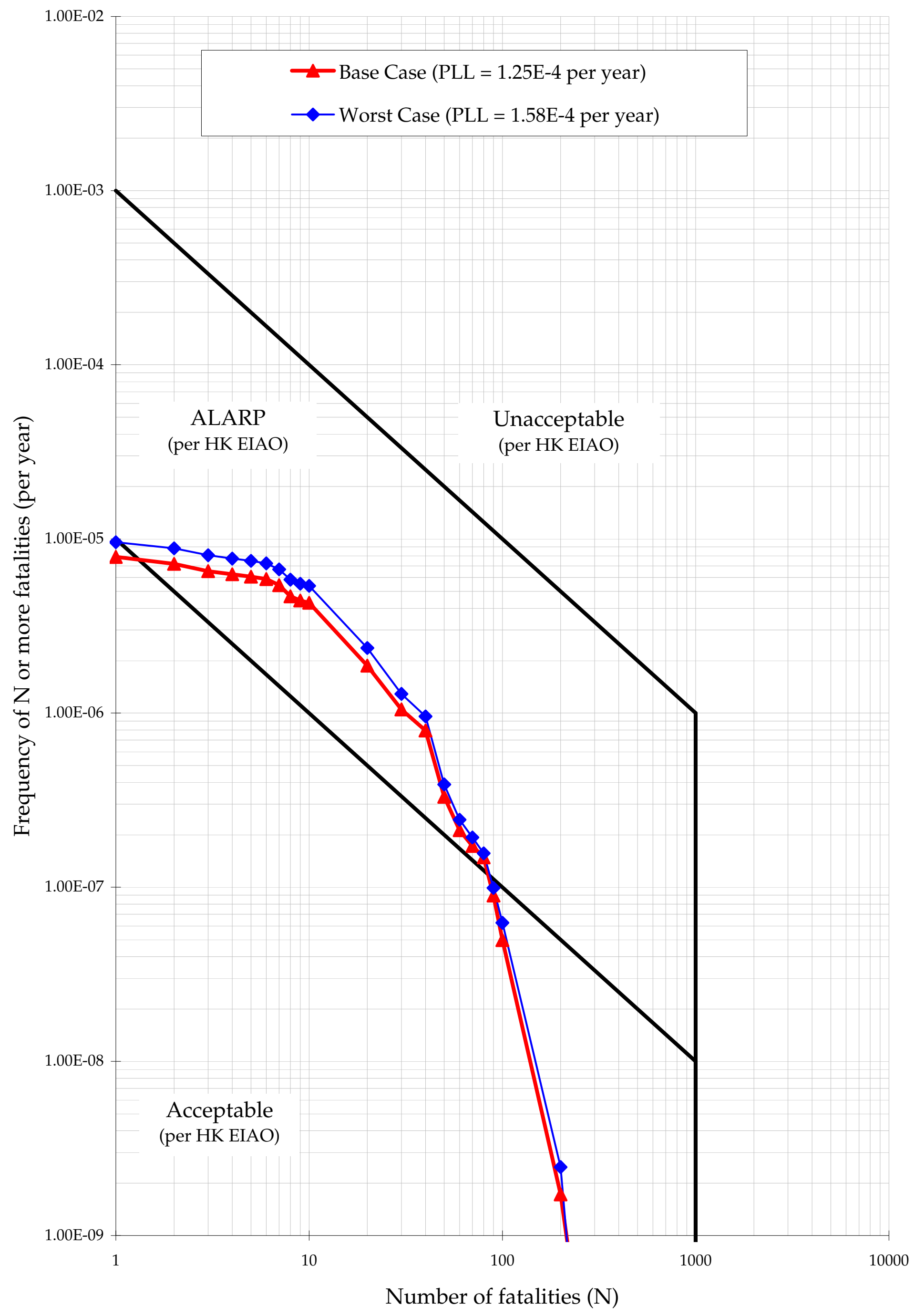


Figure 8.2 shows the F-N curve for the Base Case with a breakdown by storage and transport. It can be seen that risks from the temporary magazine are negligible compared to transport risks. This is consistent with the comments made in relation to the PLL. Population in the vicinity of the magazine sites is very low and hence the societal risks are small.

Figure 8.3 provides a breakdown by population type for Base Case. As expected, the highest risks are associated with other road users and this dominates the overall F-N curve, particularly for the low *N* scenarios. 68.4% of

the PLL (8.55×10^{-5} per year compared to the total of 1.25×10^{-4} per year) is related to population in vehicles. This is to be expected since the hazard effects from explosions diminish quickly with distance from the explosives truck. Scenarios involving high numbers of fatalities are related to fatalities in buildings close to the road.

The F-N curves show risks in the ALARP region and therefore mitigation measures need to be considered to reduce the risks. This is assessed in *Section 9*.

Figure 8.2 F-N Curve for the Base Case with Breakdown by Storage and Transport

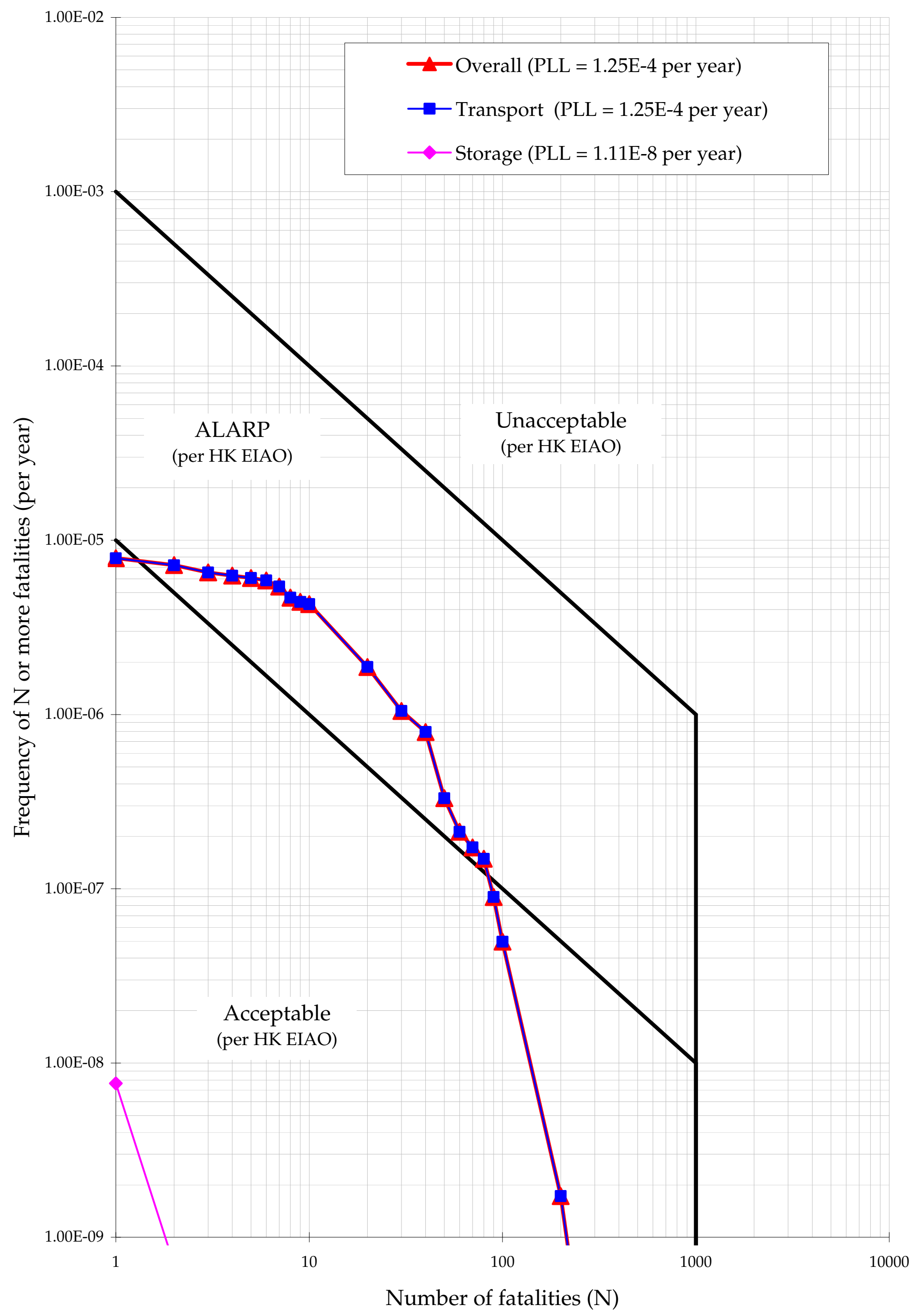
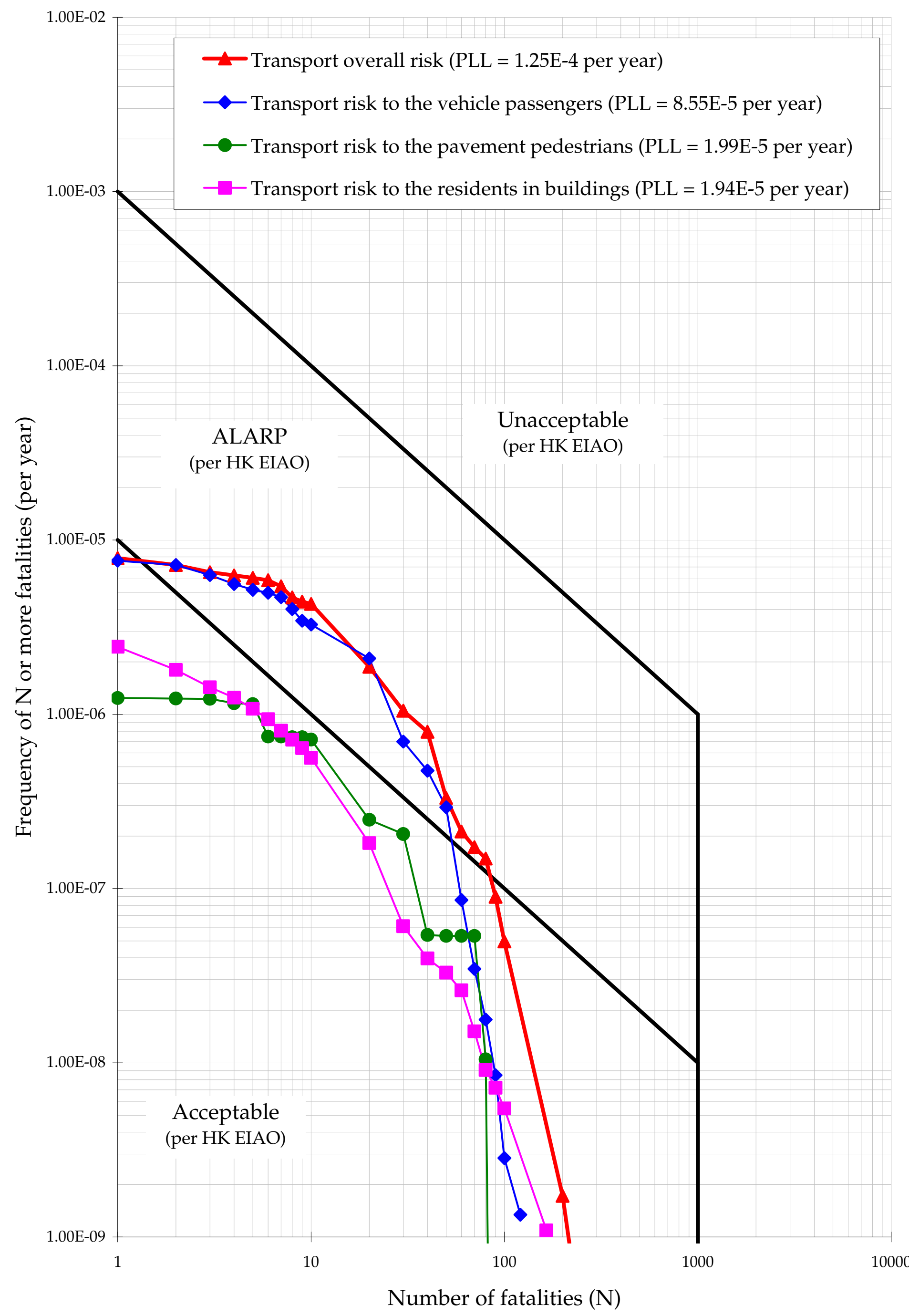


Figure 8.3 F-N Curve for the Base Case with Breakdown by Population Type



Note: The frequency of N= 1 of more fatalities per year is lower for pavement and building population groups since such population groups are outside the hazard range of the explosion for a large portion of the route. Vehicle passengers above refer to general members of public on road but not the explosives truck crew.

8.4 INDIVIDUAL RISK

The individual risk (IR) for each section of the transport route is listed in *Table 8.3*. The same data is shown graphically in *Figure 8.4*. These data take into account that some road sections are common to several transport routes; the IR is roughly proportional to the frequency of explosives trucks travelling along the road. The IR data represent the maximum individual risk, occurring on the road in the same lane as the explosives delivery truck. It can be seen that the maximum IR is about 3.94×10^{-8} per year. This is a low risk when compared to Hong Kong Risk Guidelines which require the offsite IR from a fixed installation to be below 10^{-5} per year. The low values of IR are due to the fact that the risk at any given fixed location along the route is transitory.

Table 8.3 Maximum Individual Risk for Each Section of the Transport Routes from Chung Hom Shan Magazine (Base Case)

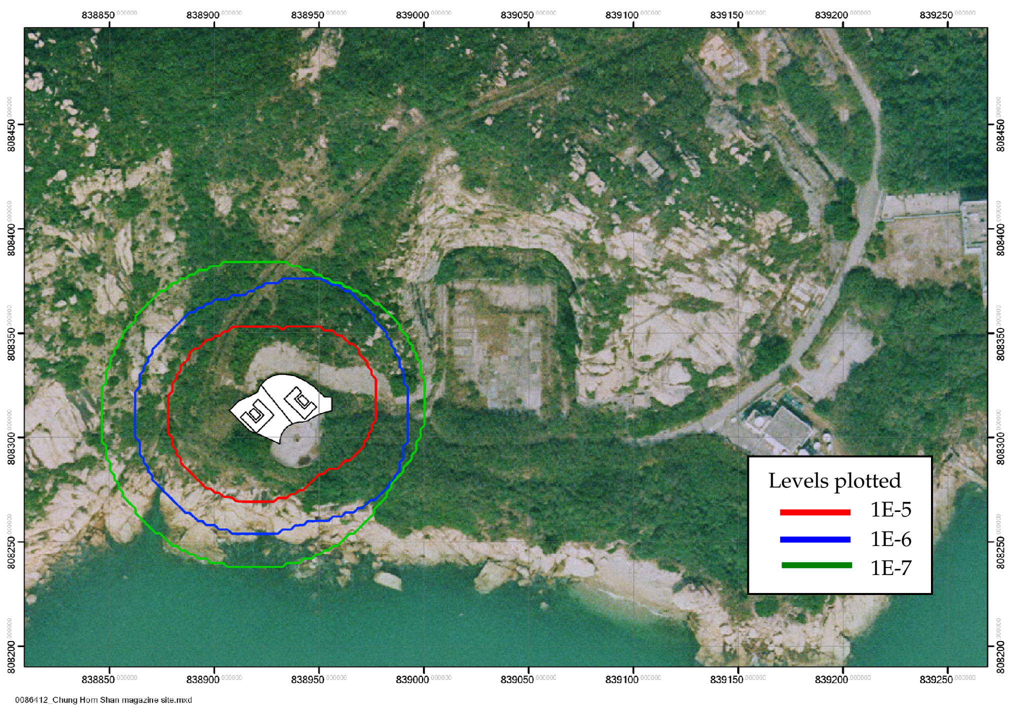
Section ID	Description	Maximum IR (per year)
<u>Route 1a (Chung Hom Shan Magazine - Ap Lei Chau)</u>		
Road 1a1	Chung Hom Kok Magazine site track	3.67E-08
Road 1a2	Chung Hom Kok Road	3.79E-08
Road 1a3	Repulse Bay Road - Tai Tam	3.91E-08
Road 1a3a	Repulse Bay Road - Tai Tam - 2nd section	3.62E-08
Road 1a4	Repulse Bay Road - South Bay	3.94E-08
Road 1a5	Island Road - Repulse Road	3.62E-08
Road 1a5a	Island Road - Repulse Road - 2nd section	3.65E-08
Road 1a6	Island Road - Deep Water Bay	3.70E-08
Road 1a7	Wong Chuk Hung Road - Island	3.61E-08
Road 1a7a	Wong Chuk Hung Road - Island sec-a	3.68E-08
Road 1a8a	Wong Chuk Hung Road - Nam Fung	3.13E-08
Road 1a8b	Wong Chuk Hung Road - Ocean Park	2.18E-08
Road 1a9	Wong Chuk Hung Road - Nam Long Shan	2.21E-08
Road 1a10	Ap Lei Chai Brigde Road	2.21E-08
Road 1a11	Lee Nam Road	2.14E-08
Road 1a11a	Lee Nam Road - sec-a	2.17E-08
<u>Route 1b (Chung Hom Shan Magazine - Nam Fung Portal)</u>		
Road 1b1	Chung Hom Kok Magazine site track	3.67E-08
Road 1b2	Chung Hom Kok Road	3.79E-08
Road 1b3	Repulse Bay Road - Tai Tam	3.91E-08
Road 1b3a	Repulse Bay Road - Tai Tam - 2nd section	3.62E-08
Road 1b4	Repulse Bay Road - South Bay	3.94E-08
Road 1b5	Island Road - Repulse Road	3.62E-08
Road 1b5a	Island Road - Repulse Road - 2nd section	3.65E-08
Road 1b6	Island Road - Deep Water Bay	3.70E-08
Road 1b7	Wong Chuk Hung Road - Island	3.61E-08
Road 1b7a	Wong Chuk Hung Road - Island sec-a	3.68E-08
Road 1b8	Nam Fung Road	3.25E-08

Figure 8.4 Maximum IR for the Delivery Routes from Chung Hom Shan Magazine (Base Case)

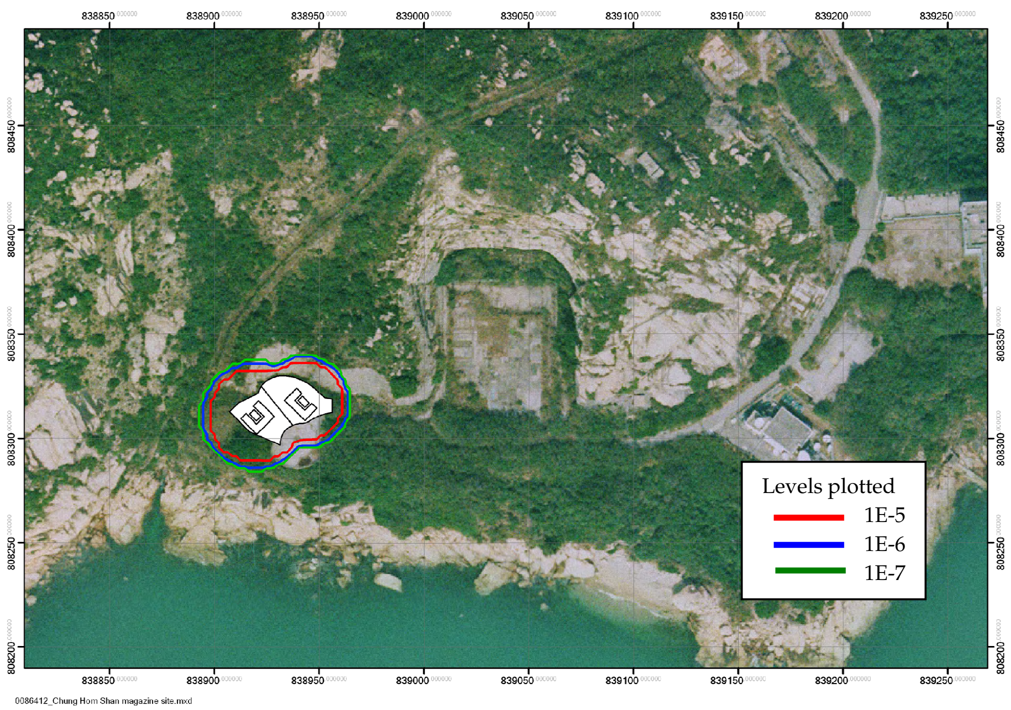
For the temporary storage Magazine, individual risk contours have been plotted and overlaid on plot layouts for Chung Hom Shan site (*Figure 8.5*). IR contours (assuming a risk exposure factor of 100%) have been presented for both outdoor and indoor populations, with the 10^{-5} per year contour extending offsite in both cases. Persons indoors experience higher risks due to breaking windows and risk of building collapse. However, there are no buildings or structures nearby that lie within these contours and hence the outdoor contours are more appropriate. The maximum IR is about 10^{-4} per year since this is the base frequency used in the analysis for explosion at a magazine. This however, neglects to take into account presence factors. The temporary magazine site is in a remote area and the 10^{-5} per year contours impacts only on rocky cliffs, slopes and woodland areas where there is no continuous presence of people. The presence of people in these areas will be rare and only temporary leading to a very small presence factor. The most exposed population group will be people potentially present adjacent to the top of the slope at the boundary of the temporary magazine site. Such persons are not expected to be present more than 1% of the time. Therefore, no member of the public will be exposed to an IR of 10^{-5} per year. The actual risk to any individual will be much smaller than 10^{-5} per year and is deemed to be acceptable.

Figure 8.5 *IR of the Chung Hom Shan Magazine*

Indoor Population



Outdoor Population



8.5 UNCERTAINTY ANALYSIS AND SENSITIVITY TESTS

The study is based on a number of assumptions as previously highlighted in various sections of this report.

A discussion on the uncertainties and sensitivity of the results is given below.

Explosion Consequence Model

The employed ESTC model, or any other established TNT explosion model, tends to overpredict the number of fatalities (or, probability of fatality for an individual) when compared to the actual fatalities in past incidents related to explosives. It can be seen that no recorded incident involving road transport had resulted in more than 12 fatalities even in urban location, while from the assessment, the maximum fatalities due to road transport is estimated as about 100-300. There is some conservatism in the model although it is acknowledged that given the dense urban environment in Hong Kong, the fatalities estimated during transport of explosives may not be too conservative.

On the other hand, a number of recent research studies performed by the HSE in the UK, indicates that the ESTC models may underpredict the fatalities caused by flying glass in highly built-up areas. Despite this recent research, the ESTC models are still recommended as the best currently available.

Intervention of the Explosives truck crew

In certain circumstances it may be possible for the crew to control a fire developing on the vehicle by using onboard safety devices. Given the quantity and type of fire extinguishers, credit has been given in combination with the fire screen protection. The two events have been assumed to be dependent.

Similarly, if it is possible and safe to do so, given the low amount of explosives to be transported on the truck, it may be possible for the crew to secure the explosive load before the fire fully develops. However, given that a fire could fully develop and critical explosive temperature can be reached within a couple of minutes, no credit was given for people to escape as a conservative assumption.

Intervention of the Fire Service Department

By the time, the fire brigade arrives at the scene in case of a fire incident involving an explosive vehicle, most likely a fire would have already fully developed. The intervention of the fire brigade would be limited to fight the fire from a safe distance, given the risk posed by the scenario, and to evacuate the area.

Regarding the evacuation, it may be possible to evacuate the accident zone surrounding the vehicle which would include vehicle occupants and people located on the pavement but evacuation of the buildings would be difficult.

For the purpose of this assessment, no or little credit has been given for the intervention of the fire brigade.

Escape and Evacuation

In certain circumstance it may be possible for people to escape from the scene of an accident by themselves before the occurrence of an explosion event. This is particularly true in the case of a fire accident, for example fire on a truck in which explosives cargo is not initially involved but is only affected after a period of gradual escalation. However, modelling such escape scenario would only reduce slightly the consequence and have minimum impact on the conclusion of this report. For the purpose of this study, no credit was given for people to escape as a conservative assumption.

Explosive Initiation under Thermal Stimulus

Although the potential consequences are known, there are still some uncertainties associated with the probability of explosion for an explosive load composed of a mix of cartridged emulsion and detonating cord when involved in a fire during transportation. The probability used in this report has been based on accident statistics applicable to ANFO which is seen as being more sensitive than emulsion and transported in a different manner. In absence of test data, this assumption may be conservative.

9 ALARP ASSESSMENT

9.1 RISK RESULTS AND APPROACH TO ALARP

The Hazard to Life Assessment of the SIL(E) project has assessed the risks arising from the proposed magazine site in Chung Hom Shan as well as the risks associated with the road transport from this site to the work areas. From *Section 8*, the risks posed by the project, for both base case and worst case considered, are within the ALARP (As Low As Reasonably Practicable) region specified in EIAO-TM Annex 4.

The risk, in terms of PLL, associated with the Worst Case, corresponding to a scenario of worst deliveries and peak combined load at each delivery point, is estimated at 1.58×10^{-4} per year, has been used for the purpose of the ALARP assessment. This approach is conservative.

The results imply that achievable risk reduction measures and / or any alternate practicable option should be explored for the project. From *Section 8* it was also found that the risks arising from explosives transport are much more significant than that of explosive storage; hence, the following assessment focuses on the transportation aspect of the explosives.

Where the risk falls into the ALARP region, the risks associated with each probable hazardous event should be reduced to a level 'as low as reasonably practicable'. This firstly requires the identification of any 'practicable' options regardless of their cost. A mitigation option is considered 'practicable' if an engineering solution exists and can be implemented for the SIL(E) project regardless of the cost without affecting the project construction programme. Secondly, the extent to which the risk should be reduced is usually measured as a trade off between the risk reduction, i.e. the safety benefits and the cost of the risk reduction measure. A mitigation option is considered 'reasonable' if the cost of implementing the option is not grossly disproportionate to the achieved safety benefits.

Risk mitigation measures may take the form of engineered measures, controls in the zones most impacted by the hazardous scenarios presented by this project, or operation and procedural controls.

The following section presents the approach and the outcome of the ALARP assessment.

9.2 APPROACH TO ALARP ASSESSMENT

The approach consists of identifying potential justifiable mitigation measures, assessing their practicability for this project and evaluating their cost and comparing with the safety benefits of implementing the measures. Combinations of mitigation measures are also considered.

Cost benefit analysis (CBA) is widely used in QRA studies to evaluate the cost-effectiveness of alternative measures and provide a demonstration that all reasonably practicable measures have been taken to reduce risks.

The safety benefits are evaluated as follows:

Safety Benefits = Value of Preventing a Fatality x Aversion Factor x Reduction in PLL value x Design life of mitigation measure

The Value of Preventing a Fatality (VPF) reflects the tolerability of risk by the society and therefore the monetary value that the society is ready to invest to prevent a fatality. For the purpose of this assessment and for consistency with previous studies, the Value of Preventing a Fatality is taken as HK$33M per person, which is the same figure as used in previous Hazard Assessment studies (derived from the UK ACDS study (ACDS, 1995)) but updated to current prices.

Depending on the level of risk, the value of preventing a fatality may be adjusted to reflect people's aversion to high risks or scenarios with potential for multiple fatalities. The methodology for application of the 'aversion factor' follows that developed by EPD (EPD, 1996), in which the aversion factor is calculated on a sliding scale from 1 (risks at the lower boundary of the ALARP region of the Risk Guidelines) up to a maximum of 20 (risks at the upper boundary of the ALARP region). The adjusted VPF using the aversion factor of 20 is HK$660M. This value is a measure of how much the society is willing to invest to prevent a fatality, where there is potential for an event to cause multiple fatalities.

The cost of implementing potential justifiable mitigation measures will be first of all checked against the Maximum Justifiable Expenditure. The Maximum Justifiable Expenditure will be estimated on the assumption that risk is reduced to zero. Mitigation measures considered justifiable will be further analysed considering the actual risk (PLL) reduction offered by the measure.

If the safety benefits are greater than the cost of implementation of a particular mitigation measure, the mitigation measure will be considered for implementation in this project; otherwise its cost would not be considered justifiable.

The cost of implementing the mitigation measures should include capital and operational expenditures but exclude any cost associated with design or design change.

It is recognized that it may not always be possible to quantify the cost-benefits of a particular measure. In some cases, a qualitative approach was adopted.

9.3 *MAXIMUM JUSTIFIABLE EXPENDITURE*

The maximum justifiable expenditure for this project is calculated as follows assuming a conservative aversion factor of 20:

Maximum Justifiable Expenditure

= Value of Preventing a Fatality x Aversion Factor x Maximum PLL value x Design life of mitigation measure

Maximum Justifiable Expenditure = HK$ 33M x 20x 1.58 x 10^{-4} x 2
= HK$ 0.21M.

The design life of a mitigation measure is assumed as 2 years based on the construction phase of the SIL(E) project during which storage and transport of explosives will be involved.

For an 'achievable' mitigation measure to be potentially justifiable, its cost should be less than the Maximum Justifiable Expenditure.

9.4 *POTENTIAL JUSTIFIABLE MITIGATION MEASURES*

The approach considered the identification of options pertaining in the following broad categories:

- Options eliminating the need for a Magazine or eliminating the risk;
- Options reducing significantly the quantities of explosives to be used such as use of hard rock TBM or alternatives to cartridged emulsion;
- Options reducing significantly the distance run by contractors' explosives trucks such as closer magazine sites and alternative routes;
- Options reducing significantly the number of trips to be carried out by contractors' explosives trucks;
- Options considering improved explosives truck design; and
- Options considering better risk management systems and procedures.

Based on the review of the risk results and a series of brainstorming sessions with MTR and explosives specialists operating in this industry, the following options were selected as potential candidates for risk mitigation.

9.4.1 *NEED FOR A TUNNEL AND PROPOSED ALIGNMENT*

According to the SIL(E) Preliminary Design Final Report (MN14) (MTR 2, 2009), the alignment of the SIL(E) has generally been designed in accordance with Section 3, Railway Engineering, of the MTR Design Standards Manual (DSM), version A4 dated February 2008. Based on this, the horizontal alignment of the SIL(E) is very constrained in places and offer a limited number of alternative alignment options.

Several alignment options were examined, considering engineering, environment, and other factors. These have been discussed in Chapter 2 of this EIA. Opting for any alternative alignment option will cost significantly more than the Maximum Justifiable Expenditure.

9.4.2 *MAGAZINE REQUIREMENT AND SELECTION PROCESS*

Magazine Requirement

Due to the 24 hour blasting requirements as described in *Section 2* and summarized in *Section 2.5.2*, it is not possible for Mines Division to deliver the required explosive quantities directly to all the work areas as this would limit the blasting to one blast per day. Direct explosives delivery by Mines Division has been already assumed for excavation works at ADM and WCH depot. A temporary explosives magazine is therefore required.

