9 RISK ASSESSMENT

9.1 Introduction

9.1.1 Background

The Preliminary Environmental Review of the proposed Project (April 1997) identified the major potential environmental and risk impacts which would require further study at the detailed design stage.

A Risk Assessment is required as part of the detailed feasibility study. This chapter presents the results of the Risk Assessment Study.

9.1.2 Aims

The purpose of the Risk Assessment Study is to provide the following information on the nature and extent of risk impacts arising from the construction and operation of the Project for the consultation zones associated with four potentially hazardous installations within 1000m of the road section between Nam Wan Kok and Sai Tso Wan:-

- To establish whether the risk impacts that arise as a result of the Project are within the established standards/guidelines;
- To identify and resolve any risk assessment issues which will impact on construction activities or operation of the Project;
- To identify and describe the elements of the community and facilities likely to be affected by the Project;
- To identify, predict and evaluate the residual (i.e. after practicable mitigation) environmental impacts and cumulative effects expected to arise during the construction and operational phases of the Project in relation to the potentially hazardous facilities and the community who could potentially be affected; and
- To identify, assess and specify methods, measures and standards, to be included in the detailed design, construction and operation of the Project, which are necessary to mitigate and reduce impacts to acceptable levels.

In the study area, the Route 9 alignment is predominantly through industrial areas or established transport corridors. The road alignment is also within 1000m of four oil terminals (Shell Oil, Caltex Oil, CRPC Oil and Esso Oil) at Tsing Yi and an initial review of the potential hazards during construction and operation is also included.

9.1.3 Study Area

The boundary of the “study area” for the purpose of risk assessment will be sections of the road alignment which fall within the 1000m radius consultation zone of the each of the potential hazardous installations (i.e., Shell, Caltex, Esso and CRPC Oil Terminals).

The 1000m radius consultation zones surrounding the four facilities encompass that section from the Route 3 interchange near the Ting Kau Bridge, elevated across Sai Tso Wan area, past Shell and Caltex, through the Nam Wan tunnel, past Esso and CRPC, to approximately 1 km south east of the eastern portal at Nam Wan Kok near the Stonecutters Bridge.

9.2 Study Scope And Objectives

9.2.1 Study Area

The Risk Assessment Study follows usual Quantitative Risk Assessment (QRA) methodology from Hazard Identification through Frequency Estimation and Consequence Assessment to Risk Assessment and Conclusions.

The analysis and results address the Route 9 sections which have been subdivided, broadly as follows:

- Western Portal to North West Tsing Yi Interchange (Shell, Caltex);
- Nam Wan tunnel and ventilation facilities, (all terminals);
- Eastern Portal and Nam Wan Kok / Chun Fa Lok Interchange (Esso, CRPC).

9.2.2 Risk Assessment

Hazards may arise because the road alignment is reasonably close to the four oil terminals at Tsing Yi. Potential hazards which may arise during construction and operation require assessment.

The objectives of the risk assessment will include the following:

- identification of all hazardous scenarios associated with transport, storage and processing of dangerous goods (DG) taking into account equipment failures and human errors;
- execution of a (QRA) expressing population risks in both individual and societal terms;
- comparison of individual and societal risks with Government Risk Guidelines and comment on the acceptability of the assessed risk;
- identification of the risk management strategies required to render the risks acceptable; and