Magazine Selection Process

The Magazine site selection process is documented in SIL(E) Working Paper on Magazine Site Options (April 2010) (MTR 4, 2010). A long list of sites has been screened by the Preliminary Design Consultant based on the following factors:

External Separation Distances

External separation distance refers to the distance from the explosive stores to inhabited areas and sensitive receivers. Amongst all the requirements from Mines Division described in *Section 2.3.2*, the Commissioner of Mines require that the minimum separation distances to sensitive receivers stipulated in the UK Manufacture and Storage of Explosives Regulations 2005 are met. For the SIL(E) project, the minimum separation distances described below shall be, at least, maintained (the main separation requirements are listed although other requirements also apply):

- Class A Receivers: Footpaths, lightly used road, waterways - 54 m;
- Class B Receivers: Minor Road, Railway Line - 81 m;
- Class C Receivers: Major road, place of public resort - 161 m;
- Class D Receivers: Buildings- 180 m;
- Class E Receivers: Vulnerable Building- 161 m;

Other factors

Other factors have been considered in the site selection process which may render the site impracticable for the project due to the constraints posed. Such factors are:

- Access for Mines Division explosive delivery vehicles;

- Site constraints such as existing conditions;
- Land availability; and
- Environment and heritage impact.

Site Selection

The magazine site selection has considered a total of 14 candidate sites and they are depicted in *Figure 9.1*. This selection process takes into account the following aspects:

- external separation distances,
- distance from mines delivery pier to magazine site,
- average distance from magazine to SIL(E) work sites,
- environmental and heritage impact,
- land availability, site constraints, and
- access of Mines explosives delivery vehicles

On this basis, the majority of the sites were found to have some constraints which made them impracticable for the project. The key issues for each candidate site are summarized in *Table 9.1*.

Figure 9.1 Candidate Magazine Sites for SIL(E) Project

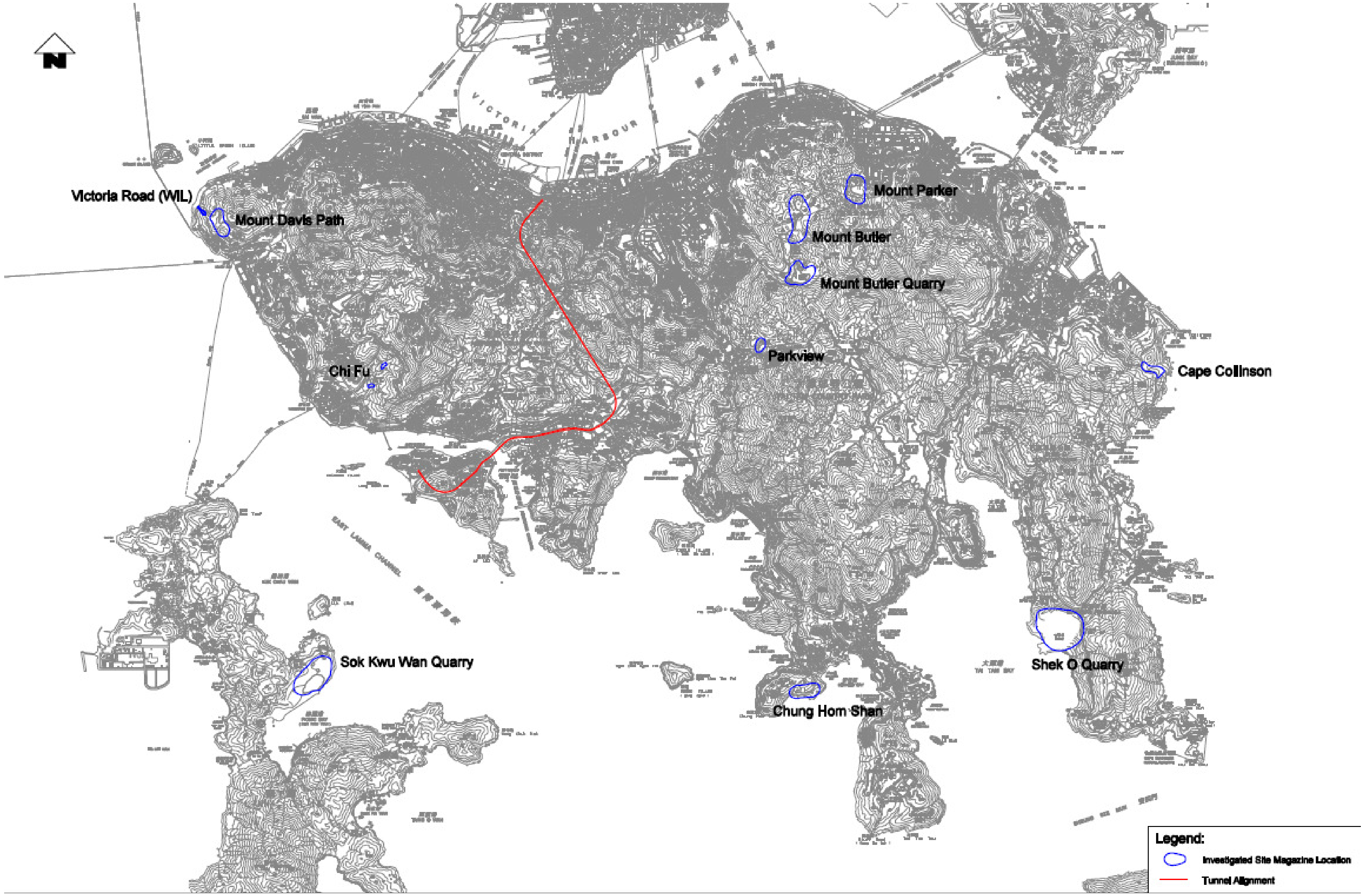


Table 9.1 Summary of Issues for Each Candidate Site

Site Ref	Site Name	Summary of Key Issues
1	Chung Hom Shan	▪ Nearby quarry area allocated for use as a nursery for Ocean Park but with no buildings. Anticipated to cease operation in early 2011. ▪ Government owned. ▪ Good access road closed to the public from Chung Hom Kok, well paved with slight overgrowth at the end close to the quarry. ▪ Requires some repairs or replacement of damaged structures. ▪ Telecommunications station located nearby, however mandatory external separation distance met.
2	Shek O Quarry	▪ The site is due to be handed back to government for use as public recreation areas ▪ Good access road is under construction ▪ Significant distance from works sites. ▪ Site availability is subject to government's programme for opening the area for recreational use and interface with other projects using the site ▪ Mandatory external separation distance requirement could be met as the proposed location is at a distance from the proposed recreational area.
3	Mount Butler Quarry	▪ The site is currently occupied by Government Emergency Services ▪ Disused and car workshop areas on the northern side of the quarry are allocated to DSD. ▪ Site not available ▪ Mandatory external separation distance requirement cannot be met.
4	Chi Fu	▪ WSD reservoir (and its access road) ,Yar Chee Villa, Shek Pai Wan and horticultural centre nearby. Major road and Chi Fu Estate are also within the separation distance. ▪ Area of disturbed terrain, construction of new access road to the magazine (200 m) is required. ▪ Mandatory external separation distance requirement cannot be met.
5	Parkview	▪ WSD reservoir and Parkview nearby. ▪ Good access on existing WSD access road ▪ Some disused war-time structures ▪ Overhead power cables make site impracticable. ▪ Mandatory external separation distance requirement cannot be met.

Site Ref	Site Name	Summary of Key Issues
6	Mount Davis Path	▪ Nearby WSD reservoir and West Island school. ▪ Long single track road with numerous recent landslide incidents. ▪ Some abandoned war-time structures next to the access road to the magazine. ▪ Mandatory external separation distance requirement cannot be met
7	Proposed underground magazine for MTR WIL project	▪ Underground magazine specifically designed for explosives storage. Normal clearance distances for surface magazines do not apply ▪ Some abandoned war-time structures nearby. ▪ The site is permitted only to be used for the WIL Project by the Central & Western District Council and is therefore not available to SIL(E). ▪ Programme overlap with WIL therefore no available capacity for the SIL(E) Project. Construction of extra niches would be required while the WIL Project will be underway, which is not practicable.
8	Mount Butler	▪ Land is allocated to PCCW for radio station. It is surrounded by radio masts. ▪ The site is situated on undulating area of natural terrain. ▪ Single track road from Mount Butler. Require upgrading of the access road to EVA standard. ▪ Mandatory external separation distance cannot be met.
9	Cape Collinson	▪ The site is situated on an undulating area of natural terrain, but at a lower level than the existing road therefore site formation is required. ▪ No nearby buildings, but the access road to Cape Collinson Correctional Institution passes nearby. There is a public rest area with pagoda and several public footpaths that are well used ▪ The access road to the site is a good surfaced single lane two-way road however it is too narrow for Mines Division vehicles, therefore this option is not practicable.
10	Mount Parker	▪ Long steep and narrow path to the magazine. Unsuitable for emergency vehicles. ▪ Access road would require upgrading. ▪ Within Tai Tam Country Park, close to well-used footpaths. ▪ Mandatory external separation distance requirement cannot be met.

Site Ref	Site Name	Summary of Key Issues
11	Underground storage niche	▪ Underground magazine specifically designed for explosive storage. Normal clearance distances for surface magazines do not apply. ▪ The site is within the worksite. ▪ Explosives storage niche directly connected to the tunnel under construction is not permitted.
12	Worksite at Nam Fung Portal	▪ Many close-by buildings.. ▪ The site is within the worksite ▪ Requires use of non-standard magazine construction, not preferred by Mines Division. ▪ Mandatory external separation distance requirement cannot be met.
13	Lamma Island Sok Kwu Wan Quarry	▪ No nearby buildings, but within a designated environmental recreation area ▪ Government owned but allocated for recreational use. ▪ No available utilities. ▪ No access for Mines vehicles ▪ No explosives delivery point available on HK Island, therefore this option is considered to be impracticable.
14	Outlying Islands	▪ No nearby buildings ▪ Hilly terrain on outlying islands, requires expenditure for site formation and construction of access roads. ▪ Requires construction of a pier suitable for unloading of Cat. 1 dangerous goods. ▪ No explosives delivery point available on HK Island, therefore this option is considered to be impracticable.

Notes:

(1) For details, refer to Working Paper on Magazine Site Options (April, 2010) (MTR 4, 2010)

(2) Separation distance requirements referred above are in accordance with the UK *"Manufacture and Storage of Explosives Regulations, 2005"* published by the UK Health & Safety Executive, as specified by the Hong Kong Commissioner of Mines in their document "*How to Apply for a Mode A Explosives Store Licence*".

(3) MTR have checked the feasibility of the magazine site at Ocean Park. Ocean Park have confirmed that the magazine store has been demolished after completion of their tunnel works and the site is currently used by Ocean Park for other purposes, therefore it is not available for SIL(E).

Table 9.2 Summary of Road Transport Distance to Work Areas from Each Practicable Site

Site Ref	Site Name	Average Distance to Work Areas (km)
1	Chung Hom Shan	9.6
2	Shek O Quarry	20.7

The magazine site selection process has been taken forward to this ALARP assessment. Those candidate sites that are in non-compliance with the Commissioner of Mines' mandatory external separation requirements can be translated into 'impracticable' and therefore ruled out of contention. Two other potential sites are also considered impracticable because of construction of additional niches (for WIL magazine) and lack of access for Mines Division vehicles (for Cape Collision). Therefore there are 2 remaining sites that are considered practicable: Chung Hom Shan and Shek O. The average road transport distances from each of these candidate sites to the two work areas (Nam Fung Portal and Ap Lei Chau) are shown in *Table 9.2*. The EIA Study Brief requires the "selection of the shortest practicable road transport routes to and from the magazine" therefore the site at Chung Hom Shan is the preferred magazine site.

9.4.3 USE OF MAGAZINES CLOSER TO THE CONSTRUCTION SITES

Amongst the initially proposed list of Magazine sites, the Chung Hom Shan site was selected for the storage of explosives, based on the site selection process and the EIA Study Brief requirement.

9.4.4 USE OF ALTERNATIVE METHODS OF CONSTRUCTION

It is possible to construct hard rock tunnels with hard rock tunnel boring machines (TBMs). The TBMs used in this project are dedicated to soft rock soils applications. For constructing the tunnels solely based on TBMs, TBMs dedicated to hard rock soils should be procured. The cost of such machines will be in the order of several hundred millions of Hong Kong Dollars each which would be much higher than the Maximum Justifiable Expenditure.

In addition, different tunnel profiles will be required leading to the need to use explosives to enlarge the circular TBM driven tunnels. Such costs and programme are not included.

It should be noted that, even if TBMs were used for tunneling, substantial quantities of explosives will still be required for caverns, shafts and adits excavation.

Finally, immediate availability of such TBMs for Hong Kong plus the additional blasting required for non-circular sector renders the option not practicable since it could lead to several months of project delay.

This option is therefore neither practicable nor justifiable on a cost basis.

9.4.5 USE OF ALTERNATIVE ROUTES

The shortest route has generally been selected for explosive deliveries to sites. Selecting an alternative route has negligible costs and therefore presents a viable option.

Based on the review of the possible transport routes for the SIL(E) project, it has been noted that the driving direction from the temporary Magazine along Chung Hom Kok Road, Repulse Bay Road, Island Road and Wong Chuk Hang Road to the two work areas is the shortest practicable route. There is no alternative route of similar distances identified. Therefore, the possibility of using an alternative transport route for the delivery is not considered further.

Use of a Combined Road / Marine Transport Option

The combined Road/Marine transport option from the temporary magazine site to the SIL(E) construction sites was also considered but ruled out due to the following impracticalities which affect both the loading of explosives at the Chung Hom Shan magazine and unloading close to the worksites:

- Public piers were studied to examine the option of delivering explosives by sea. For this option, the pier would have to satisfy the general requirements provided by Mines Division (CEDD 5) which include separation distance requirements. The key requirements by Mines Division include, amongst others:
    - Separation distance requirements, as used by the Port Authority of Queensland, with such area required to be cleared of non-essential persons. For the load to be transported in this project, the minimum separation distance requirement is 39m;
    - Suitable berthing facilities;
    - Suitable water depth; and
    - Firefighting facilities.

  It should be noted that explosives delivery vessels are not permitted to enter typhoon shelters.

  Following this survey, it was concluded that, there is no public pier available for transporting explosives for the SIL(E) project.

- For the construction of a pier (including a new Dangerous Goods pier), approval is necessary under the Foreshore and Sea-bed (Reclamation) Ordinance (FSRO). This involves application to the District Lands Office, internally circulation amongst Government departments, clearance from the Department of Justice to publish a draft gazette, a 60 day period for public response and then final approval. The process may take up to 18 months if an environmental permit is also required, either through a direct application or through an Environmental Impact Assessment. Construction would take 9 additional months. The project programme will be subject to significant delay and therefore this option is not practicable.

- The option of transporting explosives from the temporary magazine site using a vertical seawall was also considered however there is no seawall at the shoreline in the vicinity of the Chung Hom Shan site and the coastline is rocky making it difficult for the vessels to get close to. In addition to which there is a significant level difference (more than 30m) between the proposed magazine and the sea level, with a steep slope in between. Therefore this option is not considered practicable

This option is therefore not considered practicable.

9.4.6 *USE OF DIFFERENT EXPLOSIVE TYPES*

The emulsion family of explosives is considered as the safest type of explosive for blasting applications. No safety benefits will be obtained by selecting a different type of explosive.

The detonating cord in this project uses a PETN core with a melting point of around 140 ^{o}C. Different detonating cord technologies are available such as those using a RDX or HMX core with a slightly higher melting point (210 ^{o}C and 276 ^{o}C). This may offer more time before an explosion occurs following a fire event. The time gained and risk reduction achieved by implementing these technologies would however be negligible for the purpose of this assessment. This option is therefore not considered further.

9.4.7 *USE OF SMALLER QUANTITIES OF EXPLOSIVES*

This project has already considered the minimum amount of explosives for transportation as it will transport, as far as possible, initiating explosives only. Bulk blasting explosives will be manufactured on site.

This project has also considered the smallest cartridge type available on the market (125 g type).

It is possible to use smaller explosive charges for initiating explosives such as 'cast boosters'. The main explosive component of 'cast boosters' is PETN. Using such explosives will reduce the weight of explosives to be transported. However, PETN has a higher TNT equivalency. This will also not eliminate the need for detonating cord.

The cost of this option is estimated to be at least HK$ 900,000 higher than the cost of using the cartridged emulsion for initiating bulk explosives. This is based on a typical 3 times increase in sale price but a lower storage and transport cost per unit when compared to cartridged emulsion.

The additional cost of utilizing cast boosters would be much higher than the Maximum Justifiable Expenditure and therefore not justifiable on a cost basis.

Also, there are some limitations in availability of 'cast boosters' since the number of suppliers who can provide this material is limited.

There is uncertainty on the relative pricing of cast boosters versus cartridged emulsion which may change based on market demand and supply.

Use of cartridged emulsion satisfies the requirements of the TM, however MTR endeavours to follow best practice wherever possible, which includes selecting explosives with minimal impact on public safety. Currently there are some constraints on the availability and supply of cast boosters hence any recommendation to use only cast boosters could have an impact on the project schedule. However due to the risk reduction achieved the use of cast boosters is to be maximised, which is to be encouraged. MTR is to review, on an ongoing basis during the detailed design, tender and construction phases, and implement the use of cast boosters during construction to the maximum extent possible.

It should be noted that cartridged emulsion cannot be completely eliminated from the construction activity. Cast boosters can only be used as a replacement for cartridged emulsion in its role as a primer for bulk emulsion explosives, therefore cartridged emulsion will still be required for those sections that require cartridge-only blasting due to the proximity of sensitive receivers resulting in a low MIC. Also unforeseen ground conditions and fault zones dictate the use of cartridge-only blasting and hence it is essential to retain the flexibility of using cartridged emulsion for blasting if and when required.

9.4.8 *SAFER EXPLOSIVES TRUCK DESIGN*

The design of the truck has been reviewed to identify potential improvements which could reduce the risk particularly of fire escalating to the load. The analysis has already assumed that the current specification followed for Mines trucks such as use of fire screen between cabin and the load will also be followed for the Contractor's trucks. The use of fire screen is adopted overseas, although mainly for trucks carrying much larger quantities of explosives, i.e. more than 200 kg. However, this measure has been recommended for the Contractors' trucks in this project, as an improvement measure.

Further improvements to the fire and crash protection features for the explosives trucks were reviewed but no account of such practices was found worldwide and the effectiveness of such risk reduction measures is also not known.

It is however possible to implement simple measures such as reducing the combustible load on the vehicle by using fire retardant materials wherever possible and limiting the fuel tank capacity. Since the safety benefits of such measures are difficult to evaluate quantitatively such measures have been included in the recommendation section of this report, but no credit taken in the analysis.

9.4.9 LOWER FREQUENCY OF EXPLOSIVES TRANSPORT

The frequency of explosives transport has been minimized, as far as possible, with the use of alternative methods of construction, such as soft ground TBMs, etc. It has also been minimized with the use of bulk emulsion/ANFO.

As typically required by Mines Division, the amount of explosives that a 3rd party contractor's truck can transport from the magazine to the blast sites is limited to a maximum of 200 kg per truck at the moment. In this study, this limit may necessitate more than one trip to deliver the required volume of explosives for a blast in some circumstances following the envisaged SIL(E) construction programme. This is particularly relevant to the Ap Lei Chau construction area.

For a particular blast time, the overall number of trips can be significantly reduced by transporting all the required explosive load for the cavern/ tunnels/ adits/vent duct of the same work area on the same delivery truck. Where the explosives load is higher than the 200 kg limit per truck, a higher load up to 250 kg per truck may be permitted to be transported. This will reduce the number of additional deliveries while at the same time not cause any significant increase in the consequences due to the higher load.

Although, this will increase the explosives load transported on the delivery trucks, the total number of explosives deliveries during the construction period will be significantly reduced. This may offer some significant risk reduction.

This option is selected for further analysis.

9.4.10 REDUCTION OF ACCIDENT INVOLVEMENT FREQUENCY

It is possible to reduce the explosive accident probability through the implementation of training programme for both the driver and his attendants, regular "toolbox" briefing sessions, implementation of a defensive driving attitude, appropriate driver selection based on good safety record, and medical checks. Such measures are to some degree mandatory and therefore considered in the base case assessment. The actual recommended implementation of this option is given in the recommendation section of this report.

9.4.11 REDUCTION OF FIRE INVOLVEMENT FREQUENCY

It is possible to carry better types of fire extinguishers onboard the explosives trucks and with bigger capacities e.g. AFFF-type extinguishers.

Adequate emergency plans and training could also be provided to make sure the adequate fire extinguishers are used and attempts are made to evacuate the area of the incident or securing the explosive load if possible.

The actual recommended implementation of this option is given in the recommendations section of this report.

9.4.12 SUMMARY

In summary, the following option has been considered for cost-benefit analysis.

Option 1: Reduction of Explosives Transport Frequency

Other options have been either recommended for implementation or assessed comparing the implementation cost with the maximum justifiable expenditure.

9.5 OPTION CASE 1 - LOWER FREQUENCY OF EXPLOSIVES TRANSPORT

9.5.1 EXPLOSIVES TRANSPORT QUANTITIES IN LICENSED TRUCK

According to the Removal Permit generally granted by the Commissioner of Mines, a contractor's vehicle cannot carry more than 200 kg explosives. This limit may be increased upon written consent from the Commissioner of Mines Division.

By limiting the transport load to 200 kg per trip, it is expected that, for a particular blasting time, more than one trip will be required if the volume of explosives to be used at a blast time exceeds this limit. For example, at Ap Lei Chau delivery point, the blasting activities at Lei Tung Station Cavern and Lei Tung Station Entrance B will occur concurrently in September 2012 according to the envisaged SIL(E) construction programme. The explosives quantity required for the morning blasting is 227 kg. This will necessitate two trips to deliver the explosive load to the site at that time.

However, by increasing this limit, the explosives transport frequency for the whole SIL(E) project will be reduced accordingly. For instance, a single truck would be able to deliver 227 kg of explosives to Ap Lei Chau in January 2013 reducing the number of trips required by one (1) for the day.

Table 9.3 provides a comparison of the total number of trips within the peak delivery period required for the explosive delivery vehicles to each delivery point. It can be seen that the total number of trips will be reduced by about 4.8%, with a 10.2% reduction in trips to Ap Lei Chau.

Table 9.3 Number of Trips for Explosives transport to each work site

Work site	Number of Transport Trips in Peak Delivery Period	
	Worst Case Scenario	Option Case 1
Nam Fung Portal	741	741
Ap Lei Chau	647	581

9.5.2 SCENARIOS CONSIDERED

The scenarios considered are similar to the Worst Case Scenario although the frequency of explosive delivery is lower and the transported explosive load is increased up to 250 kg for any particular blast time for each contract.

Table 9.4 Scenarios Considered in Option Case 1 Assessment

Tag	Scenario	Explosives load (TNT eqv. kg)	No. of Trips per year	Remarks
Storage of Explosives				
01	Detonation of full load of explosives in Store 1 in Chung Hom Shan site	313[1]	-	Store 1 capacity is 300 kg
02	Detonation of full load of explosives in Store 2 in Chung Hom Shan site	522[1]	-	Store 2 capacity is 500 kg
03	Detonation of full load of explosives in one contractor truck on the access road within Chung Hom Shan magazine site boundary	258	1,322	
Transport of Explosives				
04	Detonation of full load of explosives in one contractor truck on public roads – from Chung Hom Shan site to Nam Fung Portal delivery point	42[1]	629	
05	Detonation of full load of explosives in one contractor truck on public roads – from Chung Hom Shan site to Nam Fung Portal delivery point	190[1]	112	
06a	Detonation of full load of explosives in one contractor truck on public roads – from Chung Hom Shan site to Ap Lei Chau delivery point	258	251	Considering the delivery in Jun 2012, Jul 2012, Sept 2012, Oct 2012, and Nov 2012. (258 kg).
06b	Detonation of full load of explosives in one contractor truck on public roads – from Chung Hom Shan site to Ap Lei Chau Portal delivery point	207	330	Considering the deliveries in Mar 2012, Apr 2012, May 2012, Aug 2012, Dec 2012, Jan 2012, and Feb 2012 (207 kg).

Note:
[1] The explosives load considered here are identical to the load applied in the Worst Case Scenario
[2] The explosives load considered here is the maximum load transported with the increased licensing limit of 250 kg.
[3] The explosives load considered here is the maximum load transported up to the 200 kg licensing limit.

Table 9.5 Summary of Consequence Results for Option Case 1 Scenarios

No.	Scenario	TNT eqv. kg)	*Indoor*		*Outdoor*	
			Fatality Prob.	Impact distance (m)	Fatality Prob.	Impact distance (m)
Storage of Explosives						
01	Detonation of full load of explosives in Store 1 in Chung Hom Shan site	313*	90%	20.9	90%	16.8
			50%	24.2	50%	17.4
			10%	35.6	10%	19.3
			3%	47.4	3%	20.8
			1%	57.3	1%	21.6
02	Detonation of full load of explosives in Store 2 in Chung Hom Shan site	522*	90%	24.8	90%	19.8
			50%	28.6	50%	20.6
			10%	42.4	10%	22.8
			3%	56.4	3%	24.5
			1%	72.5	1%	25.6
03	Detonation of full load of explosives in one contractor truck on the access road within Chung Hom Shan magazine site boundary	258	90%	19.6	90%	15.7
			50%	22.7	50%	16.4
			10%	33.6	10%	18.1
			3%	45.0	3%	19.4
			1%	58.5	1%	20.6
Transport of Explosives						
04	Detonation of full load of explosives in one contractor truck on public roads – from Chung Hom Shan site to Nam Fung Portal delivery point	42*	90%	10.8	90%	8.7
			50%	12.5	50%	9.0
			10%	18.5	10%	10.0
			3%	24.8	3%	10.7
			1%	32.1	1%	11.3
05	Detonation of full load of explosives in one contractor truck on public roads – from Chung Hom Shan site to Nam Fung Portal delivery point	190*	90%	17.7	90%	14.2
			50%	20.5	50%	14.8
			10%	30.4	10%	16.3
			3%	40.6	3%	17.5
			1%	52.4	1%	18.5
06a	Detonation of full load of explosives in one contractor truck on public roads – from Chung Hom Shan site to Ap Lei Chau delivery point	258	90%	19.6	90%	15.7
			50%	22.7	50%	16.4
			10%	33.6	10%	18.1
			3%	45.0	3%	19.4
			1%	58.5	1%	20.6
06b	Detonation of full load of explosives in one contractor truck on public roads – from Chung Hom Shan site to Ap Lei Chau delivery point	207	90%	18.2	90%	14.6
			50%	21.1	50%	15.2
			10%	31.3	10%	16.8
			3%	41.7	3%	18.0
			1%	53.6	1%	19.1

Note: * The explosives load considered here are identical to the load applied in the Worst Case Scenario

9.5.3 RISK ANALYSIS FOR OPTION CASE 1

The PLL obtained from implementing this option is estimated to be 1.56x 10^{-4} per year, which is around 1.3% decrease in risk compared to the PLL of 1.58 x 10^{-4} per year for the Worst Case Scenario.

Although this option imposes a lower risk than the Base Case and Worst case scenarios, it could result in a much higher fatality rate (i.e. up to 400 fatalities) in very low probability scenarios. This can be explained by the explosion of increased explosive load (i.e. more than 200 kg explosives) which affects other road users and population in buildings. The F-N curve of this option is shown in *Figure 9.2*.

The safety benefits over the construction period are:

Safety Benefits: HK$ 33M x 20 x 0.2 x 10^{-5} x 2 = HK$ 0.0026 M

Since the implementation cost for this option is negligible, approval from Mines Division concerning the increase in the licensing limit should be sought.

9.6 ALARP ASSESSMENT RESULTS

The evaluation of each option considered is summarized in *Table 9.6*. The F-N curve of the selected mitigation option is shown in *Figure 9.2*.

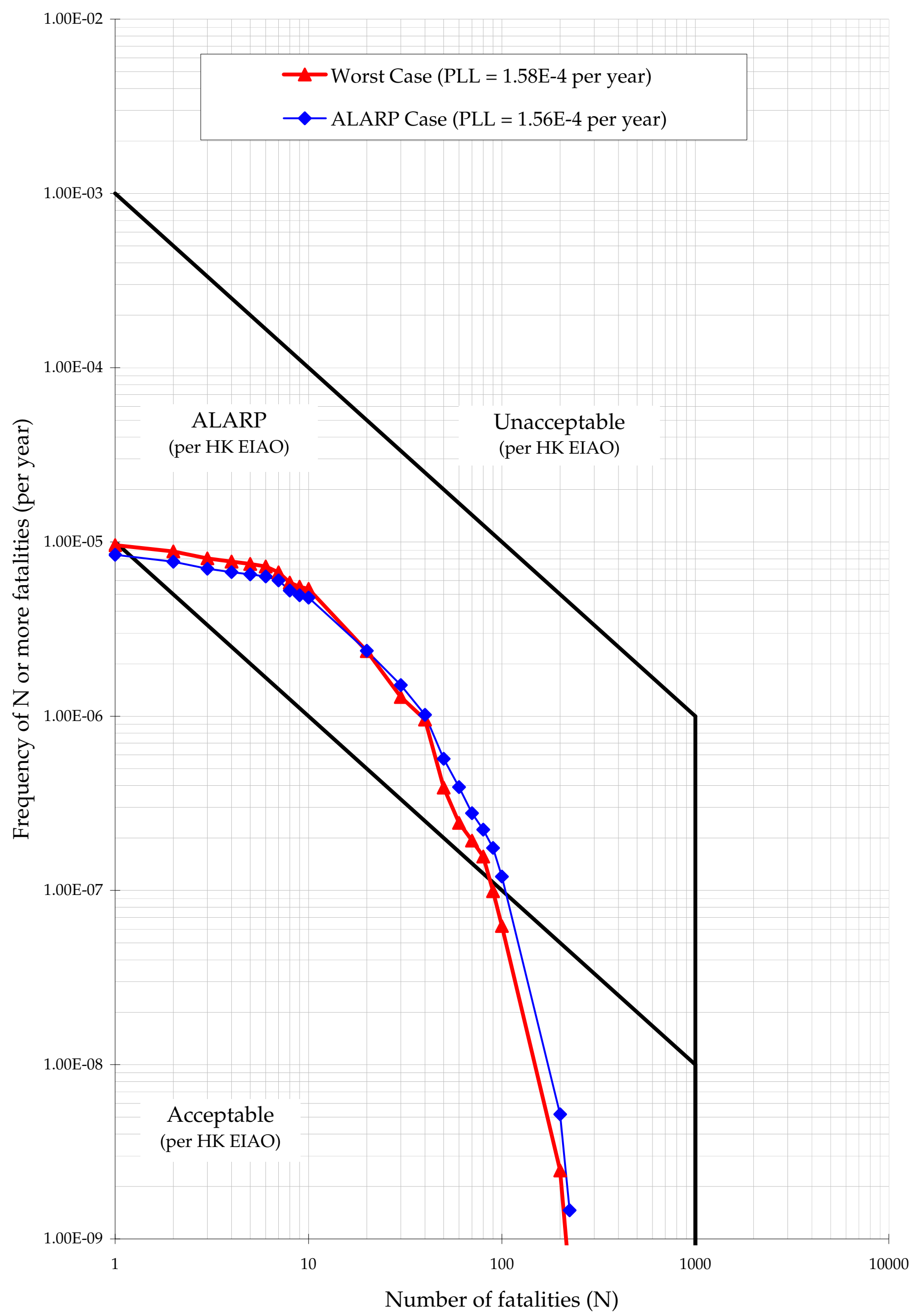
Table 9.6 ALARP Assessment Results

Option Description	**Practicability**	**Implementation Cost**	**Safety Benefits or Justifiable Expenditure**	**ALARP Assessment Result**
Use of alternative methods of construction (TBMs)	Not Practicable	> HK$ 100M	HK$ 0.21M	Not Justified
Use of Magazines Closer to the Construction Sites	Not Practicable	-	-	Closest practicable magazine site to the construction sites has been selected
Use of Alternative Route	Not Practicable	-	-	Not Justified
Use of different explosive types (different types of detonating cord)	Pose some limitations	HK$ 1M	No safety benefit	Not Justified
Use of smaller quantities of explosives	Practicable	> HK$ 0.9M	HK$ 0.9M	Use of cast boosters is not cost effective.The cast booster option will be explored further in line with the use of best practice in explosives selection. [1]
Safer explosives truck (reduced fire load)	Practicable	-	-	Based on low implementation costs, this option has been directly incorporated in recommendations
Lower Frequency of Explosives transport (Option Case 1)	Practicable upon Mines Division approval	-	HK$0.0026M	Justified.
Reduction of Accident Involvement Frequency (training programme etc.)	Practicable	-	-	Based on low implementation costs, this option has been directly incorporated in recommendations

Option Description	Practicability	Implementation Cost	Safety Benefits or Justifiable Expenditure	ALARP Assessment Result
Reduction of Fire Involvement Frequency (better emergency response, extinguisher types etc.)	Practicable	-	-	Based on low implementation costs, this option has been directly incorporated in recommendations

Note: [1] Please refer to Section 9.4.7, 8th paragraph.

Figure 9.2 *F-N Curve for the Selected Mitigation Option*



10 CONCLUSIONS AND RECOMMENDATIONS

10.1 CONCLUSIONS

A QRA has been carried out to assess the hazard to life issues arising from the storage and transport of explosives during construction of the SIL(E) Project.

The criterion of Annex 4 of the EIAO-TM for Individual Risk is met. The assessment results show that the societal risk lies within the ALARP region when compared to the criteria stipulated in the EIAO-TM. A detailed ALARP assessment has been undertaken considering a wide range of mitigation measures and the results show compliance with the ALARP principles provided that the following recommendations are followed.

A number of recommendations have been made to ensure that the requirements (including ALARP requirements) of the EIAO-TM will be met during the construction period (see *Section 10.2.1*). In additional some general recommendations have been made to minimise the risks further and in accordance best practices (see *Section 10.2.2*).

10.2 RECOMMENDATIONS

10.2.1 RECOMMENDATIONS FOR MEETING THE ALARP REQUIREMENTS

Following the ALARP principles, the following recommendations are justified and should be implemented to meet the EIAO-TM requirements:

- The truck design should be improved to reduce the amount of combustibles in the cabin. The fuel carried in the fuel tank should also be minimised to reduce the duration of any fire;
- The explosives truck accident frequency should be minimized by implementing a dedicated training programme for both the driver and his attendants, including regular briefing sessions, implementation of a defensive driving attitude. In addition, drivers should be selected based on good safety record, and medical checks;
- The contractor should as far as practicable combine the explosive deliveries for a given work area;
- Only the required quantity of explosives for a particular blast should be transported to avoid the return of unused explosives to the magazines.
- Whenever practicable, a minimum headway between two consecutive truck convoys of 10 min is recommended;
- The explosives truck fire involvement frequency should be minimized by implementing a better emergency response and training to make sure the

adequate fire extinguishers are used and attempt is made to evacuate the area of the incident or securing the explosive load if possible. All explosive vehicles should also be equipped with bigger capacity AFFF-type extinguishers; and

- Pending approval from the Commissioner of Mines Division, the licensing limit of contractors' explosives delivery truck may be increased to minimize the total number of explosives deliveries during the construction period. Where the explosives load is higher than the 200 kg limit per truck, a higher load up to 250 kg per truck may be permitted to be transported. This will reduce the number of additional deliveries while at the same time not cause any significant increase in the consequences due to the higher load.

10.2.2 *GENERAL RECOMMENDATIONS*

Blasting activities including storage and transport of explosives should be supervised and audited by competent site staff to ensure strict compliance with the blasting permit conditions.

The following general recommendation should also be considered for the storage and transport of explosives:

1. The security plan should address different alert security level to reduce opportunity for arson / deliberate initiation of explosives. The corresponding security procedure should be implemented with respect to prevailing security alert status announced by the Government.

2. Emergency plan (i.e. magazine operational manual) shall be developed to address uncontrolled fire in magazine area and transport. The case of fire near an explosive carrying truck in jammed traffic should also be covered. Drill of the emergency plan should be carried out at regular intervals.

3. Adverse weather working guideline should be developed to clearly define procedure for transport explosives during thunderstorm.

Specific recommendations for each of transport and storage of explosives are given below.

10.2.3 *STORAGE OF EXPLOSIVES IN MAGAZINE STORE*

The magazine should be designed, operated and maintained in accordance with Mines Division guidelines and appropriate industry best practice. In addition, the following recommendations should be implemented.

1. A suitable work control system should be introduced, such as an operational manual including Permit-to-Work system, to ensure that work activities undertaken during the operation of the magazine are properly controlled.

2. There should be good house-keeping within the magazine to ensure that combustible materials are not allowed to accumulate.

3. The magazine shall be without open drains, traps, pits or pockets into which any molten ammonium nitrate could flow and be confined in the event of a fire.

4. The magazine building shall be regularly checked for water seepage through the roof, walls or floor.

5. Caked explosives shall be disposed of in an appropriate manner.

6. Delivery vehicles shall not be permitted to remain within the secured fenced off magazine store area.

7. Good housekeeping outside the magazine stores to be followed to ensure combustibles (including vegetation) are removed.

8. A speed limit within the magazine area should be enforced to reduce the risk of a vehicle impact or incident within the magazine area.

9. Traffic Management should be implemented within the magazine site, to ensure that no more than 1 vehicle will be loaded at any time, in order to avoid accidents involving multiple vehicles within the site boundary. Based on the construction programme, considering that 6 trucks could be loaded over a peak 2 hour period, this is considered feasible.

10. The design of the fill slope close to the magazine site should consider potential washout failures and incorporate engineering measures to prevent a washout causing damage to the magazine stores.

10.2.4 *TRANSPORT OF EXPLOSIVES*

General Recommendations:

The following measures should also be considered for safe transport of explosives:

1. Detonators shall not be transported in the same vehicle with other Class 1 explosives. Separation of vehicles should be maintained during the whole trip.

2. Location for stopping and unloading from truck to be provided as close as possible to shaft, free from dropped loads, hot work, etc. during time of unloading.

3. Develop procedure to ensure that parking space on the site is available for the explosives truck. Confirmation of parking space should be communicated to truck drivers before delivery. If parking space on site cannot be secure, delivery should not commence.

4. During transport of the explosives within the tunnel, hot work or other activities should not be permitted in the vicinity of the explosives offloading or charging activities.

5. Ensure lining is provided within the transportation box on the vehicle and in good condition before transportation.

6. Ensure that packaging of detonators remains intact until handed over at blasting site.

7. Emergency plan to include activation of fuel and battery isolation switches on vehicle when fire breaks out to prevent fire spreading and reducing likelihood of prolonged fire leading to explosion.

8. Use only experienced driver(s) with good safety record.

9. Ensure that cartridged emulsion packages are damage free before every trip.

10. Contractor to ensure that any electro-explosive devices are sufficiently shielded from radio frequency radiation hazards.

Contractors Licensed Vehicle Recommended Safety Requirements:

- Battery isolation switch;
- Front mounted exhaust with spark arrestor;
- Fuel level should be kept as far as possible to the minimum level required for the transport of explosives;
- Minimum 1 x 9 kg water based AFFF fire extinguisher to be provided and minimum 1 x 9 kg dry chemical powder fire extinguisher to be provided for a typical vehicles with gross vehicle weight up to 9 tonnes. For a typical vehicle with gross vehicle weight of 9 tonnes or above, a minimum of four fire extinguishers, composing 2 x 2.5kg dry powder and 2 x 10-litre foam fire extinguishers of approved type, including certificates, to be provided and mounted as specified in Mines Division guidance note (CEDD 2, 2010);
- A hand-held lightning detector shall be provided in the vehicle for detection of lightning before and during loading and unloading of explosives. Should lightning signal be detected within a distance of 16km from the loading/unloading point by the hand-held detector, loading or unloading of explosives shall be ceased until lightning signal is cleared;
- Horizontal fire screen on cargo deck and vertical fire screen mounted at least 150mm behind the drivers cab and 100mm from the steel cargo compartment, the vertical screen shall protrude 150mm in excess of all three (3) sides of the steel cargo compartment;
- Cigarette lighter removed;

- Two (2) battery powered torches for night deliveries;
- Vehicles shall be brand new, dedicated explosives transport vehicles and should be maintained in good operating condition;
- Daily checks on tyres and vehicle integrity;
- Regular monthly vehicle inspections;
    - Fuel system
    - Exhaust system
    - Brakes
    - Electrics
    - Battery
    - Cooling system
    - Engine oil leaks
- Vehicle log book in which monthly inspections and maintenance requirements are recorded; and
- Mobile telephone equipped.

Recommended Requirements for the Driver of the Explosive Vehicles:

The driver shall:

- be registered by the Commissioner of Mines and must be over the age of 25 years with proven accident free records and more than 7 year driving experience without suspension.
- hold a Driving License for the class of vehicle for at least one (1) year;
- adopt a safe driving practice including having attended a defensive driving course;
- pass a medical check and is assessed as fit to drive explosives vehicles;
- not be dependent on banned substances;

Some of the following requirements may also apply to the vehicle attendant(s).

The driver is required to attend relevant training courses recognized by the Commissioner of Mines. The training courses should include the following major subjects, but not limited to:

- the laws and Regulations relating to the transport of explosives;

- security and safe handling during the transport of explosives;
- has attended training courses provided by the explosives manufacturer or distributor, covering the following:
    - explosives identification;
    - explosion hazards; and
    - explosives sensitivity;
- the dangers which could be caused by the types of explosives;
- the packaging, labeling and characteristics of the types of explosives;
- the use of fire extinguishers and fire fighting procedures; and
- emergency response procedures in case of accidents.

The driver should additionally be responsible for the following:

- The driver shall have a full set of Material Safety Data Sheets (MSDS) for each individual explosive aboard the vehicle for the particular journey;
- The MSDS and Removal Permit (where applicable) shall be produced to any officer of the Mines Division of CEDD upon request;
- A card detailing emergency procedures shall be kept on board and displayed in a prominent place on the drivers door;
- Before leaving the magazine the driver together with and/or assisted by the shotfirer shall check the following:
    - Packaging integrity and labeling;
    - Check that the types and quantities of explosives loaded onto the vehicle are as stipulated in the Removal Permit(s);
    - Check that the explosive load does not exceed the quantities stated in the removal permit;
    - Check the condition and integrity of the cargo compartment or box;
    - Check that detonators are not loaded in the explosives cargo compartment and vice versa;
    - Check that the cargo is secured and cannot be damaged during the delivery;
    - Ensure that the appropriate placards and a red flag are displayed before leaving the magazine;

    - Be competent to operate all equipment onboard the vehicle including fire extinguishers and the vehicle emergency cut-off switches;
    - Prohibit smoking when the vehicle is loaded with explosives;
    - When explosives are loaded, ensure the vehicle is not left unattended;
    - Be conversant with emergency response procedures.

Specific Recommended Requirements for the Explosive Vehicle Attendants:

- When the vehicle is loaded with explosives, it shall be attended by the driver and at least one (1) other person authorized by the Commissioner of Mines. The vehicle attendant shall:
    - Be the assistant to the driver in normal working conditions and in case of any emergency
    - Be conversant with the emergency response procedures
    - Be competent to use the fire extinguishers and the vehicle emergency cut-off switches
- One of the vehicle attendant(s) should be equipped with mobile phones and the relevant MSDS and emergency response plan.

10.2.5 TYPE OF EXPLOSIVES & THEIR DISPOSAL

Explosive Selection:

- Cartridged Emulsions with perchlorate formulation should be avoided;
- Cartridged Emulsions with high water content should be preferred.

Disposal Recommendations:

If disposal is required for small quantities, disposal should be made in a controlled and safe manner by a Registered Shotfirer.

11 REFERENCES

[1] DNV, The Risk Assessment of the Transport of Explosives in Hong Kong QRA Report, Environmental Protection Department Hong Kong Government, 1997, EPD CE63/94 (DNV, 1997)

[2] Maunsell, Hazard to Life Assessment of Explosive Storage and Handling for EIA of Ocean Park Development, 2006 (Maunsell, 2006)

[3] ERM, Penny's Bay Rail Link: Hazard Assessment of Explosive Magazine, 2001 (ERM, 2001)

[4] ERM, West Island Line: Hazard to Life Assessment for the Transport Storage and Use of Explosives, 2008 (EIA153/2008) (ERM, 2008)

[5] P A Moreton, An Investigation of the Relative Risks from the Road Transport of Blasting Explosives in Maximum Size Loads of 5te and 16te, February 1993, SRD/HSE R596 (Moreton, 1993)

[6] ACDS, Risk from Handling Explosives in Ports, HSC Advisory Committee on Dangerous Substances, HMSO, UK, 1995 (ACDS, 1995)

[7] United Nations, Recommendations on the Transport of Dangerous Goods – Manual of Tests and Criteria, 4th Revised Edition, 2003 (TDG-Test Manual, 2003)

[8] United Nations, Recommendations on the Transport of Dangerous Goods – Model Regulations, 15th Revised Edition, 2007 (TDG-Model Regulation, 2007)

[9] HSC, Selection and Use of Explosion Effects and Consequence Models for Explosives, Advisory Committee on Dangerous Substances, 2000 (ESTC, 2000)

[10] FP Lees, Loss Prevention in Process Industries, 2nd Edition, 1996 (Lees, 1996)

[11] US Department of Defense, DoD 6055.9-STD, DoD Ammunition and Explosives Safety Standards, Oct 2004 (DoD 6055.9-STD).

[12] Health and Safety Executive, The Peterborough Explosion – A report of the investigation by the Health and Safety Executive into the explosion of a vehicle explosives at Fengate Industrial Estate, Peterborough on 22 March 1989, UK, 1990 (Peterborough, 1989).

[13] DOCEP, Incident Log Reports retrieved from http://www.docep.wa.gov.au/resourcesSafety/Content/Dangerous_Goods/Incident_log_reports/index.htm (DOCEP)

[14] DOCEP, WA Government Explosives Incident Log 2001, DGEA 01/01 (DOCEP, 2001)

[15] Richard J. Mainiero and James H. Rowland III, A Review of Recent Accidents Involving Explosives Transport, NIOSH, January 2008 (NIOSH, 2008).

[16] R. Merrifield, P.A. Moreton, An examination of the major-accident record for explosives manufacturing and storage in the UK, Journal of Haz. Mats A63 (1998) 107-118. (Merrifield, 1998)

[17] Guidelines for Quantitative Risk Assessment, TNO Purple Book, CPR18E 1st Ed, Committee for the Prevention of Disasters (TNO Purple Book, 1999)

[18] F.D. Wayne, An economical formula for calculating the atmospheric infrared transmissivities, J. Loss Prev. Process Ind., 1991 Volume 4 (Wayne, 1991)

[19] HSE, Safety Report Assessment Guide for HFLs, http://www.hse.gov.uk/comah/sraghfl/images/hflcriteria.pdf (HSE HFLs, 2001)

[20] US Bureau of Mines Bulletin 656 Blasting vibrations and their effects on structures (USBM 656)

[21] ERM / Castle Peak Power Company Limited, Liquefied Natural Gas (LNG) Receiving Terminal and Associated Facilities, EIA Report No. EIA-125/2006, October 2006. (ERM, 2006)

[22] Transport Department, "Road Traffic Accident Statistics", Government of Hong Kong S.A.R, 2007 (and previous years) (TD, 2007a)

[23] Lands Department, Geographic Information System (GIS) database, http://www.landsd.gov.hk/mapping/en/digital_map/mapprod.htm The latest information on the GIS map of buildings from the Lands Department used in this study comes from 2005 (LD, 2005)

[24] Roger R Holmberg & B Folkesson , Bulk Emulsion Explosive – A Case Study, Bulamac Patlayicilar – Bir Uygulama, 615-629, retrieved from http://www.maden.org.tr/resimler/ekler/1f5738a827405b0_ek.pdf (Holmberg, 2009)

[25] P A Moreton, Controlling risks around explosives stores: Review of the requirements on the separation distances, UK HSE 2002 (Moreton, 2002)

[26] EPD, Technical Note: Cost Benefit Analysis in Hazard Assessment, Environmental Protection Department, Rev. January 1996. (EPD, 1996)

[27] Transport Department, Annual Traffic Census 2007 (ATC, 2007).

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

[29] Annual review of aircraft accident data: US General Aviation, Calendar year 2001, National Transport Safety Board. (NTSB, 2001)

[30] GEO, Seismic hazard analysis of the Hong Kong region, GEO Report No. 65, Geotechnical Engineering Office, Government of the Hong Kong SAR, 2002. (GEO Report 65, 2002)

[31] GCO, Review of earthquake data for the Hong Kong region, GCO Publication No. 1/91, Civil Engineering Services Dept., Hong Kong Government, 1991. (GCO, 1991)

[32] International Society of Explosives Engineers, Proceedings of the 22nd Annual Conference on Explosives and Blasting Techniques, 4-8 Feb 1996, (ISEE, 1996)

[33] UK HSE, "Rules of Thumb for Outcomes of Accidents Involving Small Quantities of Explosives in Small Workrooms (of the order 4 m by 4 m). (HSE, Explosion of Small Quantities of Explosives)

[34] CEDD, List of Explosives Approved for Use in Hong Kong, http://www.cedd.gov.hk/eng/services/mines_quarries/mqd_explosives.htm (CEDD 1, 2009)

[35] CEDD, Guidance Note on Requirements for Approval of an Explosives Delivery Vehicle, http://www.cedd.gov.hk/eng/services/mines_quarries/doc/gn_03_edv.pdf (CEDD 2, 2010)

[36] CEDD, How to apply for a Mode A Explosives Store Licence, http://www.cedd.gov.hk/eng/services/mines_quarries/doc/gn_mode_a_store.pdf (CEDD 3, 2009)

[37] CEDD, Guidance Note on Licensing of a Manufacturing Unit for Explosives at a Blast Site, http://www.cedd.gov.hk/eng/services/mines_quarries/doc/gn_02_lmuebs.pdf (CEDD 4, 2007)

[38] Methods for the Calculation of Physical Effects, Yellow Book, CPR14E 3rd Ed, Committee for the Prevention of Disasters (Yellow Book)

[39] Expert Review Panel Minutes, 2-3 February 2009 (ERP, 2009)

[40] ERM, Express Rail Link: Hazard to Life Assessment for the Transport and Storage of Explosives, 2009 (ESB-197/2008) (ERM, 2009)

[41] MTR, Consultancy Agreement No. NEX/1039, South Island Line (East) Preliminary Design, "VE01 – Options Report (Rev. A)", May 2008. (MTR 1, 2008)

[42] MTR, Consultancy Agreement No. NEX/1039, South Island Line (East) Preliminary Design, "MN14 – Final Report (Rev. A)", Mar 2009. (MTR 2, 2009)

[43] MTR, Consultancy Agreement No. NEX/1039, South Island Line (East) Detailed Design, Deliverable 3.13B Works Contract 902 Blasting Submissions, Dec 2009. (MTR 3, 2009)

[44] MTR, Consultancy Agreement No. NEX/1039, South Island Line (East) Preliminary Design, "Working Paper on Magazine Site Options Report (April 2010). (MTR 4, 2010)

[45] UK Health & Safety Executive, Manufacture and Storage of Explosives Regulations, 2005. (MSER, 2005)

[46] MTR, Consultancy Agreement No. NEX/1039, South Island Line (East) Preliminary Design, "Working Paper GE07 - Site Impact Assessment Report (Rev. A)", Nov 2008. (MTR 5, 2008)

[47] MTR, Consultancy Agreement No. NEX/1039, South Island Line (East) Preliminary Design, "Working Paper GE12 - Preliminary Natural Terrain Hazard Review Report (Rev. A)", Sep 2008. (MTR 6, 2008)

[48] MTR, Consultancy Agreement No. NEX/1039, South Island Line (East) Preliminary Design, "Working Paper GE06 - Ground Movement Report (Rev. A)", Aug 2008. (MTR 7, 2008)

[49] National Transportation Safety Board, Safety Recommendation, Washington D.C. 20594, 1998, retrieved from http://www.ntsb.gov/Recs/letters/1998/A98_81_82.pdf (NTSB, 1998)

[50] LegCo, Minutes of LegCo Panel on Environmental Affairs – Aircraft Noise, LC Paper No. CB(1)163/98-99, Legislative Council, Hong Kong, Aug 1998, retrieved from http://www.legco.gov.hk/yr98-99/english/panels/ea/minutes/ea180898.htm (LegCo, 1998a)

[51] LegCo, LegCo Panel on Environmental Affairs – Aircraft Noise, LC Paper No. CB(1)78/98-99(04), Legislative Council, Hong Kong, 1998, retrieved from and http://www.legco.gov.hk/yr98-99/english/panels/ea/papers/78_111.pdf (LegCo, 1998b)

Section 7B

QRA for Shell LPG Depot (PHI Assessment)

CONTENTS

1 INTRODUCTION

1.1 PURPOSE OF THE STUDY

The South Island Line (East) project (SIL(E)) is planned to be a medium capacity railway with stations at South Horizons (SOH), Lei Tung, Wong Chuk Hang, Ocean Park and Admiralty. Under Section 5(7) of the Environmental Impact Assessment (EIA) Ordinance (Cap. 499) (EIAO), the Director of Environmental Protection (Director) from the Environmental Protection Department (EPD) has issued a Study Brief No. ESB-181/2008 for this project (EIA Study Brief). Section 3.4.5 of the EIA Study Brief specifies Hazard to Life assessments to be conducted for the Project.

In Section 3.4.5.3 of the EIA Study Brief, it is stated that a hazard assessment should be carried out for aspects of the Project that fall within the Consultation Zone of the LPG Transit Depot/Bulk Domestic Supply at Lee Nam Road (the LPG Depot). For completeness, these requirements are repeated in *Table 1.1*. This Appendix addresses these requirements.

Table 1.1 EIA Study Brief - Hazard to Life Requirement

3.4.5	**Hazard to Life**
3.4.5.3	The Applicant shall carry out hazard assessment to evaluate potential hazard to life due to the construction and operation of those parts of the Project which fall within the Consultation Zone of the LPG Transit Depot/Bulk Domestic Supply at Lee Nam Road.
	The hazard assessment shall include the following:
	(i) Identify hazardous scenarios associated with the facilities/activities of the LPG Transit Depot/Bulk Domestic Supply at Lee Nam Road and then determine a set of relevant scenarios to be included in a Quantitative Risk Assessment (QRA);
	(ii) Execute a QRA of the set of hazardous scenarios determined in (i), expressing population risks in both individual and societal terms;
	(iii) Compare individual and societal risks with the criteria for evaluating hazard to life stipulated in Annex 4 of the TM; and
	(iv) Identify and assess practicable and cost-effective risk mitigation measures.
	The methodology of the hazard assessment shall be agreed and approved by the Director.

The layout of the South Horizons station in relation to the LPG Depot is shown in *Figure 1.1*. The LPG Depot is a Potentially Hazardous Installation (PHI) with two main facilities on the site: a Bulk Domestic Supply facility with 40 tonnes of LPG storage in two mounded tanks and a Transit Depot with storage shed for about 2000 LPG cylinders (up to 100 tonnes). A 500m Consultation Zone is defined around the facility as shown in *Figure 1.1*.

Societal risks from a PHI depend on population levels in the vicinity. Any development within the Consultation Zone of a PHI, that may lead to an increase in population, requires a hazard assessment to be conducted to ensure that the societal risks remain acceptable. The criteria and guidelines for

assessing Hazard to Life are stated in Annexes 4 and 22 of the Technical Memorandum (EIAO-TM Criteria).

The proposed South Horizons station is located near Yi Nam Road, about 100m from the LPG Depot. This is situated within the Consultation Zone of the LPG Depot as shown in *Figure 1.1*. Some of the work sites and plant buildings also lie within the Consultation Zone.

1.2 GENERAL METHODOLOGY

An assessment was conducted previously for the LPG facilities at Ap Lei Chau as part of the Harbour Area Treatment Scheme (HATS) (ENSR, 2008). The methodology adopted in that study is followed closely in the current study although some refinements are made. These refinements are discussed as they arise in the report.

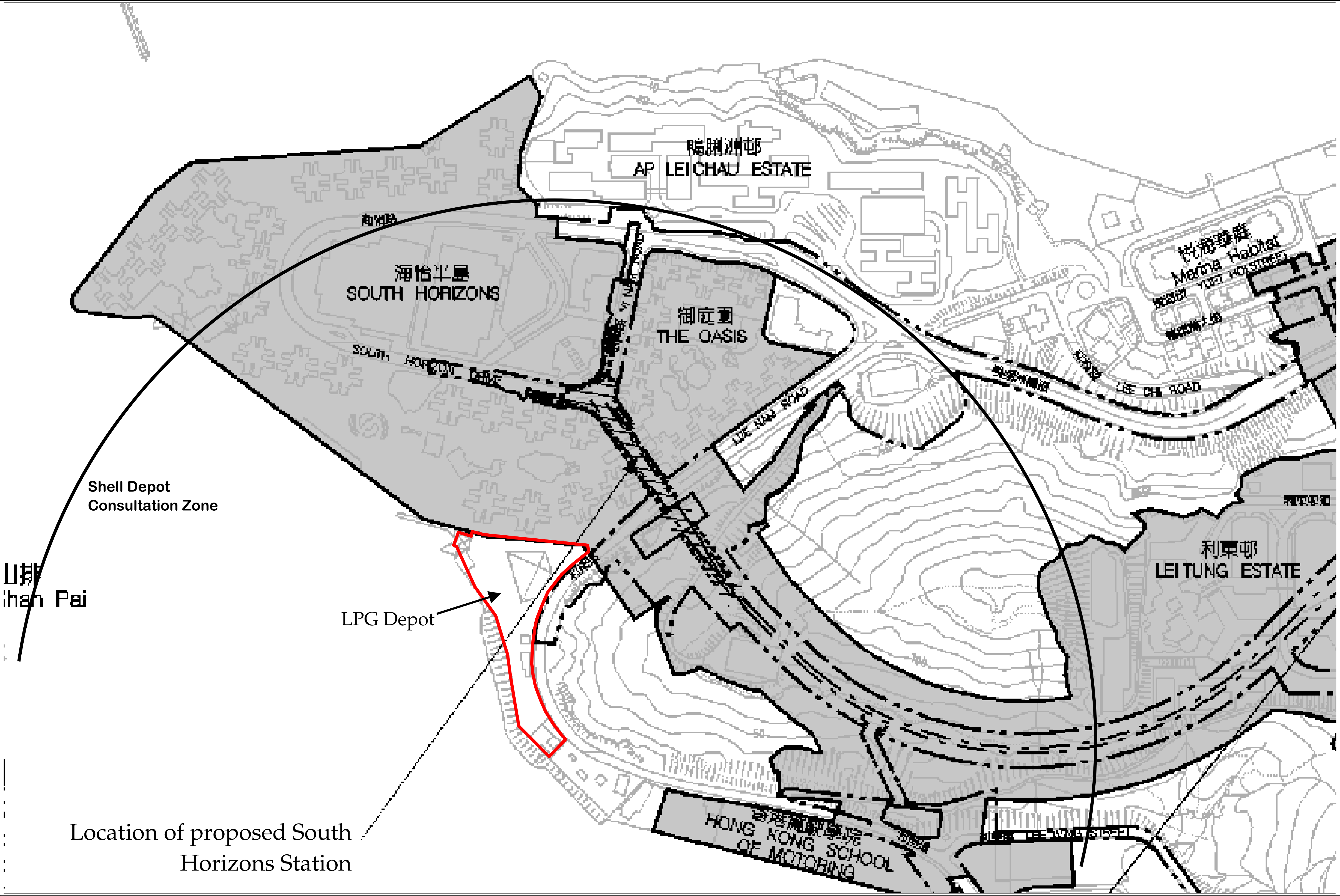
It should be noted that the separation between the South Horizons work sites and the PHI is such that activities at the work sites will not impact on the PHI. Blasting, for example, will all be underground and at distances significantly greater than that required to inflict damage to the LPG facilities. Potential impacts of construction activities on the LPG Depot are therefore not considered further in this assessment. On the other hand, incidents at the LPG Depot may extend up to a few hundred metres and may impact on the South Horizons station and/or worker population and needs to be assessed.

The South Horizons construction phase will overlap with construction work for the Preliminary Treatment Works (PTW) in Ap Lei Chau as part of the HATS project. The assessment therefore considers the increase in population due to both groups of workers. Three population cases are considered in the analysis:

- The current (2009) population;
- The construction phase (2014) population with overlapping construction activities between MTR South Horizons works and HATS works; and
- A future operational case with 2031 population.

Although the South Horizons construction phase may continue to 2015, the HATS construction is expected to be completed in 2014. Year 2014 was therefore selected as an appropriate year for the construction phase since the worker population will be at its highest during this time.

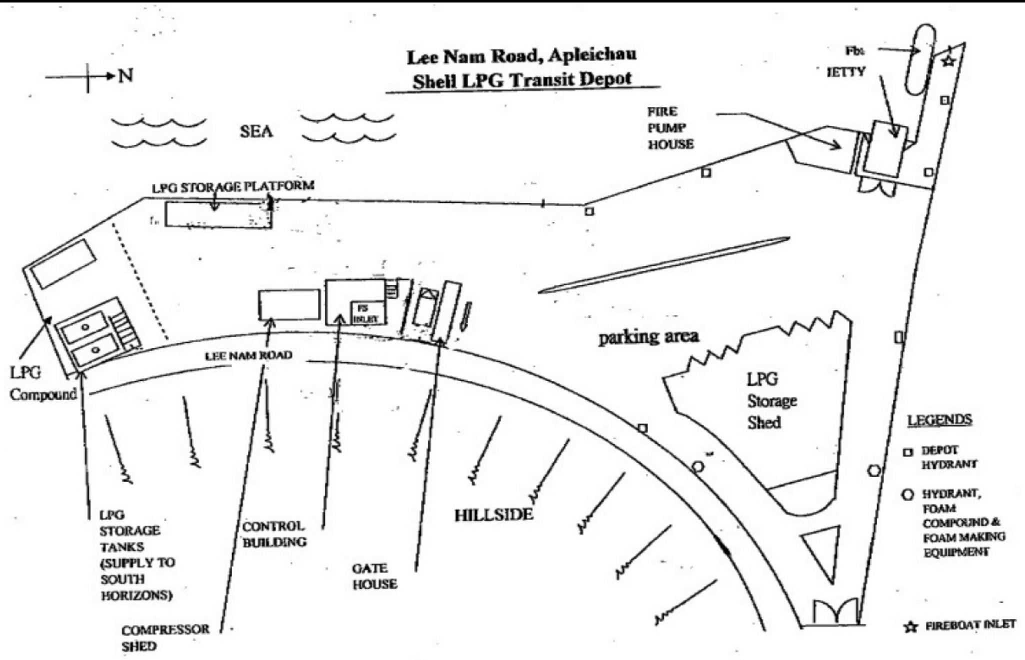
Figure 1.1 South Horizons Station Location



2.1 SHELL'S FACILITIES AT AP LEI CHAU

Shell's LPG site is defined in the 2000 PHI Register (Planning & Lands Bureau, 2000) as a PHI (Potentially Hazardous Installation) on account of storing Liquefied Petroleum Gas (LPG) in excess of 25 tonnes. The facility consists of an LPG Bulk Domestic Supply (LPG Compound) and a Transit Depot (*Figure 2.1*). The LPG Compound is located on the south side of the site while the Transit Depot (LPG Storage Shed) is situated on the north side. Deliveries are made by road tankers and cylinder wagons using Dangerous Goods ferries that berth at a jetty on the northwest of the site. An area for parking LPG road tankers and cylinder wagons is provided in front of the Storage Shed.

Figure 2.1 ***LPG Depot Layout***

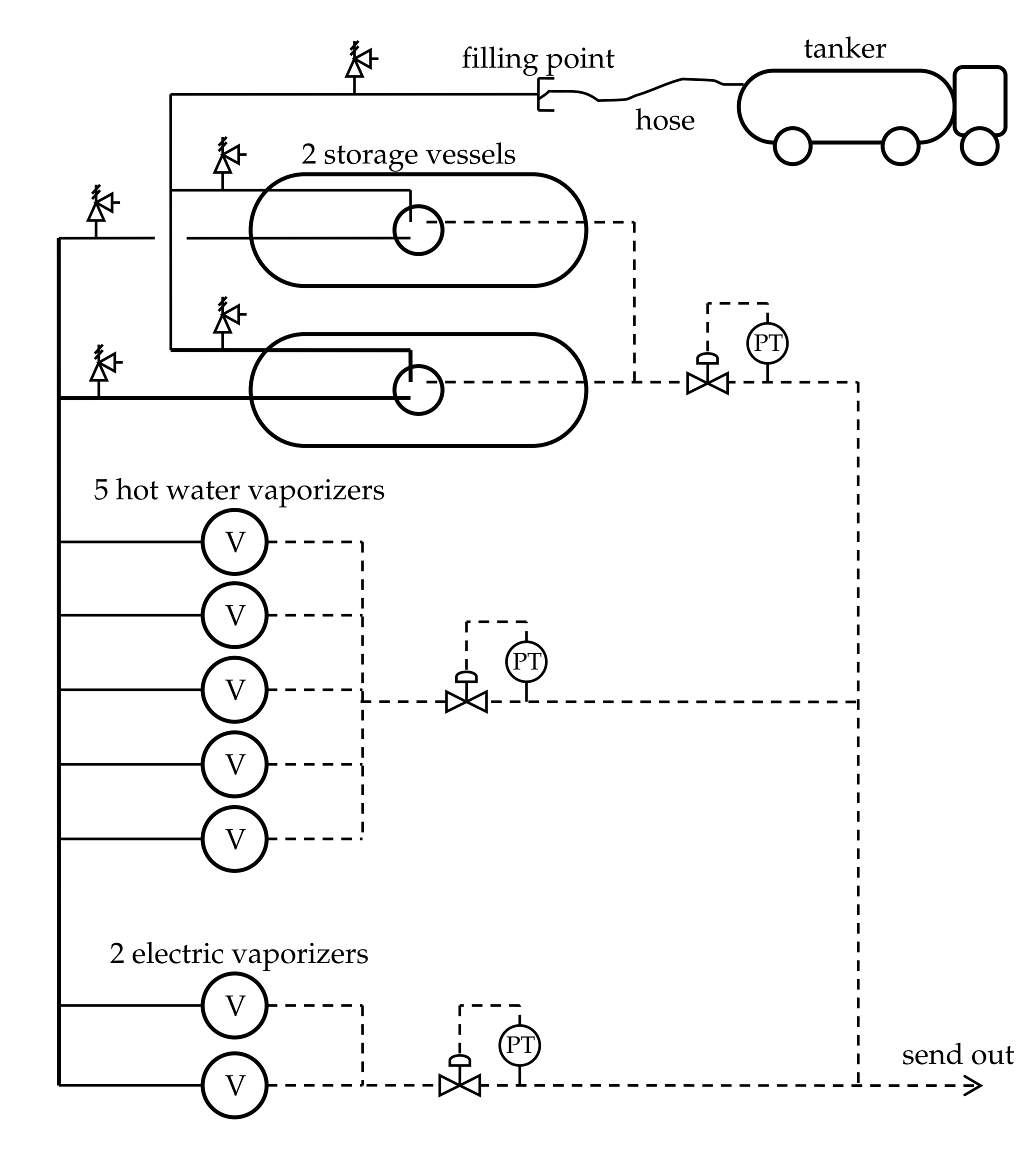


2.1.1 LPG Bulk Domestic Supply

A process flow diagram for the LPG compound is shown in *Figure 2.2*. LPG is stored in two 20 tonne mounded tanks. These tanks are filled to at most 85%, giving a maximum storage of 34 tonnes. LPG is vaporised in 5 water heated vaporisers and the pressure let down to 1 psi for send out to domestic customers in the area. 2 electrically heated vaporisers are available on standby. An unloading bay is provided for unloading LPG road tankers.

Three LPG road tanker deliveries are made per day, on a single DG ferry round trip.

Figure 2.2 ***Storage Compound Process Flow Diagram***



A summary of the Bulk Compound operating data is provided in *Table 2.1*.

Table 2.1 ***Bulk Domestic Supply Facility Operating Data***

Description	Number
LPG road tanker deliveries	3 per day (1 ro-ro ferry round trip)
LPG road tanker size	9 tonne
LPG storage	2 × 20 tonne mounded tanks (filled to 85% = 34 tonnes)
Storage pressure	~ 3.5 barg
Unloading time	2 hours
Vaporisers	5 hot water heaters + 2 electric heaters

2.1.2 LPG Transit Depot

The Transit Depot provides storage and transit for LPG cylinders. Cylinders are delivered to the store by ferry services. Cylinder capacities range from 2 kg to 49 kg, with 13.5 kg being the most common size. Typically, around 2200 filled cylinders are stored within the shed at any time, with a further 900 empty cylinders. The LPG storage platform, near the waterfront, is used for temporary handling of cylinders.

Throughput at the Transit Depot amounts to 900 (max) cylinders per day, delivered on 3 cylinder wagons and a single DG ferry round trip. The depot operators also load/unload cylinder wagons of local distributors for delivery to customers in Hong Kong Island South. These distributors' wagons may be 5.5 tonne or 8 tonne in size.

Apart from LPG cylinder wagons, the ro-ro ferry pier is also the landing place for LPG tankers supplying the LPG Compound and bulk diesel /petrol tankers (4 ~ 5 trucks per day) serving public filling stations on Hong Kong Island. 5 cylinder wagons are parked on site overnight, with a further 2 LPG tankers on stand-by overnight during typhoons.

A summary of the Transit Deport operating data (Shell, 2009) is provided in *Table 2.2*.

Table 2.2 Transit Depot Operating Data

Description	Number
LPG cylinder wagon deliveries	3 per day (1 ro-ro ferry round trip)
Cylinder throughput	900 per day max (277,000 average per year)
Cylinder storage	Max 4,300, average 2,200
Cylinder transport to customers	Distributors' wagons. 5.5 tonne (65 cylinders) or 8 tonne (125 cylinders)
Cylinder size distribution	2kg – 8% 8kg – 24% 10.5kg – 5% 13.5kg – 39% 15kg – 8% 49kg – 16%
Storage pressure	~ 3.5 barg
Construction	Storage shed with open walls and natural ventilation
Safety systems	4 gas detectors with automatic water sprinklers and hydrants.

2.2 SURROUNDING POPULATION

Population in the vicinity of the LPG Depot is summarized in *Table 2.3* and *Figure 2.3*. Population was based on the HATS study (ENSR, 2008), data from the Census and Statistics Department for mid 2006 and site surveys. A population growth of 1% per year was assumed, consistent with previous studies in Hong Kong (ERM, 2009).

The future 2031 case considers the South Horizons MTR station during operational phase. Operation of the MTR will likely shift patronage away from buses and onto the trains. This may change outdoor population distributions at street level. Bus stops are currently distributed around the South Horizons residential development and considering that some waiting at

bus stops is necessary, the shift to usage of the MTR will likely cause a reduction in outdoor population. For simplicity, the analysis conservatively assumes outdoor population will grow at the same rate as indoor population i.e. by 1% per year. No redistribution in population is imposed due to construction of the MTR station.

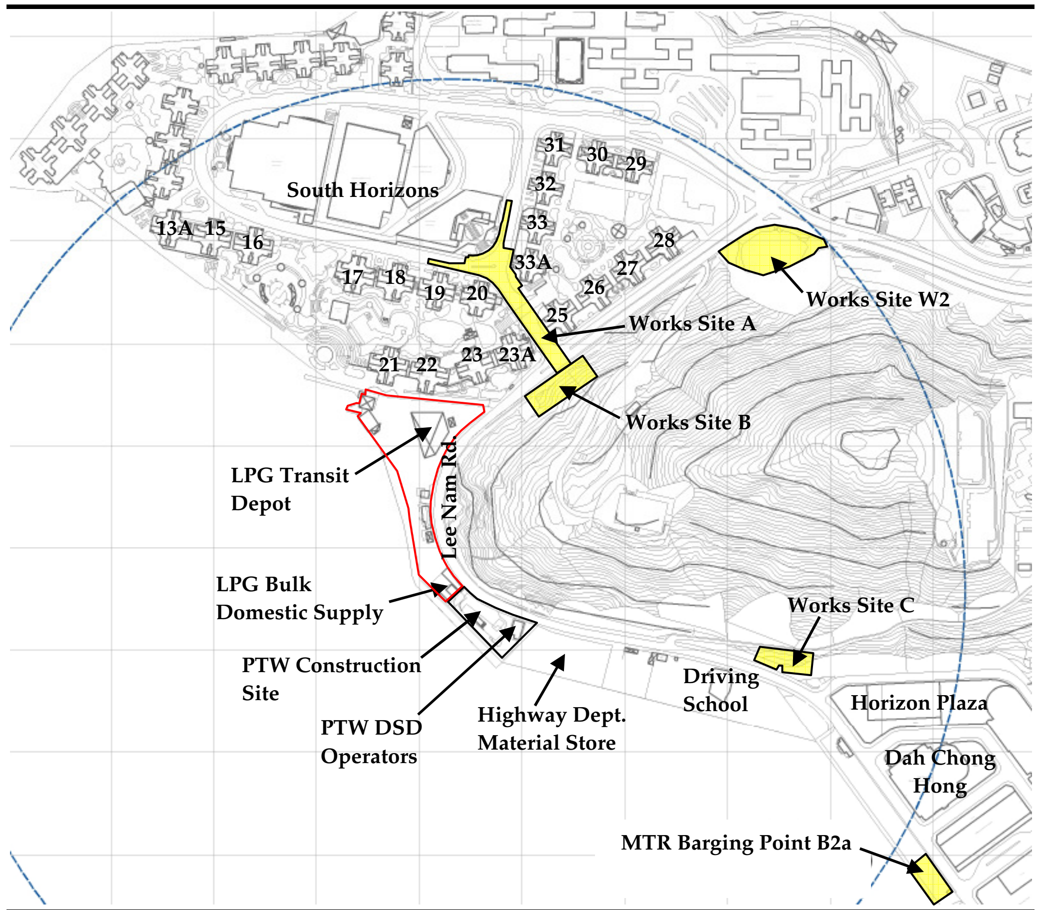
It is possible the population in Horizon Plaza may increase beyond the 1% growth rate assumed in *Table 2.3* since visiting the area will be more convenient once SIL is operational. However, it was found in the analysis that none of the accident consequences have sufficient range to reach Horizon Plaza except for projectiles which are shielded by the neighbouring residential blocks. Therefore, increasing the Horizon Plaza population further to allow for increasing visitors will have no impact on the results.

Table 2.3 Population in Vicinity of Shell Depot

Population Group	Current Population (Year 2009)	Construction Phase Population (2014)	Future Population (2031)
South Horizons Blocks 21 to 23A	3915	4074	4873
South Horizons Blocks 25 to 28	3270	3402	4070
South Horizons Blocks 29 to 33A	4508	4691	5611
South Horizons Blocks 17 to 20	4430	4610	5514
South Horizons Blocks 13A,15,16	3236	3366	4026
Horizon Plaza	3180	3309	3958
Dah Chon Hong	795	827	990
Driving School	50	50	50
Highway Dept. Material Store	2	2	2
Lee Nam Road Vehicle Pass.	20	21	25
Lee Nam Road Pedestrians	8	8	10
Sea population within 500m	10	10	12
PTW – DSD Operators*	4	3	4
PTW Construction Site	0	61	0
MTR Works Site A	0	200	0
MTR Works Site B	0	150	0
MTR Works Site C	0	250	0
MTR Works Site W2	0	100	0
MTR Barging Point B2a	0	100	0
South Horizons Station	0	0	280†

* DSD = Drainage Services Department
† Based on MTRC forecast of 63,600 passengers per day and assuming each person spends 5 minutes within the station and operations run for 19 hours per day. The station population is, however, all underground and will be unaffected by any incidents at the LPG Depot.

Figure 2.3 *Ap Lei Chau Population*



In order to reflect different populations at different times of the day, 4 time periods are used and the occupancy specified for each (*Table 2.4*). Daytime is defined as 07:00 to 19:00 and night-time from 19:00 to 07:00.

Since persons indoors will be offered some protection from fires and explosions, the analysis makes a distinction between those indoors and outdoors. The HATS study (ENSR, 2008) considered 5% of the population to be outdoors. This is refined in this study by adopting a more detailed breakdown for different types of population (*Table 2.4*), which is consistent with other studies in Hong Kong (ERM, 2006 for example).

Table 2.4 ***Population Occupancy and Indoor/Outdoor Fractions***

Population Type	**Occupancy**				**% Outdoors**			
	Weekday		Weekend		Weekday		Weekend	
	day	night	day	night	day	night	day	night
Residential	20 %	100 %	80 %	100 %	10 %	0 %	20 %	0 %
Industrial/Commercial	100 %	10 %	10 %	10 %	10 %	5 %	10 %	5 %
Shopping Centre	50 %	10 %	100 %	10 %	10 %	0 %	10 %	0 %
Road	100 %	20 %	100 %	20 %	0 %	0 %	0 %	0 %
Sea	100 %	0 %	100 %	0 %	100 %	100 %	100 %	100 %
PTW Construction	100 %	10 %	100 %	10 %	90%	5 %	90 %	5 %
MTR works sites	100 %	50 %	100 %	50 %	100 %	100 %	100%	100 %

2.3 METEOROLOGICAL CONDITIONS

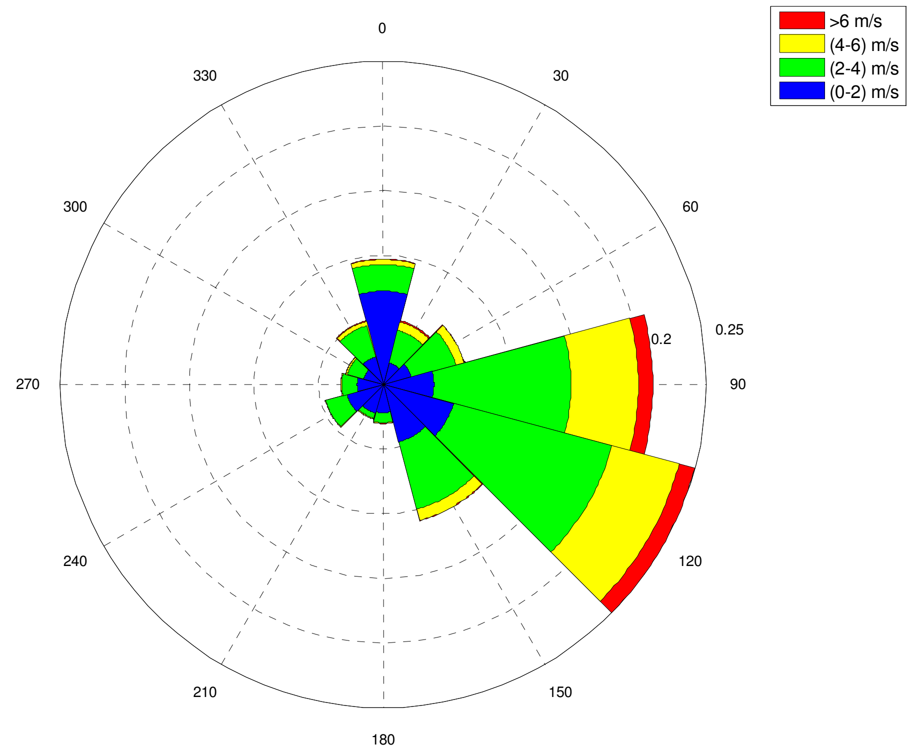
Meteorological conditions affect the dispersion behaviour of gas releases, particularly the wind speed, wind direction and atmospheric stability class. Weather data from the most recent 5 years (2004 to 2008) from Wong Chuk Hang weather station of the Hong Kong Observatory were used in the analysis. This weather data were rationalised into 5 categories to represent the range of weather conditions expected at the site. These categories were selected by reference to the HATS study (ENSR, 2008) and are denoted as 3B, 3D, 7D, 3E and 1.4F, where '3B' for example refers to a wind speed of 3 m/s and Pasquill atmospheric stability class of B.

The resulting probability of occurrence for each combination of wind speed, direction and stability class is summarised in *Table 2.5* and a wind rose plot is shown in *Figure 2.4*.

Table 2.5 ***Meteorological Data***

Wind Direction	**Weather Category – Probability of Occurrence**					
	3B	3D	7D	3E	1.4F	Total
Day						
0°	0.021	0.015	0.001	0.005	0.016	0.059
30°	0.014	0.012	0.002	0.006	0.006	0.040
60°	0.027	0.016	0.001	0.010	0.009	0.062
90°	0.080	0.050	0.020	0.022	0.016	0.189
120°	0.143	0.064	0.021	0.026	0.022	0.276
150°	0.099	0.026	0.001	0.010	0.018	0.154
180°	0.015	0.007	0.000	0.001	0.009	0.033
210°	0.008	0.005	0.000	0.001	0.007	0.022
240°	0.032	0.008	0.000	0.003	0.009	0.052
270°	0.022	0.006	0.000	0.003	0.005	0.035
300°	0.016	0.007	0.000	0.003	0.004	0.029
330°	0.020	0.012	0.001	0.009	0.006	0.048
Total	0.497	0.228	0.048	0.099	0.128	1.000
Night						
0°	0.000	0.008	0.002	0.014	0.116	0.140
30°	0.000	0.013	0.005	0.021	0.025	0.064
60°	0.000	0.013	0.002	0.021	0.032	0.068
90°	0.000	0.069	0.030	0.067	0.067	0.232
120°	0.000	0.058	0.028	0.062	0.072	0.220
150°	0.000	0.004	0.001	0.008	0.046	0.058
180°	0.000	0.000	0.000	0.001	0.026	0.027
210°	0.000	0.001	0.000	0.002	0.032	0.034
240°	0.000	0.001	0.000	0.004	0.035	0.040
270°	0.000	0.000	0.000	0.004	0.025	0.030
300°	0.000	0.003	0.000	0.006	0.022	0.031
330°	0.000	0.007	0.002	0.016	0.030	0.054
Total	0.000	0.179	0.069	0.224	0.528	1.000

Figure 2.4 *Wind Rose*



3 HAZARD IDENTIFICATION

3.1 REVIEW OF PAST ACCIDENTS

A survey of worldwide accidents involving LPG facilities and transport has been conducted and is presented below.

3.1.1 *Road Tanker Accident Review*

Kansas, USA, July 1952 – A discharge from a relief valve on the fuel tank of an LPG powered tanker at an LPG filling station ignited giving rise to a vapour-cloud explosion that killed two people and was heard 3.2 km away.

Netherlands, December 1981 – A road tanker containing 26 m^3 of LPG had been sealed by customs in Belgium. Both the storage box and valve of the line had been sealed. When commencing the unloading of the LPG at a fuelling station, the driver took hold of the line, breaking the seal. The rope connecting the seal, line and valve should have broken but did not and the valve was partly opened by the rope. Released LPG was ignited (source of ignition unclear) but despite the driver being engulfed in fire, he managed to close the valve and two other people extinguished the fire. The driver suffered first and second degree burns to his face.

Nijmgen, Netherlands, 18 December 1978 – A 27m^3 capacity LPG road tanker was refilling an above ground LPG storage tank at a refuelling station. Due to the cold weather, the tank driver went inside the office, leaving the refilling unattended. After a while a fire was seen, probably resulting from a leak during offloading. The safety valve on the tanker did not open and 45 minutes later the tanker suffered a BLEVE. Projectiles travelled up to 150m. The tanker and the fuelling station were destroyed. The safety valve on the LPG storage tank opened and up to 3000 litres of LPG burned off. The LPG storage tank did not explode. No injuries sustained.

Netherlands, March 1994 – A 20m^3 capacity underground LPG storage tank at a fuel station was being prepared for inspection when the remaining vapour in the tank was ignited by a petrol pump motor after the manway was opened. The ensuing flash fire severely injured two contractors. It was not clear to the investigation team whether the procedure for emptying the tank had been followed correctly.

Australia, 1999 – Approximately 10,000 litres of LPG escaped to atmosphere when the driver of a road tanker drove off without disconnecting the filling hose. Fortunately the gas did not ignite. Nearby residents were evacuated as a precaution. After an investigation the company was fined AU$2500 (1999), for the storage tank not meeting the Australian Standard.

New Jersey, USA, 21 Sep 1972 – A BLEVE of an LPG road tanker carrying 14te of propylene occurred on the New Jersey Turnpike. A collision at over 50 mph caused the tanker to cross the central divide and overturn. The pipework on the tanker was not isolated and started to leak. The excess flow valve failed to isolate the leak because the leak was small. The trucks diesel tank was also damaged in the crash and the leaking diesel fuel ignited. This ignited the leaking propylene to form a jet fire that engulfed the tanker.

The fire caused the PRVs to lift but because the tanker was on its side, liquid propylene was released which ignited and spread across the highway. After 25 minutes had elapsed, with an estimated 10te of propylene still in the tank, a BLEVE occurred. The fireball extended at least 100m and passed over one occupied vehicle but the occupant was not injured. 28 bystanders were injured, including 7 policemen. One of the injuries occurred 180m from the tanker and the force of the blast propelled the main tank section 400m.

Ref: HCB, Sep 1984

Saint-Amand-les-Eaux, France, 1 Feb 1973 – A BLEVE of a road tanker carrying 20te of propane. An articulated tanker travelling at 30 mph overturned in a traffic accident. Propane leaked from a PRV damaged in the accident. The gas ignited within a minute forming a jet fire 10-30m long, which deflected from the ground and spread to nearby houses. Fire services tried to cool the tanker but after 10-15 minutes a BLEVE occurred. The tank disintegrated, destroying a house and sending fragments 450m. There were a total of 9 fatalities (some from the crash rather than related to the propane release), 23 serious injuries, 22 minor injuries and 9 vehicles and 13 houses destroyed. 100 spectators only 40m from the tanker survived.

Ref: OECD 1988, "Transporting hazardous Goods by Road"

Hubert P., 1989, "Sequence and Implications of the Accident at Saint-Amand-les-Eaux" (ACDS/MHT/TWP/44)

Casula, NSW, Australia, 21 Oct 1976 – Leak from an LPG road tanker. The vehicle's tail shaft broke and hit the liquid outlet line, breaking it and causing liquid LPG to escape. The damage to the pipe also prevented the excess flow valve from functioning and the shut-off valve only reduced the flow but did not stop it. The tank contents were transferred to other tankers but 2te of LPG was released. There was no ignition and no injuries reported.

Ref: Department of Environment and Planning, 1983, "hazard Study of Liquefied Petroleum Gas in Automotive retail Outlets", New South Wales, Australia.

San Carlos, Spain, 11 Jul 1978 – A fire occurred in an articulated propylene road tanker due to overfilling. The tanker was overloaded with 23.5te of propylene, compared to its permitted load of 19.4te and the tanker was not fitted with a PRV. The tank disintegrated, due to thermal expansion of the propylene, into 3 parts which were projected up to 220m. Ignition occurred after 1 minute leading to a flash fire (although some reports describe it as a BLEVE).

The incident occurred next to a camp site. The fire destroyed several buildings and killed 217 people with an additional 67 injuries.

Ref: Hymes I., 1983, "The Physiological and Pathological Effects of Thermal radiation", SRD Report R275.

Wispertal, Germany, 4 Jul 1985 – Controlled flaring from a propane tanker. An LPG road tanker overturned on a sharp bend and fell down a steep slope, coming to rest in a tree. The accident killed the driver but there was no leak. Recovering the tanker intact was deemed to be too dangerous and the nozzle of the filling valve only reached the vapour space. Thus the vapour had to be flared with vaporisation aided by spraying warm water on the tank. The operation lasted 2.5 days.

Ref: Droste B. and Mallon M., 1989, 'A statistical Review of the Reasons Leading to LPG Accidents", BAM, Berlin.

Memphis, Tennessee, USA, 23 Dec 1988 – Fireball after propane tanker collision with a bridge. A $36m^3$ propane tanker overturned on a highway and slid along the road for 60m before colliding with a bridge buttress. The tank ruptured forming a vapour cloud that drifted 460m and then ignited in a fireball. Several vehicles on both carriageways were caught in the fire and most of their occupants died. Several buildings also caught fire and one occupant died. The tank shell was projected 120m, crushing a house and leading to secondary fires and 2 fatalities. There were a total of 9 fatalities and 12 injuries.

Ref: Loss Prevention Bulletin 094

MHIDAS

Candasnos, Spain, 31 Jan 1990 – Fireball after collision with bridge. An articulated tanker carrying 18te of propane veered off the highway after the driver fell asleep. The tanker struck a bridge buttress. Propane escaped and ignited forming a 500m radius fireball. The fireball enveloped 4 vehicles killing 6 people.

Ref: MHIDAS

Bangkok, Thailand, 24 Sep 1990 – Fire following road accident. A flat bed truck had been adapted into a tanker using 2 pressure vessels designed for static use. The tanker was unlicensed and was carrying 1.5te of LPG. The driver was under the influence of alcohol and drugs and was speeding when the vehicle overturned in an accident. LPG was released from the tanks and ignited in a flash fire that destroyed 40 vehicles. The fire also spread to adjacent shops and buildings and a squatter camp. A total of 68 people died and over 100 were injured. 48 shops and 57 cars were destroyed.

Ref: HCB, Nov 90

Toronto, Canada, 8 Apr 1991 – Leak after collision with a bridge. A 45m3 propane road tanker tried to pass under a low bridge following a diversion around a road accident. The bridge was too low and sheared off the 2 PRVs. Propane jets 3m high were formed above each valve. Over 2000 residents were evacuated and a water curtain used to disperse the gas. The release was not ignited and there were no injuries.

Ref: HCB, Oct 91

Wandong, Victoria, Australia, 26 Jun 1991 – BLEVE of an LPG road tanker. The tanker was hit from behind in a road accident, causing a leak from the drain valve. The driver used his radio to warn on-coming traffic and stopped other vehicles and persuaded them to block the traffic. These actions ensured that when the BLEVE occurred, nobody was within range. There were no injuries or fatalities.

Ref: HCB, Oct 1991.

Agen, France, 25 Aug 1992 – Leak after road accident. An LPG road tanker was hit from behind in a road accident causing a rupture of the tankers pipework. $16m^3$ of LPG was released but no ignition occurred. Nearby residents were evacuated for 10 hours.

Ref: HCB, Nov 1992.

New York, USA, 27 Jul 1994 – Fireball after collision with bridge. A tanker carrying $35m^3$ of propane veered off the road and struck a bridge support column. The tank ruptured and caught fire. The main part of the tank was projected 100m and crushed 2 homes. The fireball set fire to 8 nearby homes. 23 people were injured.

Ref: HCB, Oct 1994.

Other incidents listed in MHIDAS for LPG are summarised in *Table 3.1* and in

Table 3.2 for the IchemE database. *Table 3.3* lists incidents specifically related to LPG cylinder vehicles.

Table 3.1 Worldwide Incidents with LPG Tankers

MHIDAS Ref	Date	Location	Accident Cause	Consequence	Fatalities	Injuries	Other Damage	Material
1815	22 Oct 1936	Crowley, Louisiana, USA	Butane leaked from snapped pipe connection	Flash fire	4			Butane
2517	18 Nov 1941	Hobart, Oklahoma, USA	Leak from pipe under truck by excessive vibration	Fire & explosion	0	4	1 house & 3 cars destroyed	Butane
1821	18 Jan 1943	Los Angeles, California, USA	Failure of bottom connection	Ignition of 400m diameter cloud	5			Butane
843	31 Mar 1944	Oklahoma City, USA	Leak from 1 of 4 tanks	BLEVE	5	21		Butane
1872	21 Nov 1944	Denison, Texas, USA	Excess flow valve damaged following collision	Ignition by water heater 60m away	10	Everyone within 90m		Butane
2569	23 Jun 1946	Louisiana, USA	Master valve between tank and pump left open	Jet fire 23m high	0	0		LPG
2570	12 Feb 1947	Hope, Arkansas, USA	Collision, rollover and damage to pipework	Fire	1	0		Butane
2571	13 Oct 1948	Sacramento, California, USA	Tanker was struck by a train	Fire	2	0	Train carriage burned	Butane
2572	13 mar 1949	Martinez, California, USA	Tanker overturned on road, breaking connection	Flash fire	0	0		Butane
1827	23 Aug 1950	Wray, Colorado, USA	Brake failure leading to rollover and damage to connection. Excess flow valve failed	Vapour ignited at nearby garage. Fire	2	3		Propane
2573	14 Jun 1951	San Fernando, California, USA	Tank ruptured following accident	Jet fire	1	0		Isobutane
1875	24 Jun 1952	Kansas City, USA	Vapour leak through PRV	Explosion	2			LPG
2120	14 Nov 1958	Los Angeles, USA	Tanker overturned and damaged instrument taping	Vapour cloud, no ignition	0	0		LPG
2635	22 Dec 1958	Brownfield, Texas, USA	Tanker rolled over followi9ng collision. PRVs torn off	Fire and BLEVE	4	160		Butane
2176	2 Jun 1959	Deer lake, Pennsylvania, USA	Collision	Fire and BLEVE after 45 min	11	10	Foliage burnt up to 150m away	LPG
2633	15 Dec 1960	Glen Loch, Pennsylvania, USA	Relief valve sheared off under low bridge	Ignition by passing train	0	0		LPG

MHIDAS Ref	Date	Location	Accident Cause	Consequence	Fatalities	Injuries	Other Damage	Material
2130	27 Apr 1961	Sidney, Nebraska, USA	Tanker overturned, breaking off valve	Ignition	0	1		LPG
825	25 Jul 1962	Berlin, New York, USA	Tanker collided with tree	Fire	10	17	Explosion in nearby houses	LPG
2124	31 Jul 1963	Memphis, Tennessee, USA	Hose broke during transit	Ignition by unknown source	1	1		LPG
2749	26 Feb 1965	Aylmer, Ontario, Canada	Collision caused crack between EFV and ball valve	Ignition by starter motor	0	2	7 buildings, 2 cars and 2 trucks destroyed	LPG
2223	15 Sep 1970	Hopkinton, Massachusetts, USA	Tanker ran off highway	Fire and BLEVE after 15min	1	0		LPG
HSC (1991)	23 Oct 1970	Hull, UK	Truck carrying static tank struck low bridge. Sheared off PRV	Flash fire (0.1 of 2te cargo)	2	0		Propane
590	9 mar 1972	Lynchburg, Virginia, USA	Tanker overturned and struck embankment causing 800mm tear	Fire	2	31		Propane
592	21 Sep 1972	New Jersey Turnpike, USA	Collision caused leak from pipework	Fire and BLEVE after 25 min	2	28		Propylene
1142	1 Feb 1973	St Amand-Les-Eaux France	Tanker overturned and ruptured	Jet fire and BLEVE after 15 min	6	37		Propane
1495	24 May 1973	Lynchburg, Virginia, USA	Tanker overturned and ruptured	Ignition after 2 min, fireball		7		LPG
118	Jan 1974	Florida, USA	Hose failure	Explosion	0	0	2 warehouses destroyed. Cars crushed with 4 block area	Propane
945	11 Jan 1974	Aberdeen, UK	PRV sheared off in accident	Immediate ignition & fireball		3		Butane
1797	6 Feb 1974	Albany, Georgia, USA	Tanker collision with train	Large fire	1	2		LPG
450	29 Apr 1975	Eagle Pass, Texas, USA	Semi-trailer overturned on highway	Fire	16	35	50 cars destroyed in used car facility	LPG
180	24 Jun 1976	Zaragoza, Spain	Gas seep from tanker	Ignition and explosion	>7	40	A warehouse and 2 workshops destroyed	Butane
2109	19 Aug 1976	Flint, Michigan, USA	Tanker ran off road and ruptured	Fire & explosion	1	7		LPG

MHIDAS Ref	Date	Location	Accident Cause	Consequence	Fatalities	Injuries	Other Damage	Material
1986	28 Dec 1977	Goldonna, Louisiana, USA	Collision with train caused tank rupture	Fireball	2	10		LPG
1999	11 Jul 1978	San Carlos, Spain	Tanker rupture due to overfilling & no PRV	Flash fire	217	67	Buildings destroyed	Propylene
2040	16 Jul 1978	Tula, Mexico City, Mexico	Tanker overturned and ruptured	Explosion & fire	10-15	>150		Butane
830	27 Jul 1979	Hayfield, Derbyshire, UK	Leak from overturned tanker	No ignition	0	0	Village evacuated	LPG
2303	10 Apr 1980	Pont A Mousson, France	Release after tanker crashed down embankment	No ignition	0	1	Neighbourhood evacuated	LPG
1728	2 May 1980	Patrington, Humberside, UK	Tanker overturned	Fire	1	0		Condensate
1981	7 Aug 1980	New York City, USA	Failure of PRV	No ignition	0	0	50km traffic jam	Propane
3264	20 Apr 1984	Westville, Indiana, USA	Tanker struck by train	Fireball	>2	6	12 railcars derailed	LPG
1025	13 Jun 1984	Salmon Arm, British Columbia, Canada	Tanker fell down embankment after collision	Explosion	1	23		Propane
3618	6 Sep 1985	Prince George's County, Maryland, USA	Tanker overturned & burst into flames	Fire			400 evacuated & road closed for 17 hours	Propane
1906	1 May 1986	Severna Park, Maryland, USA	Tanker overturned onto 2 petrol pumps. Leak from tanker's propane fuel tank, not cargo	Fire of petrol & propane. Flames 8m high	1	2	Fumes overcame person 800m away	Propane
2057	1 Jul 1986	Valley Falls, Kansas, USA	Collision with train	Explosion	3	2	13 train cars derailed	Propane
2593	16 Feb 1987	Winston-Salem, North Carolina, USA	Tanker crash	Fire	0	0	50 residents evacuated	LPG
2751	6 Apr 1987	Trenton, new Jersey, USA	Tanker overturned on highway	Explosion	0	7		LPG
3093	24 May 1988	Seaford, Long Island, USA	Tanker overturned after rear axle failed	Fire burned for 2 days	0		2000 people evacuated	LPG
3430	23 Dec 1988	Memphis, Tennessee, USA	Tanker accident & rupture	Fireball	9	4	Fire engulfed several other vehicles	Propane
3695	4 Apr 1989	Muswellbrook, NSW, Australia	Tanker leak from weld	No ignition	0	0		LPG

MHIDAS Ref	Date	Location	Accident Cause	Consequence	Fatalities	Injuries	Other Damage	Material
3884	25 Sep 1989	Aquidneck Island, Maryland, USA	Tanker struck low bridge and leaked	No ignition	0	0	Houses within 400m evacuated	Propane
4287	17 Oct 1989	Kangeroo Valley, Queensland, Australia	Tanker overturned on sharp bend	No ignition	0	0	Road closed	Condensate
4141	5 Jan 1990	Melbourne, Victoria, Australia	Leak from tanker	No ignition	0	0		Propane
4156	30 Jan 1990	Candasnos, Huesca, Spain	Tanker collided with bridge	No release	0	6		Propane
4127	24 Sep 1990	Bangkok, Thailand	Truck carrying 2 LPG tanks overturned	Fire	63	100	57 cars & 48 shops	LPG
4711	9 Mar 1991	Le Roy, new York, USA	Tanker overturned. No leak		0	0	Road closed for 10 hours	Propane
5411	29 Feb 1992	Greenwich, New Jersey, USA	Tanker struck train & overturned	No spill	0	0	60 homes evacuated	Propane
5465	3 Apr 1992	Warren, Vermont, USA	Tanker fell down steep embankment	No ignition	0	0	Residents evacuated	Butane
5651	23 Jul 1992	Muthill, Scotland, UK	Empty tanker collided with low archway. Sheared off PRV	No ignition	0	0		LPG
5931	27 Oct 1992	Sarnia, Ontario, Canada	Leak from packing gland nut of empty tanker	No ignition	0	0		LPG
5969	1 Dec 1992	Ankara, Turkey	Road traffic accident	Large fire and explosion	22			LPG
6003	29 Dec 1992	Port Coquitcam, British Columbia, Canada	Leak from valve	No ignition	0	0		LPG
6095	11 Mar 1993	Shakespeare, Ontario, Canada	Collision with train	No spill	0	0		LPG
1076	26 Feb 1993	Fakenham, Norfolk, UK	Empty tanker collision	No spill	0	0		Propane
12318	14 Jul 2003	Veldhoven, Netherlands	Cab of roadtanker caught fire following accident.	No spill	0	0	Offices within 500m evacuated as precaution	LPG
12513	13 Nov 2003	Bredbury, Cheshire, UK	LPG cargo was found to be leaking after roadtanker broke down on highway.		0	0	Road in both directions closed while leak repaired	LPG
12685	4 Feb 2004	Pune, India	Tanker exploded following accident and rollover	Explosion	3	15		LPG

Table 3.2 Road Tanker Incidents from the IchemE Database

IchemE Ref	Date	Location	Accident Cause	Consequence	Fatalities	Injuries	Other Damage	Material
9668	unknown	unknown	Hose leak on modified tanker. Leak was too small to activate excess flow valve	Fire	1	0		Propane
9666	unknown	unknown	Tank rupture during transit. Likely weld defects.	Explosion	10	17		Propane
50	11 June 1941	USA	8.7m³ tanker involved in collision.	Butane vapours covered large area. No ignition	0	0		Butane
185	12 Mar 1959	unknown	Operator error	BLEVE	0	0		Butane
1698	27 July 1978	Harton, Yorks, UK	1te cylinder broke lose after tank stuck on verge. Valve fractured and leaked	No ignition	0	0		Propane
1735	7 Sep 1978	Hartburn Bank, Stockton, UK	Tanker overturned but no release	None	0	0	Residents evacuated	Butane
1939	28 Dec 1979	Briton ferry, Wales, UK	Valve on tanker froze open	Vapour cloud. No ignition	0	0	Traffic stopped as precaution	Butane
2351	2 Jan 1982	Italy	Highway collision in foggy conditions leading to tanker explosion	Explosion	5	30		Propane
3272	1 Apr 1985	Dijon, France	Tanker crashed and caught fire	Fire	0	0		Propane
4367	30 Nov 1988	Elkridge, USA	Tanker overturned		0	0	Residents evacuated as precaution	Propane
4721	21 Sep 1989	Baltimore, USA	Leak from tanker wedged under bridge	Vapour release. No ignition	0	0	Residents evacuated	Propane
5300	8 Apr 1991	Toronto, Canada	2 PRVs sheared off when passing through underpass	Vapour release	0	0	2000 people evacuated	Propane
6646	27 Jul 1994	White Plains, New York, USA	Collision with bridge support. Leak ignited.	Explosion	1	23	10 houses destroyed	Propane
1224307	Mar 2000	Basingstoke, UK	Tanker hit by another vehicle after breaking down	20 out of 30 gas canisters exploded	1	1		Propane
1247317	Apr 2000	Fayette County, USA	Collision causing rollover	Vapour release	0	0	Residents evacuated as precaution	Propane

Table 3.3 Accidents with LPG Cylinder Wagons

Source	Date	Location	Description	Consequence	Fatalities	Injuries	Other Damage	Material
MHIDAS	7 Dec 1960	Nashua, New Hampshire, USA	Truck collided with train leading to cylinder ruptures	Fire	6	30		LPG
MHIDAS	7 May 1985	Pontypridd, West Glamorgan, UK	Truck carrying 102 cylinders exploded. The ensuing fire caused 12 cylinders to rupture.	Fire, BLEVE	0	0	Damage to supermarket	LPG
Fire Prevention Oct 1988	15 Feb 1987	Oldbury, UK	A portable boiler overturned and heated 3 LPG cylinders. 2 ruptured from the heat.	BLEVE	3	4		LPG
HCB	2 Nov 1987	Pine Grove, Pennsylvania, USA	Fire in truck caused propane cylinder to rupture	BLEVE	0	0		Propane
MHIDAS	22 Dec 1987	Exeter, UK	Collision caused truck to overturn. Several cylinders fractured	Vapour release	0	0		LPG
MHIDAS	21 Mar 1989	Maryborough, Queensland, Australia	Trailer carrying 190 cylinders involved in accident.	No ignition	6 (collision)			LPG
MHIDAS	20 Sep 1990	Blackwater, Queensland, Australia	Collision with train caused cylinder to rupture & explode.	Fireball	0	1		LPG
MHIDAS	14 Jun 1991	Patcham, UK	5 cylinders fell from a truck. 1 cylinder leaked but no ignition	Vapour release	0	0		LPG
MHIDAS	30 Sep 1992	Tsing Hhang Path, Tuen Mun, Hong Kong	Vandalism – setting fire to LPG truck while parked overnight	Multiple BLEVE	0	5 (during evacuation)	14 cars, 5 trucks, 3 taxis, buildings damaged	LPG

3.1.2 *LPG Storage Accidents*

New South Wales, Australia, 19 Sep 2001 – LPG bottles led to a series of explosions in an industrial estate. Firecrews responded and no injuries were reported.

Zambia, 1996 – Human error during special operations led to leak and explosion from an LPG storage tank. 5 fatalities and 3 injuries resulted.

Guangdong, China, 5 Aug 1993 – A fire and explosion at a warehouse spread to a storage tank at a nearby LPG storage depot. 15 fatalities and 160 injuries reported.

South Korea, 7 Jan 1993 – A fire detonated LPG storage tanks in basement of 4 storey apartment block and levelled the building. No injuries or fatalities.

Kuwait, 7 Dec 1987 – Act of sabotage led to a fire in an LPG storage depot. Fire fighting was effective and safety devices functioned, preventing escalation to the storage tanks. No injuries reported.

Mexico City, 18 Nov 1984 – A leak of LPG formed a vapour cloud which was ignited by a plant flare. A fierce fire developed engulfing the LPG spheres and bullets, with 4 spheres and many bullets failing one after the other in a series of BLEVEs. 50 (out of 54) vessels were destroyed. 540 people died, 7000 injured, 200,000 evacuated. A projectile hit and killed a person 1 km away.

Cleveland, UK, 1984 – A shrub fire spread to a chemical waste disposal site and caused a BLEVE of an LPG storage tank. No injuries or fatalities.

Rhode Island, USA, 6 Jun 1983 – 30 tanks of propane exploded at an LPG storage facility. 2 fire fighters injured.

Barking, Essex, UK, 21 Jan 1980 – Fire at a warehouse spread to LPG cylinder and numerous chemicals. 9 injured.

Turkey, 1979 – An LPG storage tank exploded at an oil refinery, showering a nearby town with flaming debris. 2 fatalities and 20 injuries reported.

Belgium, May 1979 – A release of LPG from a rail tanker resulted in an explosion at a railway station. The tanker is believed to have burst when the train arrived at the station. The dispersing vapour cloud reached 300m by 400m and was ignited by sparks from the overhead power lines when the train started to pull out of the station. The resulting explosion caused the tanker to rise 10m into the air and blew the manhole cover 100m. No injuries or fatalities were reported.

USA, 15 Sep 1977 – An LPG storage vessel was overfilled due to a faulty level gauge. The relief valve failed to open and the vessel ruptured. The resulting vapours ignited leading to fires and explosions involving 2 other vertical tanks and 4 horizontal bullet tanks. 2 fatalities reported.

Florida, USA, 6 Feb 1977 – A train derailed and crashed into a LPG cylinder store. The fire destroyed 9 cylinders. No injuries or fatalities.

Brazil, 30 March 1972 – An LPG tank constructed in 1961 was being filled with relatively high temperature LPG. The tank was fitted with only a single pressure relief valve and a single drain valve. Due to the temperature, the pressure within the tank rose rapidly above the safe working pressure but the relief valve failed to work. It was speculated that operators noticed the high pressure and opened the drain valve. LPG was released and the drain valve froze, preventing it from being closed. The gas spread and ignited, killing 37 people and inuring a further 37.

1972 – A high wall surrounding an LPG cylinder storage depot collapsed, crushing some 12 kg cylinders. A large quantity of gas escaped and ignited causing a fire. Three explosions occurred within the building and some cylinders exploded, scattering fragments over a distance of 100m. No injuries reported.

22 Oct 1971 – A butane sphere was overfilled due to a faulty level gauge. The pressure relief lifted and released liquid butane with formed a vapour cloud. Fortunately, the valve reseated and the vapour cloud was not ignited. No injuries were reported.

France, 4 Jan 1966 – An operator failed to follow procedures during the draining of water from an LPG sphere. The resulting vapour cloud spread until it reached a road and was ignited by a passing car. The fire spread back to the liquid pool that had formed within the bund, resulting in a BLEVE of the sphere. The incident escalated to cause a BLEVE of a neighbouring tank and rupture 3 other spheres. 21 fatalities and 52 injuries were reported.

California, USA, 1961 – During the draining of water from a horizontal LPG tank, a connection failed and released LPG through a 1” hole. The cloud was ignited within a minute resulting in a fire that caused the failure of all six storage tanks on site within 35 minutes, some failing violently. 2 injuries.

Kentucky, USA, Oct 1961 – A substandard installation of a 1,000 gallon LPG storage tank fell from its concrete block foundation. This damaged the outlet connection and produced a vapour cloud that spread over a large area. After 15 minutes, the cloud was ignited resulting in an explosion. No injuries or fatalities reported.

California, USA, 13 July 1954 – The driver of an LPG delivery tanker had filled his tanks from a storage tank and drove away without disconnecting the transfer and vent lines. LPG flooded the area and was ignited 10 minutes later. The flash fire caused secondary fires including one on top of the storage tank where the vapour connection had cracked. The storage tank eventually ruptured from the heat of the fire. 4 fatalities resulted from the flash fire.

USA, 27 Jan 1952 – A buried tank leaked into the surrounding earth through a threaded connection. The resulting fires and explosion damaged 216 buildings. Fortunately, occupancy was low and only 1 injury was reported.

Georgia, USA, 7 Oct 1950 – A transfer line between an LPG tanker and 1000 gall storage tank broke at the tank. The vapours were ignited. No injuries or fatalities.

USA, 25 April 1945 – Escaping vapours from a 100 tonne LPG storage tank ignited. The explosion shattered buildings and caused 5 fatalities.

3.2 *HAZARD IDENTIFICATION*

Based on the above review, the main hazard associated with an LPG facility is an uncontrolled release of LPG resulting in a fire or explosion upon ignition. There is also the potential for escalation of a fire event to cause a Boiling Liquid Expanding Vapour Explosion (BLEVE) of the LPG road tanker or the cylinders and this may produce fragments that can travel hundreds of metres. Connection/ disconnection errors and tanker drive away during unloading can also lead to leaks.

The initiating events leading to an LPG release could occur due to one of the following:

- Spontaneous failure of pressurised LPG equipment, i.e.:
  - Storage vessel failure;
  - Road tanker failure;
  - Pipework failure;
  - Hose failure;
  - Flange failure;
  - Valve leak; and
  - LPG cylinder failure.
- Loading failures, i.e. an LPG release that occurs as a direct result of the road tanker unloading operation.
  - Hose Failure;
  - connection/disconnection error (during tanker unloading);
  - Tanker drive away error;
  - Tanker impact;
  - Loading pipework overpressurisation; and
  - Storage tank overfilling/overpressurisation.
- External events, such as:
  - Earthquake;
  - Aircraft crash;
  - High wind loading;

  - External fire; and
  - Subsidence.

The following events could result from a release of LPG:

- Jet fire;
- Flash fire;
- Vapour Cloud Explosion (VCE);
- Fireball; and
- BLEVE

The likelihood or frequency of these events is discussed in *Section 4*.

Based on the considerations above, representative LPG release events considered in the assessment are as summarised in *Table 3.4*.

Rupture of vessels may result in fireballs, flash fires or vapour cloud explosions (VCE). Leaks may cause jet fires, flash fires or VCE, or may escalate leading to catastrophic failure of a vessel in a Boiling Liquid Expanding Vapour Explosion (BLEVE). BLEVE of the LPG Compound storage vessel is not considered possible since these are mounded tanks. BLEVE of road tankers and LPG cylinders is considered in the analysis however.

Leaks from all equipment are piping are taken to be 1" or 2", depending on the size of connections. Leaks from LPG cylinders are taken to be 1mm since anything larger would effectively lead to emptying of a cylinder in a matter of seconds and would essentially be the same as a rupture scenario.

VCE from LPG cylinders is not considered possible because of the very limited inventory in a cylinder. CCPS (1999) suggests that the minimum flammable mass required to allow transition from flash fire to VCE, based on experimental studies, is 100 kg. The inventory of all cylinders is less than this.

Additional risks potentially arise from the transit of petrol/diesel tankers through the site from the jetty. Petrol/diesel could be released from the tankers to form a liquid pool on the ground and a pool fire if ignited. These scenarios are included in the analysis.

Table 3.4 *Release Events Considered*

Equip. ID	Equipment Description	Event Description	Release Type	Hole Size	Potential Hazardous Event Outcomes*
1	Storage vessel	Catastrophic failure	Instantaneous	Rupture	Fireball, VCE, flash fire
		Partial failure	Continuous	1" leak	Jet fire, VCE, flash fire
2	LPG road tanker	Catastrophic failure	Instantaneous	Rupture	Fireball, VCE, flash fire
		Partial failure	Continuous	2" leak	Jet fire, VCE, flash fire, BLEVE
		Partial failure	Continuous	1" leak	Jet fire, VCE, flash fire, BLEVE
3	Filling line to storage vessel	Guillotine failure	Continuous	Pipe full bore	Jet fire, VCE, flash fire
		Partial failure	Continuous	1" leak	Jet fire, VCE, flash fire
4	Flexible hose	Guillotine failure	Continuous	Hose full bore	Jet fire, VCE, flash fire
		Partial failure	Continuous	1" leak	Jet fire, VCE, flash fire
5	Line from storage vessel to vaporizers	Guillotine failure	Continuous	Pipe full bore	Jet fire, VCE, flash fire
		Partial failure	Continuous	1" leak	Jet fire, VCE, flash fire
6	Vaporizer	Guillotine failure	Continuous	Pipe full bore	Jet fire, VCE, flash fire
7	Send-out piping downstream of vaporizers	Guillotine failure	Continuous	Pipe full bore	Jet fire, VCE, flash fire
		Partial failure	Continuous	1" leak	Jet fire, VCE, flash fire
8	LPG cylinder	Catastrophic failure	Instantaneous	Rupture	Fireball, flash fire
		Partial failure	Continuous	1mm leak	Jet fire, flash fire, BLEVE
9	Petrol/diesel road tanker	Catastrophic failure	Instantaneous	Rupture	Pool fire
		Partial failure	Continuous	1" leak	Pool fire

4.1 BASE EVENT FREQUENCIES

The previous HATS study (ENSR, 2008) performed a detailed Fault Tree Analysis (FTA) to assess the frequency of each failure listed in *Table 3.4*. This included consideration of causes such as spontaneous failures, overfilling, truck collisions, connection/disconnection errors etc. and took credit for safety systems such as operator intervention, check valves, excess flow valves, pressure relief valves etc. The frequencies reported for this FTA were checked and found to be broadly consistent with those of previously approved studies in Hong Kong (for example, Maunsell 2006, ERM 2003, 2008). For conciseness, the FTA analysis has not been repeated here, since the frequencies have been largely adopted unaltered. Minor changes were made to scale frequencies to reflect updated information provided by the depot operators (Shell, 2009):

- Failure rates for LPG road tankers were increased to allow for 3 tanker deliveries per day instead of 2;
- Failure rates for LPG cylinders on wagons have been increased to allow for 3 wagon deliveries per day instead of 2. Also, the parking of 5 cylinder wagons on site overnight has been taken into account in the frequency calculations;
- Failure rates for 5 loaded bulk tankers (assumed to be three 20-tonne petrol tankers and two 20-tonne diesel tankers) have been included, and
- The number of cylinders in the Transit Depot has increased from 2000 to 2200. These cylinders have been further divided as 25% at 49kg and 75% at 13.5kg to reflect the actual size distribution (*Table 2.2*);

Base event frequencies adopted in this study are summarised in *Table 4.1* and *Table 4.2* for the LPG Compound and LPG Transit Depot respectively.

Table 4.1 ***Base Event Frequencies for the LPG Compound***

Event Description	Failure Rate (per year)
Cold catastrophic failure of storage vessel	6.72×10^{-7}
Cold partial failure of storage vessel	1.17×10^{-5}
Cold catastrophic failure of road tanker	1.48×10^{-7}
Cold partial failure of road tanker	3.62×10^{-7}
Rupture of filling line to storage vessel	5.14×10^{-7}
Leak of filling line to storage vessel	7.69×10^{-7}
Rupture of flexible hose	3.82×10^{-5}
Leak of flexible hose	3.92×10^{-5}
Rupture of line from storage vessel to vaporizers	4.00×10^{-6}
Leak of line from storage vessel to vaporizers	1.30×10^{-5}
Rupture of vaporizer	3.64×10^{-8}
Rupture of send-out piping downstream of vaporizers	4.00×10^{-6}
Leak of send-out piping downstream of vaporizers	1.30×10^{-5}
Rupture of LPG cylinder in storage shed	2.20×10^{-3}
Leak of LPG cylinder in storage shed	5.72×10^{-3}

Table 4.2 ***Base Event Frequencies for the Transit Depot***

Event Description	Failure Rate (per year)
Road Tanker / Cylinder Wagon Transport Events	
Cold rupture of road tanker	5.69×10^{-7}
Large liquid release from road tanker	3.94×10^{-6}
Large vapour release from road tanker	4.60×10^{-7}
Medium liquid release from road tanker	1.49×10^{-6}
Rupture of LPG cylinder on wagon	6.13×10^{-6}
Cold rupture of petrol tanker[1]	1.25×10^{-7}
Liquid release due to leak from petrol tanker[1]	3.13×10^{-7}
Cold rupture of diesel tanker[1]	8.33×10^{-8}
Liquid release due to leak from diesel tanker[1]	2.08×10^{-7}
Road Tanker/Cylinder Wagon Stationary Events	
Cold rupture of road tanker	2.08×10^{-9}
Large liquid release from road tanker	1.88×10^{-9}
Large vapour release from road tanker	1.88×10^{-9}
Medium liquid release from road tanker	1.88×10^{-9}
Rupture of LPG cylinder on wagon	3.54×10^{-7}
Rupture of LPG cylinder on wagon while parked overnight[2]	1.70×10^{-5}

- (1) Frequency calculated based on failure rate of 5×10^{-6} per tanker-year for a 1" leak, 2×10^{-6} per tanker-year for rupture (Crossthwaite, Fitzpatrick, and Hurst, 1988) and presence time of half an hour for each tanker.
- (2) Frequency calculated based on failure rate of 6.8×10^{-6} per vehicle-year, for 5 wagons parked overnight for 12 hours per day.

It may be noted that, following the HATS methodology, scenarios involving LPG cylinders are grouped with the LPG Compound (*Table 4.1*) to represent effectively the static facilities. LPG tankers during unloading are also included in *Table 4.1*. Events involving tankers and cylinder wagons during transit or parking outside the storage shed are listed under the Transit Depot (*Table 4.2*). Separate risk results are shown in *Section 6* for the Compound and Transit depot, in addition to results for the overall risks.

4.2 EVENT TREE ANALYSIS

Event tree analysis (ETA) is used to model the evolution of an event from the initial release through to the final outcome such as jet fire, fireball, flash fire etc. This may depend on factors such as whether immediate or delayed ignition occurs, or whether there is sufficient congestion to cause a vapour cloud explosion.

4.2.1 *Storage Vessel Scenarios*

The event tree for rupture of a storage vessel is shown in *Figure 4.1*. Immediate ignition is assigned a probability of 0.3 for large releases following Cox, Lees and Ang (Lees, 1996), see *Table 4.3*. Immediate ignition results in a fireball.

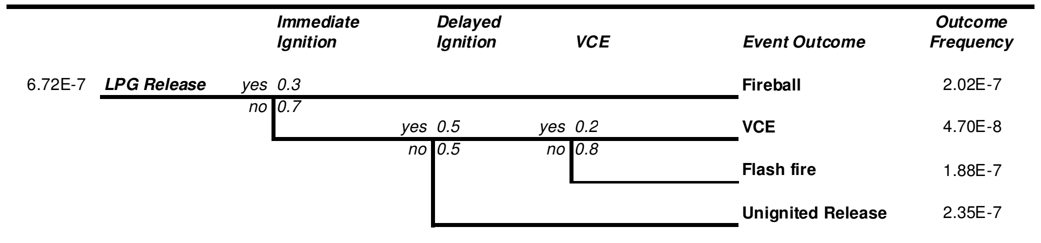
Table 4.3 *Ignition Probabilities from Cox, Lees and Ang*

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

Delayed ignition is assigned a probability of 0.5 (ENSR, 2008).

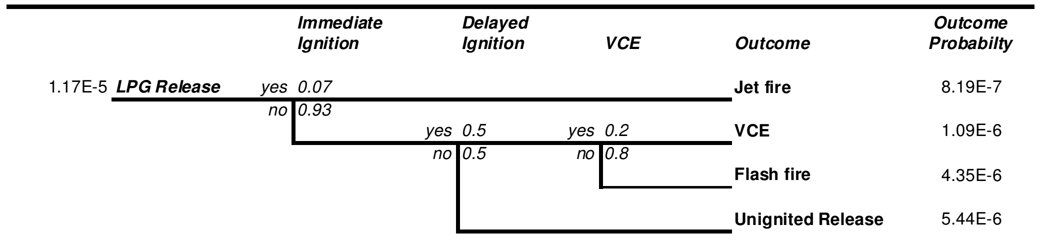
Delayed ignition may produce a flash fire or vapour cloud explosion (VCE). To achieve a VCE, a dispersing vapour cloud must accumulate in a confined and/or congested area and subsequently be ignited. Given the fairly open nature of the surroundings, an explosion probability of 0.2 was assumed.

Figure 4.1 *Event Tree for Catastrophic Rupture of Storage Vessel*



For smaller leaks, a lower immediate ignition probability of 0.07 is applied from *Table 4.3*. In other aspects, the event tree (*Figure 4.2*) is similar. Immediate ignition results in a jet fire, while delayed ignition may produce a flash fire or VCE.

Figure 4.2 *Event Tree for Partial Failure of Storage Vessel*



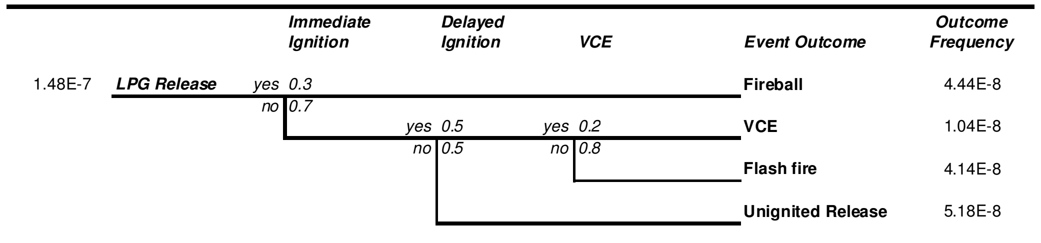
4.2.2 *Road Tanker Scenarios*

The event tree for catastrophic failure of an LPG road tanker is identical to that for the storage vessel (*Figure 4.1*), except for a different base frequency (see *Figure 4.3*).

Partial failure of a road tanker is similar to the leak case for a storage vessel except that the possibility of flame impinging on the tanker and escalation to a BLEVE is also considered in the event tree (*Figure 4.4*). The probability of flame impingement is estimated at 1/6 (ERM, 2003). Credit is also taken for the passive fire protection (Chartek) coating on the road tankers, and time for

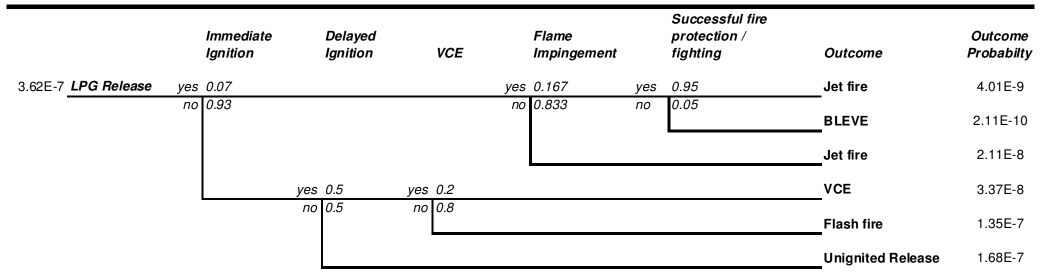
emergency services to take action before a BLEVE occurs. The probability that Chartek will fail to prevent hot spots forming and leading to failure is assigned as 0.1 (Maunsell, 2006), and the probability that fire Services will be ineffective in preventing a BLEVE is assigned as 0.5 (Maunsell, 2006).

Figure 4.3 *Event Tree for Catastrophic Rupture of LPG Road Tanker*



Event tree applies to failure of road tanker in LPG Compound. Event trees for road tankers in the Transit Depot are similar except for the different base frequency (*Table 4.2*)

Figure 4.4 *Event Tree for Partial Failure of LPG Road Tanker*

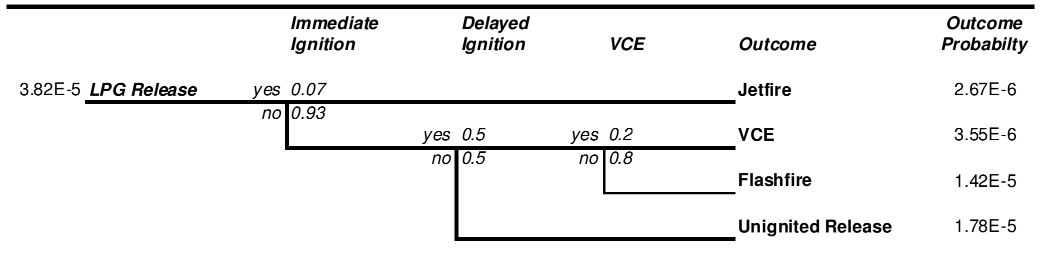


Event tree applies to failure of road tanker in LPG Compound. Event trees for road tankers in the Transit Depot are similar except for the different base frequency (*Table 4.2*)

4.2.3 *Hose and Piping Scenarios*

The event trees for leaks and ruptures of hoses, piping and vaporizers are essentially similar, except for different base frequencies. The event tree for a hose rupture is shown in *Figure 4.5*.

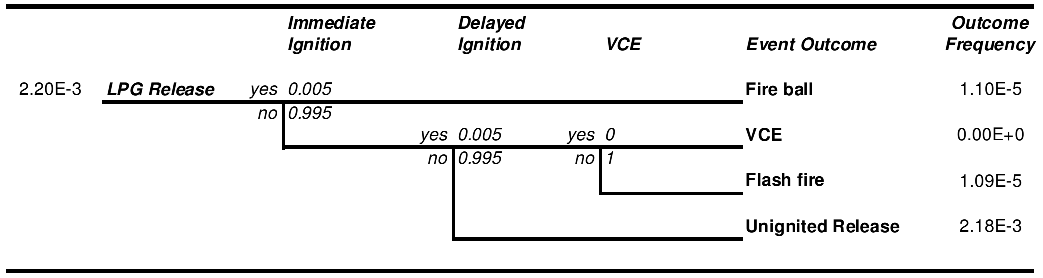
Figure 4.5 *Event Tree for Hose Rupture*



4.2.4 *LPG Cylinder Scenarios*

The event tree for cylinder rupture is shown in *Figure 4.6*. Immediate ignition results in a fireball while delayed ignition gives a flash fire. VCE is assigned a probability of zero since the inventory in a cylinder is too small to cause a VCE.

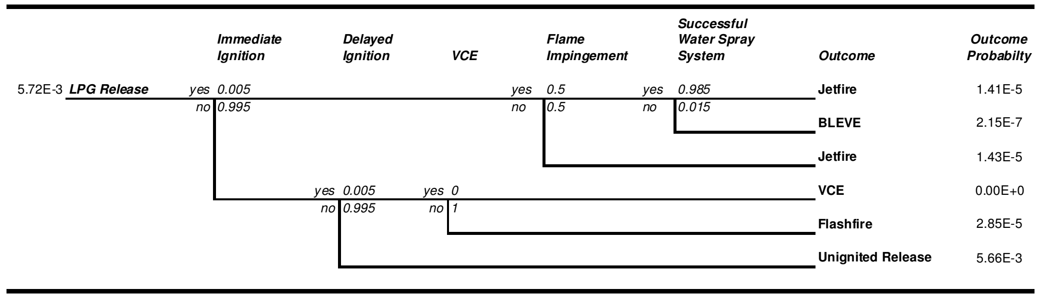
Figure 4.6 *Event Tree for LPG Cylinder Rupture*



Event tree applies to failure of cylinders in storage shed. Event trees for cylinders on wagons are similar except for the different base frequency (*Table 4.2*).

For leaks from a cylinder, the probability of impinging on a neighbouring cylinder is taken to be 0.5. This is a rather high probability to reflect that cylinders are stored in stacks. To escalate to a BLEVE, however, would require fire protection systems (gas detectors and water sprinklers) to fail which has been assigned a probability of 0.015 (Maunsell, 2006).

Figure 4.7 *Event Tree for LPG Cylinder Leak*



Event tree applies to failure of cylinders in storage shed. Event trees for cylinders on wagons are similar except for the different base frequency (*Table 4.2*).

4.2.5 *Transit Depot Scenarios*

The event trees for the LPG release at the Transit Depot are essentially similar to those for the bulk compound except for the different base frequencies (see *Table 4.2*).

Petrol/Diesel Tanker Scenarios

The event tree for petrol tankers is shown in *Figures 4.8*. Ignition probabilities are adopted from the values for liquids in *Table 4.3*, namely 0.08 for ruptures and 0.03 for leaks. Ignition of a spill will lead to a pool fire. The event tree for diesel tankers is shown in *Figure 4.9*. Given the high flash point of diesel, it is relatively more difficult to ignite. Diesel is actually classified as combustible rather than flammable. As such, a lower ignition probability is appropriate and a values ten times lower is assumed in the analysis.

Figure 4.8 *Event Tree for Petrol Tankers*

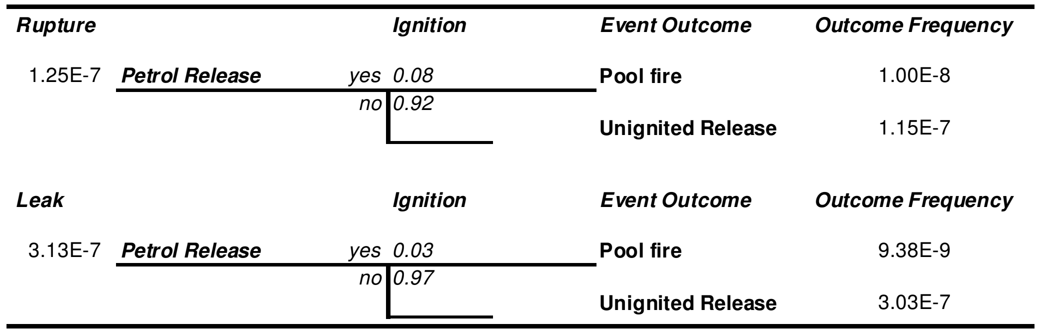
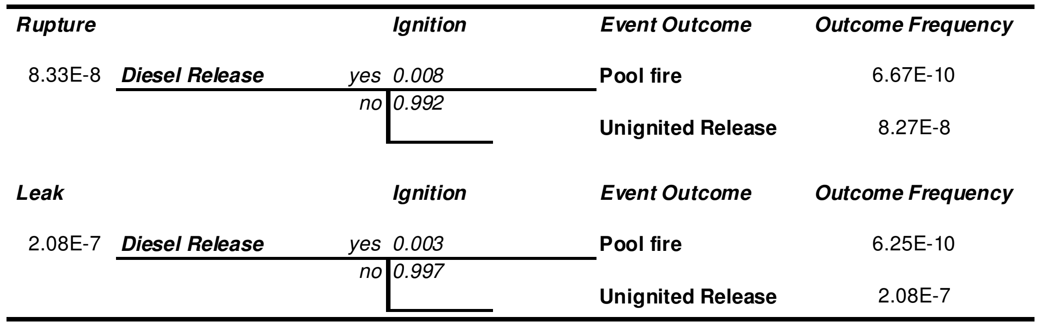


Figure 4.9 *Event Tree for Diesel Tankers*



4.3 PROJECTILES

Rupture of an LPG cylinder, due either to spontaneous failure or a BLEVE, may produce fragments that can cause fatal injuries hundreds of metres away. This is discussed further in this section.

4.3.1 *Cylinder Rupture Frequency*

Rupture of an LPG cylinder may be caused by spontaneous failures (material defects, overpressurisation, external damage etc. or by engulfment in a fire leading to a BLEVE.

Spontaneous failure of a cylinder is assigned a frequency of 1×10^{-6} per cylinder-year (Purple Book; ENSR, 2008). With 2200 cylinders in the store on average, the spontaneous rupture frequency is estimated at 2.2×10^{-3} per year.

An event tree for escalation of leaks to cause a major fire and multiple BLEVEs was shown in *Figure 4.7*. A cylinder leak frequency of 2.6×10^{-6} per cylinder-year (ENSR, 2008) is applied, which amounts to 5.72×10^{-3} per year for 2200 cylinders. An immediate ignition probability of 0.005 is used, based on ignition probabilities for small leaks from *Table 4.3*, assuming an even split between immediate and delayed ignition. If a leak is ignited, a jet fire will result. This will need to impinge directly on a neighbouring cylinder in order for the event to escalate (either by causing that cylinder to fail in a BLEVE or by causing its safety valve to open and add more fuel to the fire). Given that cylinders are stored in stacks, a relatively high flame impingement probability of 0.5 is assumed. The storage shed is equipped with gas detectors and automatic sprinkler systems. These would need to fail for the event to escalate to a major fire. The probability of failure of the fire protection system is taken as 0.015 (Maunsell, 2006). This gives an overall frequency of major fire of 2.15×10^{-7} per year.

A major fire could lead to multiple, sequential BLEVEs. LPG cylinders, however, are fitted with safety valves to release the gas in case of overpressurisation. Not all cylinders will fail in a BLEVE. Conservatively assuming that 10% of cylinders will fail in a BLEVE gives 220 BLEVE events with a frequency of 2.2×10^{-7} per year. This is equivalent to one BLEVE with a frequency of 4.8×10^{-5} per year. This is small compared to the spontaneous failure rate, suggesting a total rupture frequency of 2.2×10^{-3} per year.

Number of Fragments

Brittle failure of LPG storage tanks have been known to produce up to 30 fragments in a catastrophic failure. However, brittle failures are not relevant to the current study since they generally occur under low temperatures. For ductile failures, Baum (1988) has reported that less than five projectiles will be produced. Holden and Reeves (1985) report that there is an 80% chance that a rupture will produce fragments and there will be 2 to 4 fragments for each failure. Most scenarios involve the valve being ejected so that there are 2 fragments (the valve and the cylinder). Assuming that 90% of incidents produce 2 fragments, 10% of incidents produce 5 fragments and only 80% of incidents produce any fragments, the average number of fragments may be estimated as 0.8×(0.9×2 + 0.1×5) = 2.

Cylinders are stored in stacks so that fragments produced from failure of inner cylinders are likely shielded by the outer cylinders. It is assumed that 50% of fragments will escape the stack and launch as a projectile (ENSR, 2008).

Fragment Range

In order to determine the range of the fragment, the initial velocity of the fragment must be determined. Range can then be found by solving equations for trajectory motion, allowing for the effects of drag.

Several models have been proposed to estimate the initial velocity of a fragment. The Brode and Baum models are described by Lees (1996) and the Center for Chemical Process Safety (CCPS, 1999) and were applied in this study.

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

$$E_k = \frac{k p_1 V}{\gamma - 1}$$

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

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

where

v_i = initial fragment velocity (m/s)

E_k = kinetic energy (J)

M = total mass of the empty cylinder (kg)

k = fraction of internal energy converted to fragment kinetic energy

p_1 = absolute pressure in cylinder (Pa)

p_o = ambient pressure (Pa)

V = volume of the vessel (m^3)

γ = ratio of specific heats of the gas

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

Baum developed empirical correlations for the initial velocity for an end cap breaking away from a cylindrical vessel, a cylindrical vessel breaking into two parts, and a single small fragment ejected from the vessel. As an example, the model for a single small fragment is presented in the equations below. The model for end cap and cylinder breaking into 2 parts are similar.

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

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

$$v_i = 2a_o\left(\frac{Fs}{r}\right)^{0.5}$$

where

F = parameter for calculation of initial velocity

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

r = radius of the vessel

M_f = mass of fragment (kg)

a_o = speed of sound (m/s)

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

R = ideal gas constant (J/kmol-K)

m = molecular mass of cylinder contents (kg/kmol)

s = dimension of the fragment

With the initial velocities known, the maximum range can be estimated by solving the equations of motion. Baker et al. solved these computationally, incorporating drag effects, and presented the results graphically (Lees, 1996).

Applying the above models to LPG cylinders gives the results presented in *Table 4.4*. It can be seen that there is some variation in the predictions but a maximum range of about 350m is predicted which is consistent with most past incident reports.

Summary of assumptions used in the model:

- LPG composition is 30% propane, 70% butane
- Failure pressure of cylinder is taken as 1.21 times the design pressure (CCPS, 1996)
- Cylinder design pressure is 1.86 Mpa (Shell, 2009)
- The temperature of the gas at failure is taken to be 120°C (Stawczyk, 2003)
- Drag coefficient for a spherical fragment = 0.47 (CCPS, 1996).
- Empty cylinder mass is 10 kg and 30 kg for the 13.5 and 49 kg capacity cylinders
- Cylinder volume is 30.5 L and 110 L respectively.

Table 4.4 Fragment Range

				Brode		Baum	
Cylinder Type	**Fragment Case**	**Fragment Mass (kg)**	**Surface Area of Fragment (m^2)**	**Initial Velocity (m/s^2)**	**Maximum Range (m)**	**Initial Velocity (m/s^2)**	**Maximum Range (m)**
13.5 kg	end cap	2.05	0.087	127	154	252	230
13.5 kg	valve	0.5	0.012	127	270	173	352
13.5 kg	split	5	0.37	127	111	170	131
49 kg	end cap	2.05	0.087	140	165	252	230
49 kg	valve	0.5	0.012	140	287	173	352
49 kg	split	15	0.77	140	143	193	185

Many past incidents and experiments have been documented in the literature. Baker et al. reported 20 events that he classified into 6 event groups (Lees, 1996). The most relevant data is for cylindrical vessels containing 512 kg of propane gas, for which 98% of the fragments had a range of less than 500 m.

Another study by Holden and Reeves reviewed 27 events involving cylindrical vessels (Lees, 1996). The events are classified into 2 groups; vessels above 90 m^3 and vessels below 90 m^3. It was reported that 80% of the fragments travelled less than 200 m and that fragment ranges are much less than the maximum range from theoretical estimates. Also, it was found that smaller vessels projected fragments further. In contrast to Holden and Reeves, Birk (1996) suggested that smaller vessels produce lower projectile ranges.

Stawczyk (2003) found that the maximum range for 11 kg LPG cylinders is 300 m. This is perhaps the most relevant study since the size and contents of the cylinders are very close to that used in the Shell Depot. The maximum range of 300m is consistent with the predictions in *Table 4.4*.

The study of Baker et al. also provides information on the fragment range distribution, rather than simply the maximum fragment range. Although this study assessed data from larger storage vessels and gives a maximum range of 500m, it is conservatively applied in this study for lack of more relevant data. The distribution in fragment range is summarised in *Table 4.5*.

Table 4.5 Distribution of Fragment Range

Range	**0-100 m**	**100-200 m**	**200-300 m**	**300-400 m**	**400-500 m**
Probability	0.54	0.30	0.10	0.04	0.02

Shielding Factors

Most of the buildings in South Horizons are partly shielded by three residential blocks, numbers 21, 22 and 23. These blocks are 70m from the storage depot and are 110m tall, so all projectiles launched with a takeoff angle of less than 58° will strike these nearest residential blocks. To travel over these buildings and fall on areas behind would require an initial launch angle of between 58 and 90°. It is therefore assumed that 36% of fragments will have this launch angle. The exposure factor for buildings and open areas lying behind the front row of residential blocks is therefore estimated at 0.36.

With reference to *Figure 4.10*, buildings with direct line-of-sight (shaded blue) are assigned an exposure factor of 1 (no shielding). Buildings highlighted in green are shielded and assigned an exposure factor of 0.36.

Buildings shown in gray are considered to be totally shielded by virtue of either being short buildings in the shadow of a tall building, or because they are located tightly behind another building. In either case, any fragments that impact these buildings will simply fall on the roof and have no impact on the occupants.

Figure 4.10 ***Shielding Factors***

Populated buildings/areas with direct line-of-sight to LPG depot

Partly shielded buildings/areas

Fully shielded buildings/areas

No shielding was applied to road and pedestrian population on Lee Nam Road, although the LPG Depot perimeter wall is about 2m tall and may provide some protection.

The analysis also neglects any shielding effects from the storage shed roof. This is a corrugated iron structure and is assumed to provide little protection.

Target Area

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

The probability of a building being hit is estimated from the solid angle subtended by the building compared to the solid angle of a hemisphere (2π), taking into account the exposure (shielding) factor and the fraction of fragments that have sufficient range to reach the building (*Table 4.6*). Rupture fragments will not have sufficient energy to penetrate the concrete walls of residential buildings in Hong Kong, such that a person can only be hurt if the

fragment flies through a window. The ratio of window area to total wall area of the building in South Horizons is about 50% (Centamap, 2009).

The probability of a person being struck by a fragment is therefore calculated based on:

- The probability that the building will be hit, based on solid angles, shielding factor and the fraction of fragments that have sufficient range to reach the building;
- A probability of 0.5 that a fragment will pass through a window;
- A persons target area of $0.3m^2$;
- The number of persons in a building estimated from number of units facing the LPG Depot and assuming 3 persons per unit; and
- A time average occupancy of 66% (from *Table 2.4*);

Calculations for outdoor population are a little more straightforward. The probability of a target being struck is calculation from the target area, fraction of fragments that have sufficient range to reach the target and the shielding (exposure) factors.

The results of this analysis are summarised in *Table 4.6*. It can be seen that for each projectile emanating from the LPG Depot, the probability of a person being struck and fatally injured is about 2×10^{-3}. This includes the construction phase population for MTR and PTW.

Table 4.6 ***Summary of Cylinder Projectile Analysis***

Area/Building	Exposure Factor	Probability of Area/Building being Hit	Probability of a Person being Hit
South Horizons Block 13A	0.36	1.30E-04	1.04E-06
South Horizons Block 15	0.36	4.33E-04	3.25E-06
South Horizons Block 16	1	1.56E-03	1.15E-05
South Horizons Block 17	0.36	2.75E-03	2.51E-05
South Horizons Block 18	0.36	2.99E-03	3.11E-05
South Horizons Block 19	0.36	3.31E-03	3.60E-05
South Horizons Block 20	0.36	3.33E-03	3.55E-05
South Horizons Block 21	1	4.75E-02	4.05E-04
South Horizons Block 22	1	5.65E-02	5.64E-04
South Horizons Block 23	1	4.65E-02	4.07E-04
South Horizons Block 23A	0.36	6.21E-03	4.80E-05
South Horizons Block 29	0.36	8.54E-05	6.41E-07
South Horizons Block 30	0.36	8.64E-05	7.29E-07
South Horizons Block 33A	0.36	1.63E-03	1.33E-05
Horizon Plaza	1	4.99E-05	3.46E-06
Dah Chong Hong	1	4.92E-05	6.61E-07
Outdoor Population (0 to 100 m)	1	3.41E-02	7.01E-05
Outdoor Population (100 to 200 m)	0.36	1.04E-02	1.17E-04
Outdoor Population (200 to 300 m)	0.36	2.00E-03	2.25E-05
Outdoor Population (300 to 400 m)	0.36	1.35E-03	1.51E-05
Outdoor Population (400 to 500 m)	0.36	3.29E-04	3.70E-06
Ap Lei Chau PTW	1	9.56E-03	2.86E-06
Driving School	1	4.40E-04	5.31E-07
Maine Population	1	4.00E-01	1.91E-06

Area/Building	Exposure Factor	Probability of Area/Building being Hit	Probability of a Person being Hit
MTR Works Site A	1	3.63E-03	3.18E-05
MTR Works Site B	1	1.79E-03	1.59E-05
MTR Works Site C	1	2.13E-04	3.98E-06
MTR Works Site W2	1	2.17E-04	1.06E-06
		Total	**1.87E-03**

Summary of Projectile Analysis

The frequency of cylinder ruptures was estimated at 2.2×10^{-3} per year. Each rupture was estimated to produce 2 fragments on average, but 50% of these will be trapped within cylinder stacks. This gives a frequency for fragments leaving the LPG Depot of 2.2×10^{-3} per year.

The probability that a fragment will cause a fatality was estimated at 1.87×10^{-3}. This is likely conservative since the analysis assumes all projectile impacts on a person will lead to a fatality. Combining the fragment frequency of 2.2×10^{-3} per year with the probability of 1.87×10^{-3} that a fragment will lead to fatality gives a projectile fatality rate of 4.1×10^{-6} per year.

A single point is therefore added to the FN curves at N=1 and F=4.1×10^{-6}.

4.4 SUMMARY

The frequencies of hazardous outcomes assessed in this study are summarised in *Table 4.7* and *Table 4.8*.

Table 4.7 Event Outcome Frequencies for the LPG Compound

Equip. ID	Equipment Description	Event Description	Outcome	Outcome Frequency (per year)
1	Storage vessel	Rupture	Fireball	2.02×10^{-7}
			VCE	4.70×10^{-8}
			Flash fire	1.88×10^{-7}
		Leak	Jet fire	8.19×10^{-7}
			VCE	1.09×10^{-7}
			Flash fire	4.35×10^{-6}
2	Road tanker	Rupture	Fireball	4.44×10^{-8}
			VCE	1.04×10^{-8}
			Flash Fire	4.14×10^{-8}
		Leak	Jet fire	2.51×10^{-8}
			VCE	3.37×10^{-8}
			Flash fire	1.35×10^{-7}
		Escalation events	BLEVE	2.11×10^{-10}
3	Filling line to storage vessel	Full bore rupture	Jet fire	3.60×10^{-8}
			VCE	4.78×10^{-8}
			Flash fire	1.91×10^{-7}
		Leak	Jet fire	5.33×10^{-8}
			VCE	7.15×10^{-8}
			Flash fire	2.86×10^{-7}
4	Flexible hose	Full bore rupture	Jet fire	2.67×10^{-6}
			VCE	3.55×10^{-6}
			Flash fire	1.42×10^{-5}
		Leak	Jet fire	2.74×10^{-6}
			VCE	3.65×10^{-6}
			Flash fire	1.46×10^{-5}
5	Line from storage vessel to vaporisers	Full bore rupture	Jet fire	2.80×10^{-7}
			VCE	3.72×10^{-7}
			Flash fire	1.49×10^{-6}
		Leak	Jet fire	9.10×10^{-7}
			VCE	1.21×10^{-6}
			Flash fire	4.84×10^{-6}
6	Vaporisers	Full bore rupture	Jet fire	2.55×10^{-9}
			VCE	3.39×10^{-9}
			Flash fire	1.35×10^{-8}
7	Send-out piping downstream of vaporisers	Full bore rupture	Jet fire	2.80×10^{-7}
			VCE	3.72×10^{-7}
			Flash fire	1.49×10^{-6}
		Leak	Jet fire	9.10×10^{-7}
			VCE	1.21×10^{-6}
			Flash fire	4.84×10^{-6}
8	LPG Cylinder *	Rupture	Fireball	1.10×10^{-5}
			Flash fire	1.09×10^{-5}
		Leak	Jet fire	2.84×10^{-5}
			Flash fire	2.85×10^{-5}
		Escalation events	BLEVE	2.15×10^{-7}

* 25% of cylinders are assumed to be 13.5kg and 75% are 49kg (see *Table 2.2*). Outcome frequencies are assigned proportionally

Table 4.8 Event Outcome Frequencies for the Transit Depot

Equipment Description	Event Description	Outcome	Outcome Frequency (per year)
Road Tanker/Cylinder Wagon Transport Events			
Road tanker	Rupture	Fireball	1.71×10^{-7}
		VCE	3.98×10^{-8}
		Flash Fire	1.59×10^{-7}
	Large liquid leak	Jet fire	2.74×10^{-7}
		VCE	3.66×10^{-7}
		Flash fire	1.47×10^{-6}
	Large vapour leak	Jet fire	3.22×10^{-8}
		VCE	4.28×10^{-8}
		Flash fire	1.71×10^{-7}
	Medium liquid leak	Jet fire	1.03×10^{-7}
		VCE	1.39×10^{-7}
		Flash fire	5.54×10^{-7}
	Escalation events	BLEVE	3.17×10^{-9}
Cylinder wagons *	Rupture	Fireball	3.07×10^{-8}
		Flash fire	3.05×10^{-8}

Equipment Description	Event Description	Outcome	Outcome Frequency (per year)
Petrol tankers	Rupture	Pool fire	1.00×10^{-8}
	Liquid leak	Pool fire	9.38×10^{-9}
Diesel tankers	Rupture	Pool fire	6.67×10^{-10}
	Liquid leak	Pool fire	6.25×10^{-10}
Road Tanker/Cylinder Wagon Stationary Events			
Road tanker	Rupture	Fireball	6.24×10^{-10}
		VCE	1.46×10^{-10}
		Flash fire	5.82×10^{-10}
	Large liquid leak	Jet fire	1.31×10^{-10}
		VCE	1.75×10^{-10}
		Flash fire	6.99×10^{-10}
	Large vapour leak	Jet fire	1.32×10^{-10}
		VCE	1.75×10^{-10}
		Flash fire	6.99×10^{-10}
	Medium liquid leak	Jet fire	1.31×10^{-10}
		VCE	1.75×10^{-10}
		Flash fire	6.99×10^{-10}
	Escalation events	BLEVE	2.20×10^{-12}
Cylinder wagon *	Rupture	Fireball	1.77×10^{-9}
		Flash fire	1.76×10^{-9}
Cylinder wagon whilst parked overnight *	Rupture	Fireball	8.50×10^{-8}
		Flash fire	8.46×10^{-8}

* 25% of cylinders are assumed to be 13.5kg and 75% are 49kg (see *Table 2.2*). Outcome frequencies are assigned proportionally

5 CONSEQUENCE ANALYSIS

5.1 OVERVIEW

Consequence analysis comprises of:

- Source term modelling;
- Physical effects modelling to determine the effects zone of the various hazardous outcomes such as jet fires and fireballs; and
- Assessment of the impact on the exposed population.

In this study, consequence analysis is performed using the PHAST suite of models, developed by DNV.

5.2 SOURCE TERM MODELLING

A source term is the information required by gas dispersion, fireball, vapour cloud explosion or other consequence models to describe the discharge rate and quantity of hazardous substance to be considered. Standard orifice type calculations are used to determine the rate of discharge, based on conditions of pressure, temperature and phase of material. Duration of discharge is determined from inventory and release rate.

LPG in Hong Kong is a mixture of 70% butane and 30% propane. Vessels are conservatively assumed to be full at time of failure; 17 tonnes for each storage vessel and 9 tonnes for an LPG road tanker.

LPG cylinders stored in the Transit Depot are refined into two groups, 25% at 49 kg and 75% at 13.5 kg (see *Table 2.2*). It is assumed that LPG cylinders loaded on wagons have the same size distribution.

LPG is stored in liquid form by pressurisation to moderate pressures of about 4 to 5 barg, depending on ambient temperature. A significant portion of LPG flashes upon release, forming a vapour cloud. Liquid droplets may be entrained with the vapour or rainout to the ground forming a liquid pool. In the current study, pool fires were not found to be significant compared to jet fires. The more serious jet fire consequences were therefore used in the analysis.

5.3 PHYSICAL EFFECTS MODELLING

PHAST is used for the modelling of:

- Fireballs;
- BLEVEs;
- Jet fires;
- Pool fires

- Gas dispersion and flash fires; and
- Vapour cloud explosions (VCE).

Each hazard is modelled for a range of meteorological conditions (see *Section 2.3*) to determine the size of the hazard footprint.

5.3.1 *Fireballs and BLEVEs*

Catastrophic failures are characterised by a rapid propagation of a crack leading to a sudden release of the contents inside a pressurised vessel. Immediate ignition results in a fireball, which gives a massive transient dose of thermal radiation. Due to its short duration, large size and high intensity, fireballs are not significantly influenced by weather, wind direction or wind speed. Its size, height, duration and thermal radiation flux are calculated using the HSE model within PHAST. People entrapped inside the fireball radius are seriously injured and the fatality is taken as 100%. Outside the fireball radius, radiation effects were found to be negligible due to the short duration of fireballs for the size of releases encountered in this study.

A BELVE is similar to a fireball except that it is caused by a hot failure from fire impingement and therefore occurs from escalation events. The physical effects are calculated in the same way as fireballs.

5.3.2 *Gas Dispersion and Flash Fires*

LPG evaporates rapidly following a release, generating a dispersing vapour cloud if there is no ignition source nearby. The cloud expands and migrates from its release point and may affect offsite locations. The built-in dispersion model in PHAST is used to predict the shape, size, concentration and migration of the vapour cloud.

The principal hazard arising from delayed ignition of an LPG vapour cloud is a flash fire. The flash fire envelope is modelled by calculating the dispersion distance up to the lower flammability limit (LFL).

It is considered that there is no scope for escape for persons within the flammable limits of a flash fire: a fatality probability of 100% is assumed. Flash fires are, however, short duration events with low levels of thermal radiation outside the flash fire. Persons outside the flash fire envelope are therefore assumed to be unaffected by a flash fire.

5.3.3 *Vapour Cloud Explosion*

If a dispersing vapour cloud undergoes delayed ignition in a confined and/or congested area, significant levels of overpressure (explosion) may occur. VCE effects were modelled using the Baker-Strehlow model (CCPS, 1999). This takes into account the reactivity of LPG and the volume, level of congestion and level of confinement in determining the explosion overpressures.

Given the generally open nature of the surrounding, the modelling assumed 3D confinement (i.e. the vapour cloud explosion is free to expand in 3

dimensions) and medium congestion. For explosions within the vaporizer room, a higher level of confinement, 2D, was assumed.

Fatality rates for persons outdoors are estimated from the HSE probit equation (Hurst et al. 1989):

$Y = 1.47 + 1.35 \ln(P)$

where

Y = probit

P = overpressure (psi)

For persons indoors, fatality rates if 55%, 15% and 3.5% are used for 5psi, 3psi and 2psi respectively, based on CIA (1998) guidelines. Fatality rates are higher for persons indoors because of the additional risk from projectiles such as breaking windows.

5.3.4 *Jet Fires and Pool Fires*

Jet fires occur from the immediate ignition of an LPG release from pressurised conditions. The flame length is determined from the initial momentum of the release. If a jet fire impinges on a LPG road tanker or a LPG cylinder, thermal intrusion and heat radiation could induce over-pressurization and the subsequent rupture of the container, releasing its inventory instantaneously to cause a BLEVE.

Pool fires are caused by the ignition of liquid pools spreading on the ground.

The major hazard from a jet fire or a pool fire is thermal radiation. Persons caught in the fire zone are assumed to suffer 100% fatality. Persons outside the flame zone are assigned a harm probability using the Green Book probit equation:

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

Y = probit

I = radiation thermal flux (W/m^2)

t = exposure time, assumed to be 30 s

The exposure time for jet fires is taken to be 30s, the time assumed for an able person to seek shelter (ERM, 2008).

A summary of harm probabilities used in the current assessment is provided in *Table 5.1*. Persons indoors are expected to be offered some protection from fires due to shielding from the building structure; the indoor fatality is taken to be 10% that of the outdoor population. This is in line with previous studies in Hong Kong (ERM, 2006; ERM, 2008 for example).

The harm probabilities for persons indoors are somewhat different from those used in the HATS study (ENSR, 2008). In that study, indoor harm probabilities for radiation effects are assumed to be 50% of those for outdoor population, and persons indoors who are within the flame envelope are assumed to have the same harm probability as those outdoors. These assumptions are considered to be very conservative and are the main difference between the previous HATS study and the current analysis. The HATS study also did not provide the probit equation/harm probabilities used for VCE effects although it may be discerned that the same harm probability was used for indoor and outdoor populations.

Table 5.1 ***Summary of Harm Probabilities***

Consequence Event	Endpoint Criteria	Outdoor Harm Prob.	Harm Prob. Inside Buildings
Flash fire	LFL	1	0.1
Jet fire/Pool fire	Fire zone	1	0.1
	20.9 kW/m^2	0.9	0.09
	14.4 kW/m^2	0.5	0.05
	7.3 kW/m^2	0.01	0.001
Fireball and BLEVE	Fireball radius	1	0.1
VCE	5 psi overpressure	0.09	0.55
	3 psi overpressure	0.02	0.15
	2 psi overpressure	0.005	0.035

5.4 HAZARD IMPACT ON OFFSITE POPULATION

Population in the vicinity of the Shell depot can be potentially affected by the hazardous outcomes depending on the consequence distances. Fireballs from the LPG storage vessels have a radius of up to 71 m and a lift-off height of 142m, which covers the majority of the adjacent PTW construction site. Fireballs and BLEVEs of LPG road tankers have a radius of up to 60 m and a lift-off height of 121 m, which can reach the nearest residential high-rise buildings (South Horizons Blocks 21 & 22). Due to the lift-off and rise of fireballs, they are assumed to affect the full height of residential blocks facing the LPG Depot. Units that are not overlooking the LPG Depot are assumed to be unaffected by fireballs. Similarly, VCE are assumed to affect only units overlooking the LPG Depot.

The maximum height of a dispersing vapour cloud was found to be 36m. It was therefore assumed in the modelling that flash fires affect only the lowest 12 floors of residential blocks. Similarly, only 12 floors of population were taken for jet fires since radiation effects are unable to reach higher floors.

5.5 GAS INGRESS INTO SOUTH HORIZONS MTR STATION

The future 2031 case considers the South Horizons station during operational phase. All parts of the station will be underground, and as such, will be unaffected by any incident at the LPG Depot. Ventilation for the station will be via vents situated on the second level of the 2-storey plant building located on Lee Nam Road at the toe of Yuk Kwai Shan. This plant building is about 200m from the LPG Compound storage vessels and 123m from the road tanker parking area. Vapour clouds from ruptures of these vessels/tankers

can reach the plant building. The maximum vapour cloud depth at the plant building is predicted to be 8m for a tanker rupture and 12m for a storage vessel rupture. This compares to a vent height of about 8m above Lee Nam Road. Ingress into the vent is therefore possible although the transit time for the vapour cloud to blow past the plant building is only 17 seconds. For such a short transit time, there is no possibility for vapours to enter the station and achieve flammable concentrations. For example, typical ventilation rates for buildings are in the range of 5 to 10 volume changes per hour. This gives a time constant for concentration changes within the station of between 1/5 to 1/10 hours (6 to 12 minutes). It is not possible for a passing gas cloud to cause significant rise in concentration within the station in just 17 seconds.

No impact on South Horizons station population was therefore considered in the assessment.

Despite this, as an additional safeguard it is recommended to install gas detectors in the HVAC air intakes for the plant building that close the dampers in case of gas detection. Usually, three such gas detectors are provided with two-out-of-three voting logic to improve the reliability of the system.

5.6 CONSEQUENCE RESULTS

A summary of consequence results is listed in *Table 5.2*. Results for all consequences are presented in terms of 4 parameters, *d c s m*. These are defined as (*Figure 5.1*):

d: maximum downwind distance (m)

c: maximum half width (m)

s: offset between release point and start of hazard footprint (m) (value may be positive or negative)

m: distance from release point to position of maximum half width (m)

Figure 5.1 ***Hazard Footprint Notation***

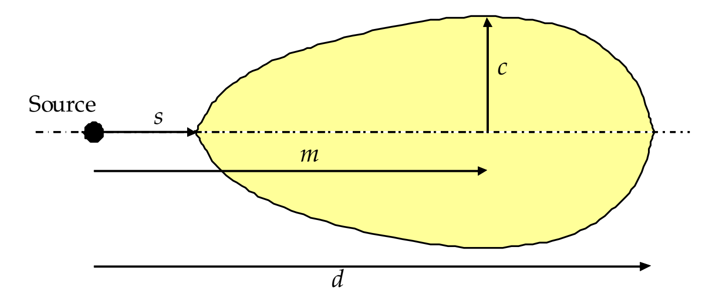


Table 5.2 Consequence Results

Section No.	Description	Leak Size	Outcome	Criteria	Weather Conditions																			
					3B				3D				7D				3E				1.4F			
					d	c	s	m	d	c	s	m	d	c	s	m	d	c	s	m	d	c	s	m
1	Storage vessel	Rupture	Flash fire	LFL	153	51	-20	70	179	60	-24	88	264	54	-15	160	182	60	-20	90	120	62	-30	50
			VCE	5 psi	122	53	16	69	143	54	35	89	223	47	129	176	148	49	50	99	115	68	-21	47
				3 psi	203	134	-65	69	225	136	-47	89	303	127	49	176	230	131	-32	99	183	136	-89	47
				2 psi	273	204	-135	69	297	208	-119	89	384	208	-32	176	298	199	-100	99	255	208	-161	47
			Fireball	Fireball radius	71	71	-71	0	71	71	-71	0	71	71	-71	0	71	71	-71	0	71	71	-71	0
		Leak	Flash fire	LFL	38	2	8	28	40	2	8	30	30	1	8	20	42	2	8	32	47	4	8	36
			VCE	5 psi	10	10	-10	0	11	11	-11	0	9	9	-9	0	12	12	-12	0	13	13	-13	0
				3 psi	21	21	-21	0	23	23	-23	0	19	19	-19	0	24	24	-24	0	26	26	-26	0
				2 psi	32	32	-32	0	35	35	-35	0	30	30	-30	0	36	36	-36	0	40	40	-40	0
			Jet fire	Fire zone	37	13	1	19	37	13	1	19	33	14	1	17	37	13	1	19	43	12	2	22
				20.9 kW/m2	41	18	1	21	41	18	1	21	37	18	-1	18	41	18	1	21	46	18	2	24
				14.4 kW/m2	44	21	0	22	44	21	0	22	40	21	-2	19	44	21	0	22	49	22	1	25
				7.3 kW/m2	51	29	-1	25	51	29	-1	25	47	29	-3	22	51	29	-1	25	55	30	-1	27
2	LPG road tanker	Rupture	Flash fire	LFL	105	34	-20	55	110	34	-20	55	185	33	-15	110	112	35	-15	55	69	35	-25	30
			VCE	5 psi	67	36	-5	31	82	45	-8	37	122	34	54	88	85	47	-9	38	78	59	-40	19
				3 psi	167	136	-105	31	170	133	-96	37	188	100	-12	88	173	135	-97	38	155	136	-117	19
				2 psi	239	208	-177	31	239	202	-165	37	290	202	-114	88	243	205	-167	38	227	208	-189	19
			Fireball	Fireball radius	60	60	-60	0	60	60	-60	0	60	60	-60	0	60	60	-60	0	60	60	-60	0
		Leak	Flash fire	LFL	108	7	7	78	106	7	7	78	107	6	7	75	107	8	7	80	105	11	7	85
			VCE	5 psi	25	25	-25	0	25	25	-25	0	24	24	-24	0	27	27	-27	0	29	29	-29	0
				3 psi	49	49	-49	0	51	51	-51	0	48	48	-48	0	53	53	-53	0	59	59	-59	0
				2 psi	75	75	-75	0	77	77	-77	0	74	74	-74	0	81	81	-81	0	90	90	-90	0
			Jet fire	Fire zone	73	28	1	37	73	28	1	37	65	29	-1	32	73	28	1	37	83	27	1	42
				20.9 kW/m2	80	37	0	40	80	37	0	40	73	36	-1	46	80	37	0	40	89	37	1	45
				14.4 kW/m2	86	44	-2	42	86	44	-2	42	78	43	37	37	86	44	-2	42	95	45	-1	47
				7.3 kW/m2	100	61	-4	48	100	61	-4	48	92	60	-10	41	100	61	-4	48	108	61	-2	53
		Escalation	BLEVE	Fireball radius	60	60	-60	0	60	60	-60	0	60	60	-60	0	60	60	-60	0	60	60	-60	0
		Large liquid leak	Flash fire	LFL	108	7	7	78	106	7	7	78	107	6	7	75	107	8	7	80	105	11	7	85
			VCE	5 psi	25	25	-25	0	25	25	-25	0	24	24	-24	0	27	27	-27	0	29	29	-29	0
				3 psi	49	49	-49	0	51	51	-51	0	48	48	-48	0	53	53	-53	0	59	59	-59	0

Section No.	Description	Leak Size	Outcome	Criteria	Weather Conditions																			
					3B				3D				7D				3E				1.4F			
					d	c	s	m	d	c	s	m	d	c	s	m	d	c	s	m	d	c	s	m
				2 psi	75	75	-75	0	77	77	-77	0	74	74	-74	0	81	81	-81	0	90	90	-90	0
			Jet fire	Fire zone	73	28	1	37	73	28	1	37	65	29	-1	32	73	28	1	37	83	27	1	42
				20.9 kW/m2	80	37	0	40	80	37	0	40	73	36	-1	46	80	37	0	40	89	37	1	45
				14.4 kW/m2	86	44	-2	42	86	44	-2	42	78	43	37	37	86	44	-2	42	95	45	-1	47
				7.3 kW/m2	100	61	-4	48	100	61	-4	48	92	60	-10	41	100	61	-4	48	108	61	-2	53
		Large vapour leak	Flash fire	LFL	12	1	0	7	14	1	0	8	11	1	0	6	14	1	0	8	15	1	0	9
			VCE	5 psi	4	4	-4	0	4	4	-4	0	3	3	-3	0	4	4	-4	0	4	4	-4	0
				3 psi	8	8	-8	0	8	8	-8	0	7	7	-7	0	8	8	-8	0	8	8	-8	0
				2 psi	12	12	-12	0	12	12	-12	0	11	11	-11	0	12	12	-12	0	12	12	-12	0
			Jet fire	Fire zone	20	3	4	12	20	3	4	12	23	3	5	14	20	3	4	12	19	3	5	12
				20.9 kW/m2	22	6	4	13	22	6	4	13	25	6	5	15	22	6	4	13	20	5	4	12
				14.4 kW/m2	24	9	4	14	24	9	4	14	27	8	5	16	24	9	4	14	22	7	4	13
				7.3 kW/m2	28	13	4	16	28	13	4	16	29	13	3	16	28	13	4	16	27	14	3	15
		Medium liquid leak	Flash fire	LFL	37	1	6	28	40	2	6	30	32	1	6	22	42	2	6	32	47	3	6	34
			VCE	5 psi	25	25	-25	0	25	25	-25	0	24	24	-24	0	27	27	-27	0	29	29	-29	0
				3 psi	49	49	-49	0	51	51	-51	0	48	48	-48	0	53	53	-53	0	59	59	-59	0
				2 psi	75	75	-75	0	77	77	-77	0	74	74	-74	0	81	81	-81	0	90	90	-90	0
			Jet fire	Fire zone	39	14	1	20	39	14	1	20	35	14	1	17	39	14	1	20	39	14	1	20
				20.9 kW/m2	42	18	1	21	42	18	1	21	38	18	0	19	43	19	1	22	48	19	1	24
				14.4 kW/m2	45	21	1	23	45	21	1	23	41	21	-1	20	46	23	0	23	51	23	1	26
				7.3 kW/m2	53	31	-3	25	53	31	-3	25	50	31	-4	23	53	21	-1	26	58	32	0	29
3	Filling line to storage vessel	Full bore Rupture	Flash fire	LFL	19	1	0	13	20	1	0	14	16	1	0	10	21	1	0	16	23	1	0	18
			VCE	5 psi	6	6	-6	0	6	6	-6	0	4	4	-4	0	6	6	-6	0	7	7	-7	0
				3 psi	12	12	-12	0	13	13	-13	0	9	9	-9	0	13	13	-13	0	14	14	-14	0
				2 psi	18	18	-18	0	19	19	-19	0	14	14	-14	0	20	20	-20	0	22	22	-22	0
			Jet fire	Fire zone	25	8	1	13	25	8	1	13	22	9	1	11	25	8	1	13	29	8	3	16
				20.9 kW/m2	27	11	0	14	27	11	0	14	25	11	1	13	27	11	1	13	31	11	1	16
				14.4 kW/m2	29	14	-1	14	29	14	-1	14	27	14	-1	13	29	14	0	14	33	14	1	17
				7.3 kW/m2	34	19	-2	17	34	19	-2	17	31	19	-3	14	34	19	0	17	37	20	-1	18
		Leak	Flash fire	LFL	12	1	0	8	14	1	0	9	10	1	0	7	14	1	0	9	17	1	0	13
			VCE	5 psi	4	4	-4	0	4	4	-4	0	3	3	-3	0	4	4	-4	0	4	4	-4	0

Section No.	Description	Leak Size	Outcome	Criteria	3B d	3B c	3B s	3B m	3D d	3D c	3D s	3D m	7D d	7D c	7D s	7D m	3E d	3E c	3E s	3E m	1.4F d	1.4F c	1.4F s	1.4F m
				3 psi	8	8	-8	0	8	8	-8	0	7	7	-7	0	8	8	-8	0	8	8	-8	0
				2 psi	12	12	-12	0	12	12	-12	0	11	11	-11	0	13	13	-13	0	13	13	-13	0
			Jet fire	Fire zone	20	6	2	11	20	6	2	11	17	7	1	9	20	6	2	11	23	6	3	12
				20.9 kW/m2	22	9	2	12	22	9	2	12	19	9	-1	9	22	9	2	12	24	9	2	12
				14.4 kW/m2	23	11	1	12	23	11	1	12	21	11	-1	10	23	11	1	12	26	11	2	14
				7.3 kW/m2	27	14	1	14	27	14	1	14	25	15	-1	12	27	14	1	14	29	15	-1	14
4	Line from storage vessel to vaporizers	Full bore Rupture	Flash fire	LFL	38	2	8	27	41	2	8	30	31	1	8	20	43	2	8	33	48	4	8	30
			VCE	5 psi	21	21	-21	0	21	21	-21	0	18	18	-18	0	22	22	-22	0	24	24	-24	0
				3 psi	33	33	-33	0	34	34	-34	0	29	29	-29	0	36	36	-36	0	39	39	-39	0
				2 psi	47	47	-47	0	48	48	-48	0	41	41	-41	0	51	51	-51	0	55	55	-55	0
			Jet fire	Fire zone	38	13	1	19	38	13	1	19	33	14	0	16	38	13	1	19	43	12	1	22
				20.9 kW/m2	42	18	1	21	42	18	1	21	38	18	0	19	42	18	1	21	46	18	1	23
				14.4 kW/m2	45	22	1	23	45	22	1	23	41	21	-1	20	45	22	1	23	49	22	1	25
				7.3 kW/m2	52	30	-2	25	52	30	-2	25	48	30	-4	22	52	30	-2	25	56	30	0	28
		Leak	Flash fire	LFL	12	1	0	8	14	1	0	9	10	1	0	7	14	1	0	9	17	1	0	13
			VCE	5 psi	7	7	-7	0	7	7	-7	0	7	7	-7	0	8	8	-8	0	8	8	-8	0
				3 psi	12	12	-12	0	12	12	-12	0	11	11	-11	0	12	12	-12	0	13	13	-13	0
				2 psi	17	17	-17	0	17	17	-17	0	15	15	-15	0	18	18	-18	0	18	18	-18	0
			Jet fire	Fire zone	20	6	2	11	20	6	2	11	17	7	1	9	20	6	2	11	23	6	3	12
				20.9 kW/m2	22	9	2	12	22	9	2	12	19	9	-1	9	22	9	2	12	24	9	2	12
				14.4 kW/m2	23	11	1	12	23	11	1	12	21	11	-1	10	23	11	1	12	26	11	2	14
				7.3 kW/m2	27	14	1	14	27	14	1	14	25	15	-1	12	27	14	1	14	29	15	-1	14
5	Vaporisers	Full bore Rupture	Flash fire	LFL	5	1	0	3	5	1	0	3	4	1	0	2	5	1	0	3	6	1	0	4
			VCE	5 psi	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
				3 psi	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
				2 psi	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
			Jet fire	Fire zone	10	1	0	9	10	1	0	9	10	1	0	9	10	1	0	9	10	1	0	9
				20.9 kW/m2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
				14.4 kW/m2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
				7.3 kW/m2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
6	Flexible hose	Full bore Rupture	Flash fire	LFL	19	1	0	13	20	1	0	14	16	1	0	10	21	1	0	16	23	1	0	18

Section No.	Description	Leak Size	Outcome	Criteria	3B d	3B c	3B s	3B m	3D d	3D c	3D s	3D m	7D d	7D c	7D s	7D m	3E d	3E c	3E s	3E m	1.4F d	1.4F c	1.4F s	1.4F m
			VCE	5 psi	6	6	-6	0	6	6	-6	0	4	4	-4	0	6	6	-6	0	7	7	-7	0
				3 psi	12	12	-12	0	13	13	-13	0	9	9	-9	0	13	13	-13	0	14	14	-14	0
				2 psi	18	18	-18	0	19	19	-19	0	14	14	-14	0	20	20	-20	0	22	22	-22	0
			Jet fire	Fire zone	25	8	1	13	25	8	1	13	22	9	1	11	25	8	1	13	29	8	3	13
				20.9 kW/m2	27	11	0	14	27	11	0	14	25	11	1	13	27	11	1	13	31	11	1	16
				14.4 kW/m2	29	14	-1	14	29	14	-1	14	27	14	-1	13	29	14	0	14	33	14	1	17
				7.3 kW/m2	34	19	-2	17	34	19	-2	17	31	19	-3	14	34	19	0	17	37	20	-1	18
		Leak	Flash fire	LFL	12	1	0	8	14	1	0	9	10	1	0	7	14	1	0	9	17	1	0	13
			VCE	5 psi	4	4	-4	0	4	4	-4	0	3	3	-3	0	4	4	-4	0	4	4	-4	0
				3 psi	8	8	-8	0	8	8	-8	0	7	7	-7	0	8	8	-8	0	8	8	-8	0
				2 psi	12	12	-12	0	12	12	-12	0	11	11	-11	0	13	13	-13	0	13	13	-13	0
			Jet fire	Fire zone	20	6	2	11	20	6	2	11	17	7	1	9	20	6	2	11	23	6	3	12
				20.9 kW/m2	22	9	2	12	22	9	2	12	19	9	-1	9	22	9	2	12	24	9	2	12
				14.4 kW/m2	23	11	1	12	23	11	1	12	21	11	-1	10	23	11	1	12	26	11	2	14
				7.3 kW/m2	27	14	1	14	27	14	1	14	25	15	-1	12	27	14	1	14	29	15	-1	14
7	Send-out piping downstream of vaporizers	Full bore Rupture	Flash fire	LFL	14	1	0	10	16	1	0	11	11	1	0	6	17	1	0	12	23	2	0	16
			VCE	5 psi	5	5	-5	0	7	7	-7	0	4	4	-4	0	8	8	-8	0	12	12	-12	0
				3 psi	11	11	-11	0	14	14	-14	0	9	9	-9	0	16	16	-16	0	25	25	-25	0
				2 psi	17	17	-17	0	22	22	-22	0	13	13	-13	0	24	24	-24	0	38	38	-38	0
			Jet fire	Fire zone	24	1	0	23	24	1	0	23	24	1	0	23	24	1	0	23	24	1	0	23
				20.9 kW/m2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
				14.4 kW/m2	24	2	2	13	24	2	2	13	24	2	2	13	24	2	2	13	19	2	1	10
				7.3 kW/m2	25	4	1	13	25	4	1	13	25	4	1	13	25	4	1	13	20	5	0	10
		Leak	Flash fire	LFL	2	1	0	1	2	1	0	1	2	1	0	1	2	1	0	1	3	1	0	2
			VCE	5 psi	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
				3 psi	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
				2 psi	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
			Jet fire	Fire zone	5	1	0	4	5	1	0	4	5	1	0	4	5	1	0	4	5	1	0	4
				20.9 kW/m2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
				14.4 kW/m2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
				7.3 kW/m2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0

Section No.	Description	Leak Size	Outcome	Criteria	3B d	3B c	3B s	3B m	3D d	3D c	3D s	3D m	7D d	7D c	7D s	7D m	3E d	3E c	3E s	3E m	1.4F d	1.4F c	1.4F s	1.4F m
8	LPG Cylinder 13.5kg	Rupture	Flash fire	LFL	11	3	-2	2	11	3	-2	2	15	3	-2	4	11	4	-2	5	6	4	-3	2
			Fireball	Fireball radius	7	7	-7	0	7	7	-7	0	7	7	-7	0	7	7	-7	0	7	7	-7	0
		Leak	Flash fire	LFL	2	1	0	1	2	1	0	1	2	1	0	1	2	1	0	1	2	1	0	1
			Jet fire	Fire zone	2	0	0	1	2	0	0	1	2	0	0	1	2	0	0	1	2	0	0	1
				20.9 kW/m2	2	1	0	1	2	1	0	1	2	1	0	1	2	1	0	1	2	1	0	1
				14.4 kW/m2	2	1	0	1	2	1	0	1	2	1	0	1	2	1	0	1	2	1	0	1
				7.3 kW/m2	3	1	0	1	3	1	0	1	3	1	0	1	3	1	0	1	3	1	0	1
		Escalation	BLEVE	Fireball radius	7	7	-7	0	7	7	-7	0	7	7	-7	0	7	7	-7	0	7	7	-7	0
9	LPG Cylinder 49kg	Rupture	Flash fire	LFL	19	6	-4	8	19	6	-4	8	29	5	-3	16	17	6	-4	7	11	6	-5	3
			Fireball	Fireball radius	11	11	-11	0	11	11	-11	0	11	11	-11	0	11	11	-11	0	11	11	-11	0
		Leak	Flash fire	LFL	2	1	0	1	2	1	0	1	2	1	0	1	2	1	0	1	2	1	0	1
			Jet fire	Fire zone	2	0	0	1	2	0	0	1	2	0	0	1	2	0	0	1	2	0	0	1
				20.9 kW/m2	2	1	0	1	2	1	0	1	2	1	0	1	2	1	0	1	2	1	0	1
				14.4 kW/m2	2	1	0	1	2	1	0	1	2	1	0	1	2	1	0	1	2	1	0	1
				7.3 kW/m2	3	1	0	1	3	1	0	1	3	1	0	1	3	1	0	1	3	1	0	1
		Escalation	BLEVE	Fireball radius	11	11	-11	0	11	11	-11	0	11	11	-11	0	11	11	-11	0	11	11	-11	0
10	Cylinder Wagon 13.5kg	Rupture	Flash fire	LFL	11	3	-2	2	11	3	-2	2	15	3	-2	4	11	4	-2	5	6	4	-3	2
			Fireball	Fireball radius	7	7	-7	0	7	7	-7	0	7	7	-7	0	7	7	-7	0	7	7	-7	0
		Escalation	BLEVE	Fireball radius	7	7	-7	0	7	7	-7	0	7	7	-7	0	7	7	-7	0	7	7	-7	0
11	Cylinder Wagon 49kg	Rupture	Flash fire	LFL	19	6	-4	8	19	6	-4	8	29	5	-3	16	17	6	-4	7	11	6	-5	3
			Fireball	Fireball radius	11	11	-11	0	11	11	-11	0	11	11	-11	0	11	11	-11	0	11	11	-11	0
		Escalation	BLEVE	Fireball radius	11	11	-11	0	11	11	-11	0	11	11	-11	0	11	11	-11	0	11	11	-11	0
12	Petrol tanker	Rupture	Pool fire	Fire zone	42	42	-42	0	42	42	-42	0	42	42	-42	0	42	42	-42	0	42	42	-42	0
				14.4 kW/m2	44	44	-44	0	44	44	-44	0	43	43	-43	0	44	44	-44	0	44	44	-44	0
				7.3 kW/m2	68	54	-44	12	68	54	-44	12	79	60	-43	18	68	54	-44	12	59	50	-45	7
		Leak	Pool fire	Fire zone	18	18	-18	0	18	18	-18	0	18	18	-18	0	18	18	-18	0	18	18	-18	0
				14.4 kW/m2	19	19	-19	0	19	19	-19	0	19	19	-19	0	19	19	-19	0	19	19	-19	0
				7.3 kW/m2	38	26	-19	11	38	26	-19	11	45	29	-19	15	38	26	-19	11	34	25	-19	8
13	Diesel tanker	Rupture	Pool fire	Fire zone	40	40	-40	0	40	40	-40	0	40	40	-40	0	40	40	-40	0	40	40	-40	0
				14.4 kW/m2	41	41	-41	0	41	41	-41	0	41	41	-41	0	41	41	-41	0	41	41	-41	0
				7.3 kW/m2	65	51	-41	12	65	51	-41	12	76	57	-42	17	65	51	-41	12	56	48	-44	6

Section No.	Description	Leak Size	Outcome	Criteria	3B d	3B c	3B s	3B m	3D d	3D c	3D s	3D m	7D d	7D c	7D s	7D m	3E d	3E c	3E s	3E m	1.4F d	1.4F c	1.4F s	1.4F m
		Leak	Pool fire	Fire zone	22	22	-22	0	22	22	-22	0	22	22	-22	0	22	22	-22	0	22	22	-22	0
				14.4 kW/m2	26	23	-22	3	26	23	-22	3	25	23	-22	2	26	23	-22	3	26	23	-22	3
				7.3 kW/m2	43	30	-22	12	43	30	-22	12	50	34	-22	15	43	30	-22	12	37	28	-22	8

6 RISK RESULTS

6.1 RISK SUMMATION

Risk summation combines the estimates of the consequences of an event with the event frequencies to give an estimate of the resulting risk of fatalities. The Consultants in-house software RISKPLOT™ has been used for risk summation. The inputs to the software comprise a number of files:

- *Release cases file* detailing all identified hazardous events and their frequencies;
- *Release location file* containing the locations of hazardous events either at given points or along given routes;
- *Consequences file/effect zone dimensions*, which inputs the calculated consequences of each event under each possible weather condition, as appropriate;
- *Weather frequencies file* that details the local meteorological data according to a matrix of weather class (speed/stability combinations) and wind directions;
- *Population data file*. The population data are divided into geographical areas of polygonal shape dependent on the population density within that area. Point and line populations may also be defined.

RISKPLOT™ takes into account all of the above information and models each event under each combination of conditions (weather, location, etc.). It calculates the number of fatalities from each event with a given probability of occurrence. The number of fatalities is based upon the proportion of each population area overlapped by the hazard effect.

The two types of risk measures considered are societal risk and individual risk.

6.2 SOCIETAL RISK

Societal risk is defined as the risk to a group of people due to all hazards arising from a hazardous installation or activity. The simplest measure of societal risk is the Rate of Death or Potential Loss of Life (PLL), which is equivalent to the predicted number of fatalities per year.

The frequency (f) and fatalities (N) associated with each outcome event are derived as described in earlier sections. The Potential Loss of Life is then calculated as follows:

$$PLL = f_1N_1 + f_2N_2 + f_3N_3 + \ldots + f_nN_n$$

The PLL results are presented in *Table 6.1* for the existing, construction and

future phases. The highest risks are associated with the construction phase due to the additional worker population. The PLL for this year amounts to 3.39×10^{-5} per year, or equivalently, one fatality every 30,000 years.

The future 2031 case is marginally higher than the existing risks, in line with the general growth in residential population assumed in the analysis. This increase is not due to MTRC operations however, since all station population will be below ground and unaffected by any incidents at the LPG Depot.

Table 6.1 Potential Loss of Life

Project Phase	PLL (per year)		
	LPG compound	LPG transit	Overall
Existing risk (2009)	5.96×10^{-6}	1.25×10^{-5}	1.84×10^{-5}
Construction phase (2014)	1.99×10^{-5}	1.41×10^{-5}	3.39×10^{-5}
Future operational phase (2031)	6.38×10^{-6}	1.55×10^{-5}	2.19×10^{-5}

A breakdown of PLL by population group for the construction year 2014 is shown in *Table 6.2*. It can be seen that a major component of the societal risks arise from the Preliminary Treatment Works construction workers. This is due to the close proximity of these workers with the LPG Compound. The additional population injected from MTR workers contribute only 1% to the societal risks since they are located further from the LPG Depot. This is a negligible increase in risks.

Table 6.2 PLL Breakdown by Population Group for Construction Phase

Population Group	PLL	% of Total
MTR construction workers	1.88×10^{-7}	1 %
PTW construction workers	1.46×10^{-5}	43 %
Other population	1.92×10^{-5}	56 %
Total	3.39×10^{-5}	100 %

Societal risk can also be expressed in the form of an F-N curve, which represents the cumulative frequency (F) of all event outcomes leading to N or more fatalities. This representation of societal risk highlights the potential for accidents involving large numbers of fatalities.

FN curves for the LPG Depot are shown in *Figure 6.1*. The risks for the current year, construction phase and future operational phase all lie in the acceptable region. It may be noted that the curves are in good agreement with the previous HATS study (ENSR, 2008). Although the current analysis made some refinements to the methodology, the approach is essentially very similar to that adopted by ENSR (2008). The main difference is in the indoor harm probabilities and the inclusion of projectile effects from the LPG Transit Depot. A test was conducted using the same indoor harm probabilities as those used in the previous HATS study. This increased the risks marginally and further improved the agreement between the two studies, but the differences are not significant.

Comparing the existing risks (2009) with the future operational phase (2031), it can be seen that the societal risks increase slightly. As discussed above, this is due to the general increase in population in the surrounding area, modelled as a 1% increase per year. The population within South Horizons station does not contribute to this increase since the population is underground and will not be impacted by incidents at the LPG Depot.

The highest risks are again observed during the construction phase, due to the additional outdoor population on work sites. A breakdown of risks by population group for the construction phase is shown in *Figure 6.2*. It can be seen that the increase is predominantly due to workers at the Preliminary Treatment Works (PTW) which is immediately adjacent to the LPG Compound site. Risks to MTR construction workers are very much smaller and make negligible contribution to the overall societal risks.

Separate results for the LPG Compound and LPG Transit depot are shown in *Figures 6.3* and *6.4*.

Figure 6.1 Societal Risk Results

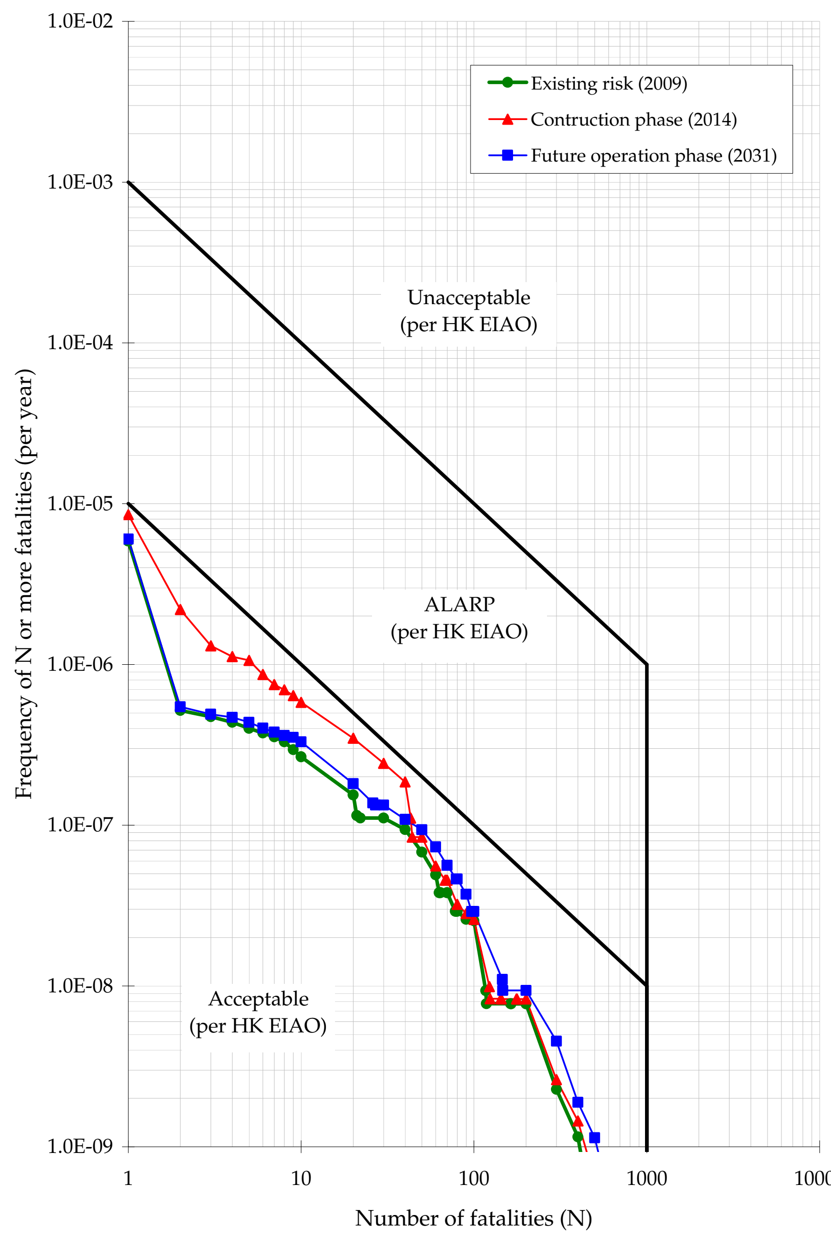


Figure 6.2 Construction Phase Risk Breakdown by Population Type

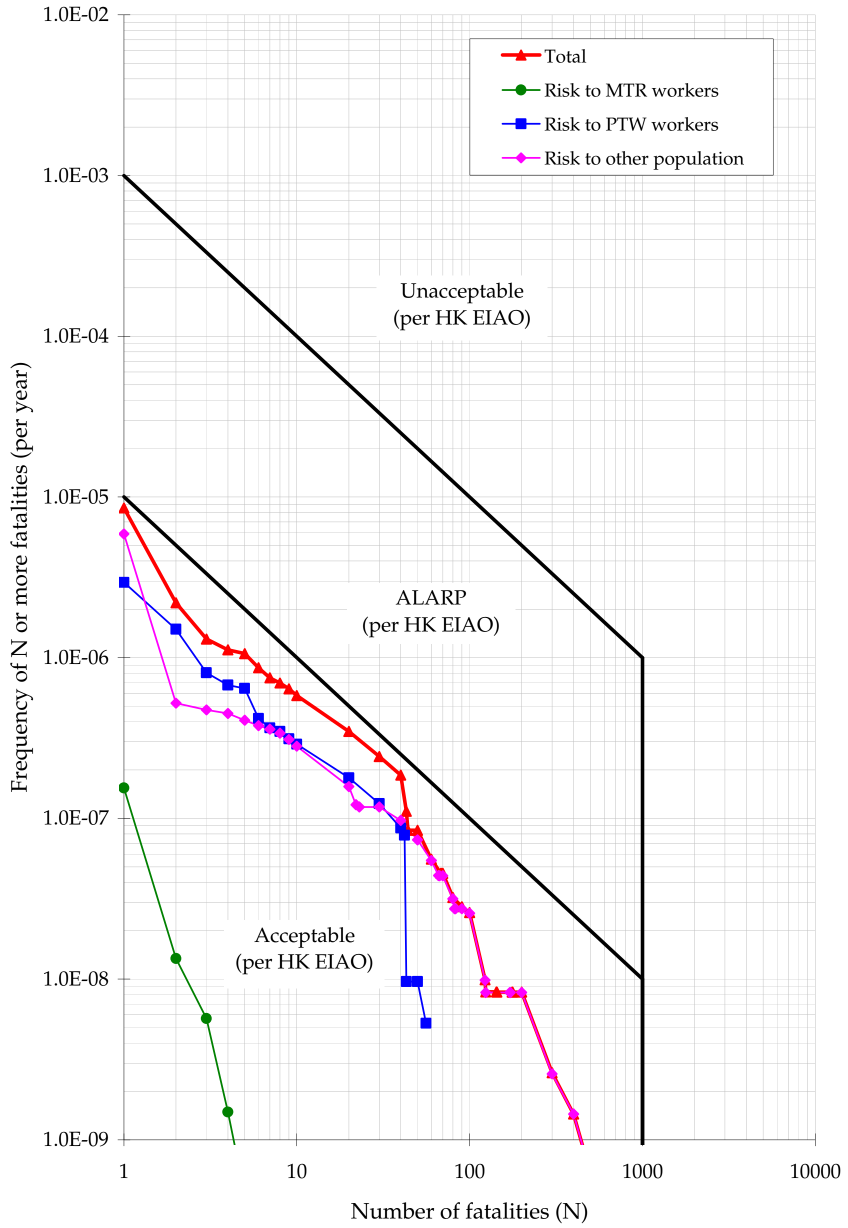


Figure 6.3 Societal Risk Results (LPG Compound)

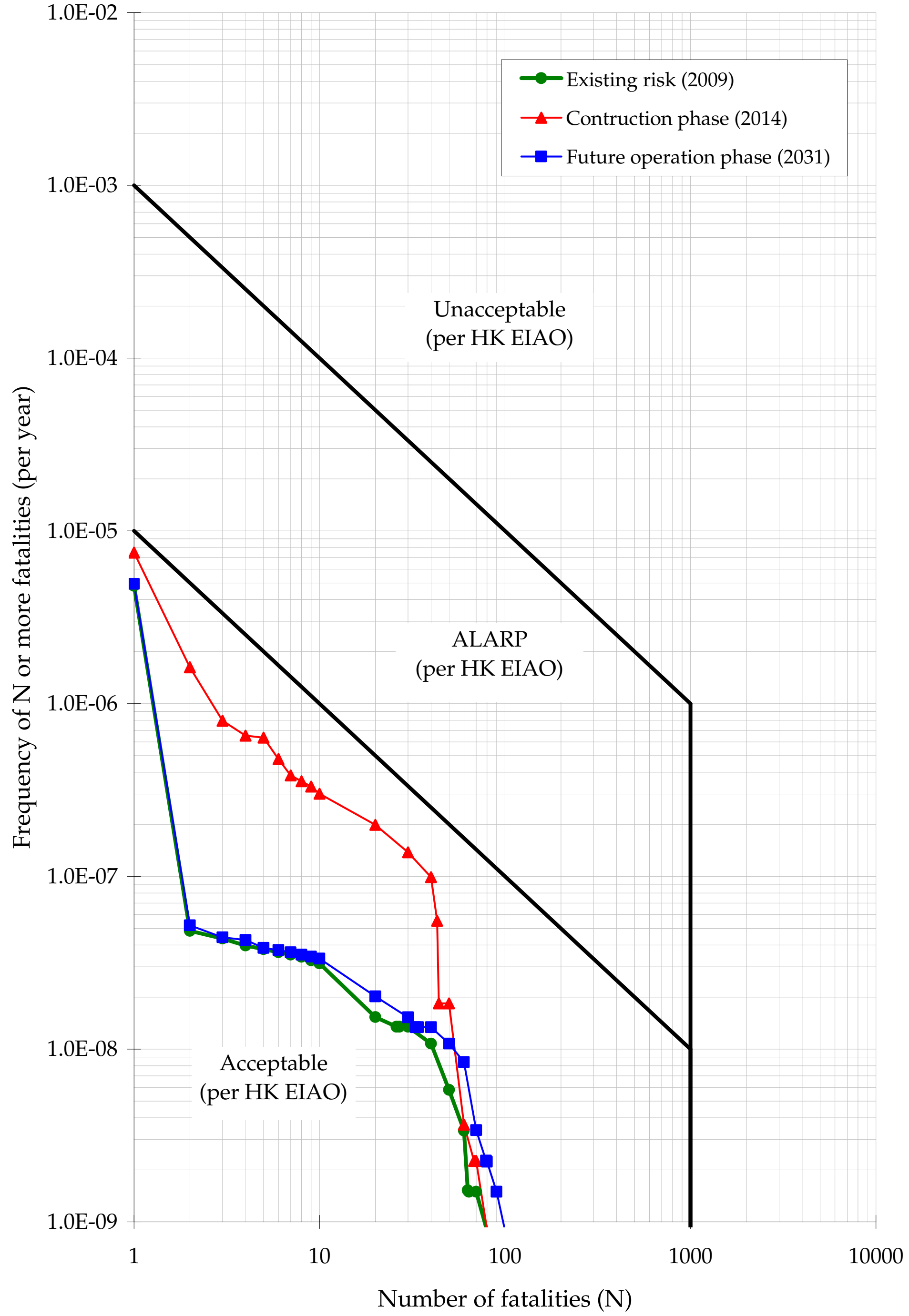
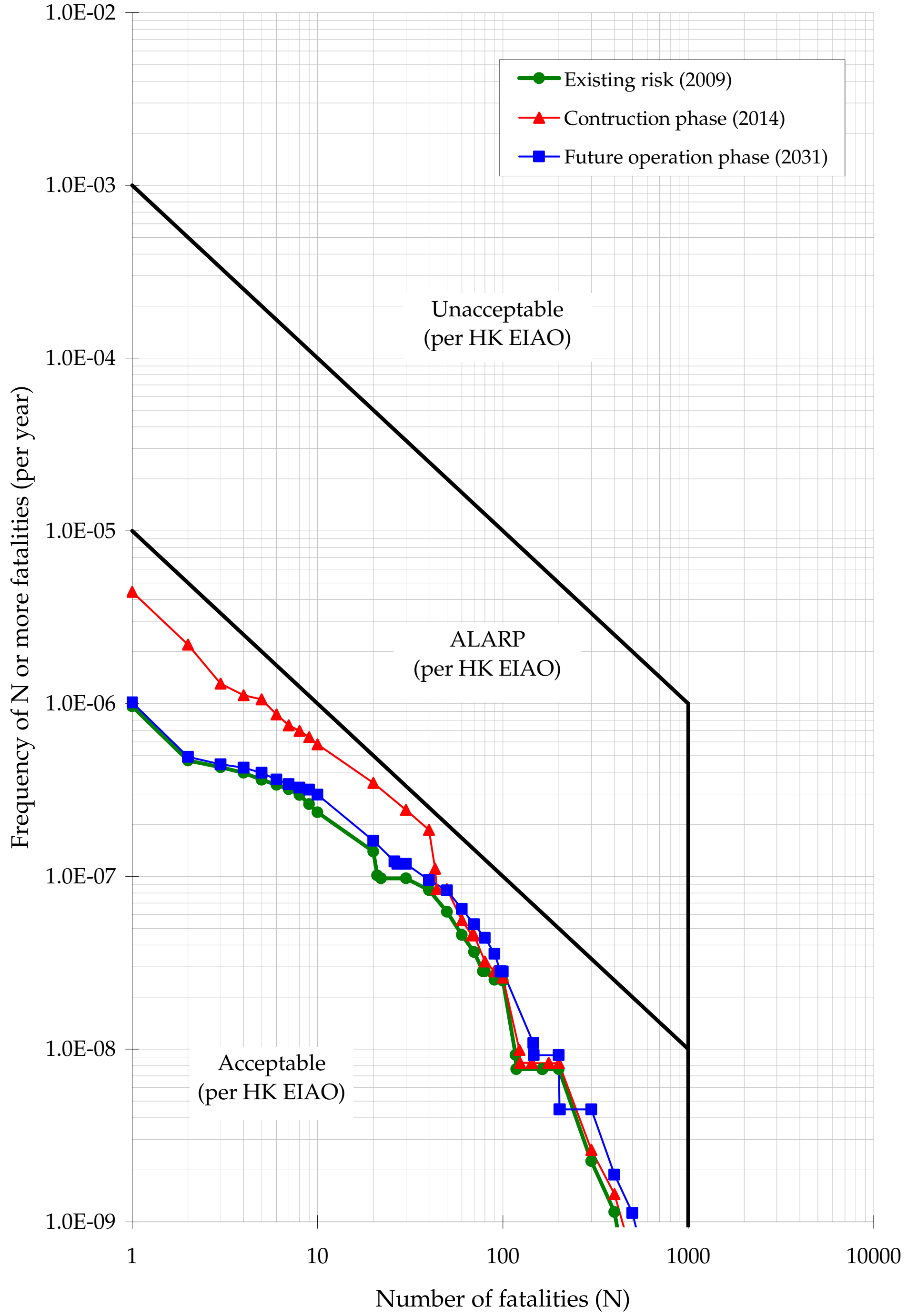


Figure 6.4 ***Societal Risk Results (LPG Transit Depot)***



6.3 *INDIVIDUAL RISK*

Individual risk may be defined as the frequency of fatality per individual per year due to the realisation of specified hazards. Individual Risk may be derived for a hypothetical individual present at a location 100% of time or a named individual considering the probability of his presence etc. (the latter case is known as Personal Individual Risk).

Individual risk contours for the LPG Depot are presented in *Figure 6.5, Figure* 6.6 *and Figure* 6.7. The 1×10^{-5} per year risk contour lies inside the depot boundary and therefore meets the Hong Kong risk criterion for individual

risk.

It may be noted that individual risk, unlike societal risk, is a property of the LPG Depot alone and is unaffected by surrounding population. As such, individual risk is unchanged by any changes in population that may arise from the project.

The highest individual risk occurs in the Storage Shed area due to the large number of cylinders stored there. However, incidents involving LPG cylinders have only short range effects and the risks diminish quickly away from the Storage Shed. The risks at greater distances from the facility are caused by flash fires from releases from larger inventories such as road tankers and storage vessels.

Figure 6.5 ***Individual Risk Contours***

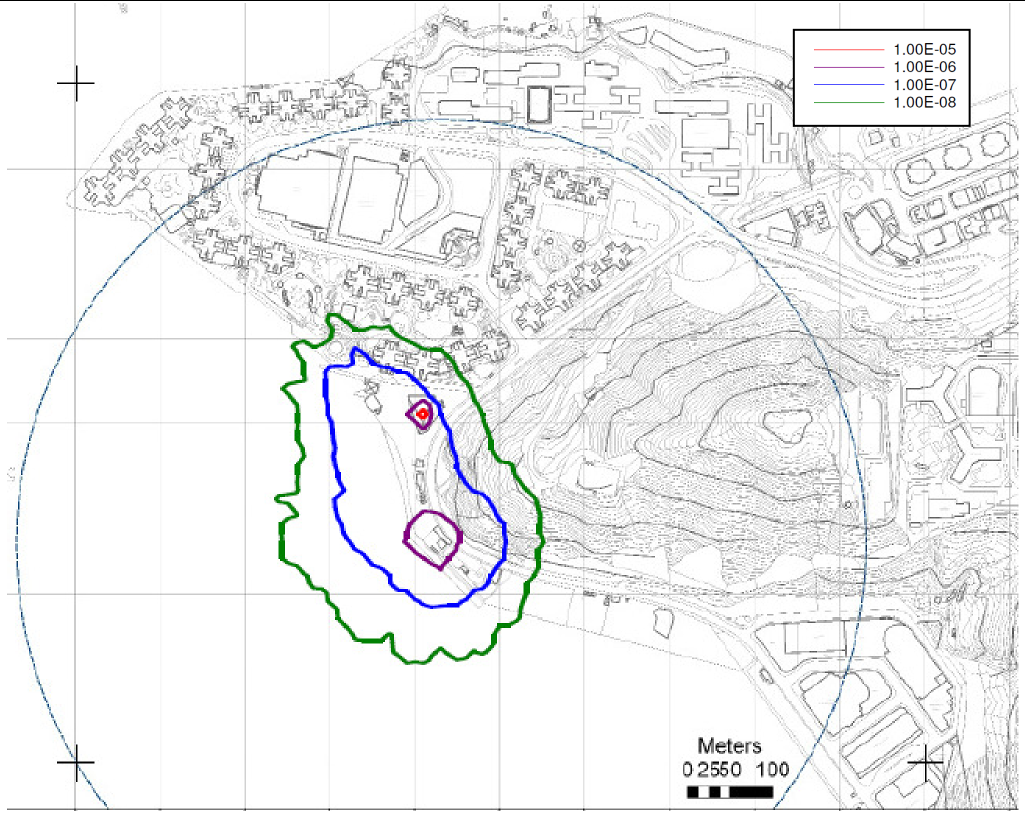


Figure 6.6 Individual Risk Contours (LPG Compound)

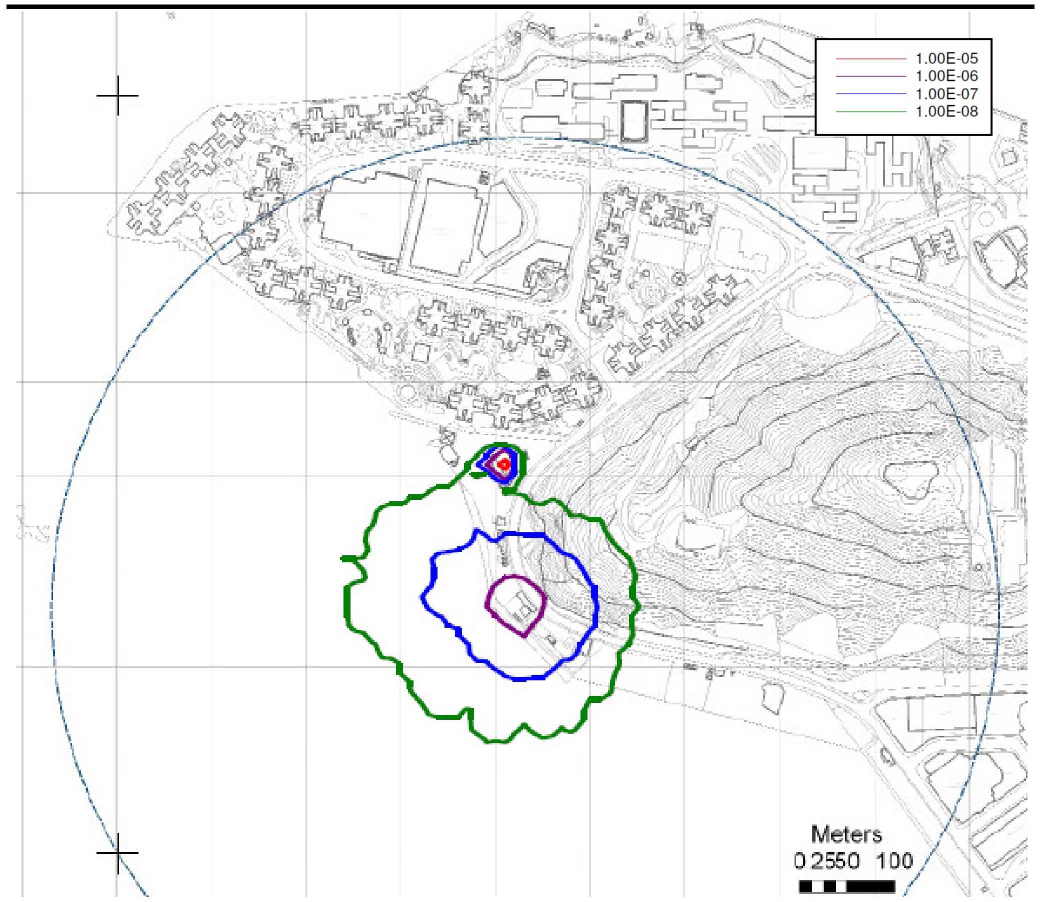
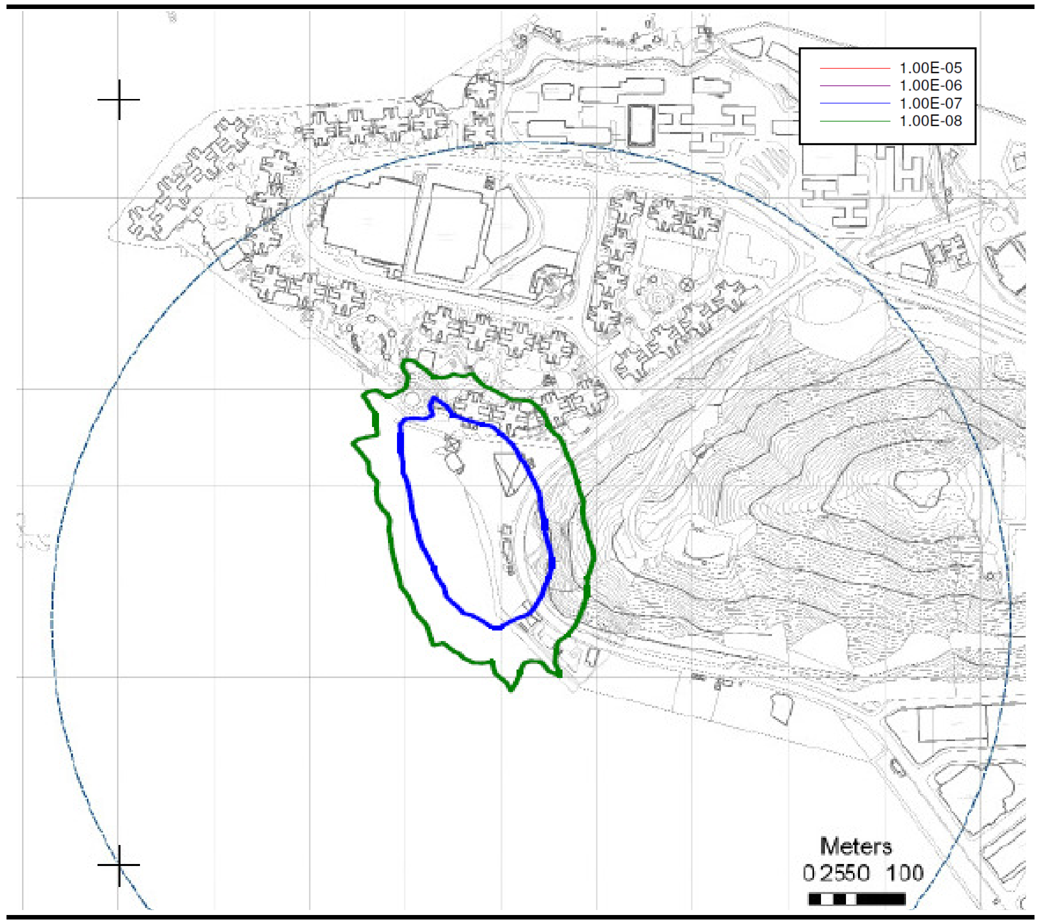


Figure 6.7 Individual Risk Contours (LPG Transit Depot)



6.4 *THE LPG DEPOT AND EXPLOSIVES DELIVERIES VIA LEE NAM ROAD*

Explosives deliveries from the Chung Hom Shan Magazine to the Ap Lei Chau delivery point will use Lee Nam Road, a section of which adjoins the LPG Depot. In the event of an explosives vehicle detonation within this road section, there could be an impact on the LPG containing equipment inside the depot. Conversely an explosion in the LPG facility could impact on the explosives vehicle. This section presents an assessment of the risk that the explosives vehicle poses to or suffers from the LPG Depot.

Since the entire LPG Depot is enclosed by a 2.4 m high solid boundary wall, damage to the LPG facilities is considered only possible if the explosion overpressure is sufficient to damage the wall and the fragments generated strike the equipment inside.

Lees suggests an overpressure of 2.3 psi as the lower limit of serious structural damage and an overpressure of 2 -3 psi could shatter concrete (not reinforced) or cinder block walls (Lees, 1996). It is therefore deemed appropriate to assume an overpressure of below 2 psi would not affect the equipment inside the boundary wall. For comparison, an overpressures below 2 psi is expected to result in only minor damage such as slight distortion of the steel frame of a clad building (1.3 psi), shattering of windows (0.5 – 1 psi) and minor structural damage (0.4 psi).

In the worst case the maximum quantity of explosives to be transported along Lee Nam Road will be 207 kg TNT equivalent. Based on the TNT explosion model from the Yellow Book, an overpressure of 2 psi could reach up to a distance of 62 m from the source of explosion.

The two concerned road sections to be considered are a 10 m route along the boundary of the LPG compound and a 40 m route along the cylinder shed. For the LPG compound, the vulnerable length of the road can be calculated as 134 m (i.e. 10m + 62m + 62m). Based on the maximum foreseeable usage of Lee Nam Road of 787 trips per year and the probability of initiation of explosives during road transport (non-expressway) of 7.96×10^{-10} per km, the probability of truck explosion impacting the LPG compound is 8.4×10^{-8} per year. Similarly, the frequency of impacting the LPG shed can be calculated as 1.0×10^{-7} per year.

It should be noted that in the ALARP case a maximum 250 kg load (258kgTNT equivalent) can be transported for a maximum of 670 trips, with a 2 psi overpressure distance of 67m, giving corresponding impact frequencies of 7.7×10^{-8} and 9.3×10^{-8}, which is less than in the worst case.

Even without considering that the tanks are mounded, the probability of the equipment being struck, and then being struck with a high energy fragment sufficient to rupture the steel vessels or piping, these explosion impact frequencies are already about 3 to 4 orders of magnitude lower than the base event frequencies assumed for the QRA (*Table 4.1* and *4.2*). For example, the failure rate of LPG vessels is 1.24×10^{-5} per year and for LPG cylinders it is

7.92×10^{-3} per year. Therefore, the increased risk of a truck explosion impacting the equipment inside the depot is considered negligible.

The scenario of a major fire or explosion within the LPG depot leading to an initiation of explosives in the truck is also considered negligible from the risk standpoint. The presence time of an explosives truck on the road along the LPG Depot is estimated to be about 3.5 hours per year (assuming a driving speed of 50km/hr for a 250m road), this equates to a presence factor of 3.98×10^{-4}. Combining this presence factor with the event frequencies of a jet fire, explosion or flash-fire of between 10^{-5} and 10^{-7} per year (*Table 4.7*), and considering the directional probability of a jet fire impinging on the explosives truck, the protection from the boundary wall, and that a flash-fire would not ingress into the truck, would give frequency values of well below 10^{-9} per year.

It is therefore concluded that the explosives truck travelling alongside the LPG Depot on Lee Nam Road poses negligible additional risk to the LPG Depot and vice versa.

7 CONCLUSIONS

A QRA was conducted on Shell's LPG Depot in Ap Lei Chau to assess the increase in societal risk from the SIL(E) construction and operation. The methodology adopted followed closely that of an earlier study conducted for the same facility as part of the Harbour Area Treatment Scheme (HATS) assessment. Refinements to the methodology were applied in a few respects, but nevertheless, the results obtained are closely consistent with those obtained from the previous study.

Results for the existing risks, construction phase and future operational phase all lie in the acceptable region of the FN curves, although they lie close to the ALARP region. Societal risks are highest during the construction phase which overlaps with construction for the Preliminary Treatment Works. The additional population from these groups of workers increases the societal risks but risks remain in the acceptable region. This increase in risk is predominantly due to workers at the Preliminary Treatment Works site which is immediately adjacent to the LPG Depot. Additional risks from the MTR construction workers are negligible and amount to about 1%.

The South Horizons station, once complete, is also expected to make negligible contribution to societal risks since the station population will be below ground and will be unaffected by possible incidents at the LPG Depot.

Assessment of large gas releases from road tanker or storage tank ruptures suggest that it is not possible for flammable gas to ingress into the South Horizons Station through vent ducts in significant quantities. Nevertheless, as an additional precaution, it is recommended to provide gas detectors in the air intakes which automatically close the HVAC dampers in case of gas detection.

The 10^{-5} per year individual risk contour remains on site and meets Hong Kong Risk Guidelines criteria.

8 REFERENCES

Alvanon, 2008, Chinese Body Measurement Study, www.avanon.com

Baum M. R., 1988, Disruptive failure of pressure vessels – preliminary design guidelines for fragment velocity and the extent of the hazard zone, J. Press. Vess. Technol. – Trans ASME 1988:110:168-76.

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

CCPS, 1999, Guidelines for Evaluating the Characteristics of Vapor Cloud Explosions, Flash Fires, and BLEVEs, Center for Chemical Process Safety.

Centamap, 2009, http://www.centamap.com

CIA, 1998, Guidance for the Location and Design of Occupied Buildings on Chemical Manufacturing Sites, Chemical Industry Association, CIA/CISHEC/9802/CP/500/2M.

ENSR, 2008, Harbour Area Treatment Scheme (HATS) – Stage 2A EIA Study – Investigation, Agreement No. CE 43/2005.

ERM, 2003, Discovery Bay's 4th LPG Compound: Quantitative Risk Assessment.

ERM, 2006, Liquefied Natural Gas (LNG) Receiving Terminal and Associated Facilities – EIA Study.

ERM, 2008, Introducing NG/LPG Buses and Heavy Duty Vehicles in Hong Kong – Feasibility Study, Agreement No. CE 49/2006, Electrical & Mechanical Services Department, Government of Hong Kong SAR.

ERM, 2009, Environmental Impact Assessment of Hong Kong Section of Guangzhou-Shenzhen-Hong Kong Express Rail Link: Appendix 13 - Hazard to Life Assessment.

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

Crossthwaite, P. J., Fitzpatrick, R. D., and Hurst, N. W., Risk assessment for the siting and developments near liquefied petroleum installations, IChemE Symposium Series No. 110, 1988.

Lees, F. P., 1996, Loss Prevention in the Process Industries, Butterworth-Heinemann.

Maunsell Environmental Management Consultants, 2006, QRA for Tung Chung LPG and Petrol Filling Station.

N.W. Hurst, C. Nussey, R.P. Pape, 1989, Development and Application of a Risk Assessment Tool (RISKAT) in the Health and Safety Executive, Chem. Eng. Res. Des., Vol. 67.

Planning and Lands Bureau, 2000, PHI Register, Government of Hong Kong S.A.R.

Shell, 2009, Personal Communication.

Stawczyk, J., 2003, Experimental Evaluation of LPG Tank Explosion Hazards, Journal of Hazardous Materials B96, pp.189-200.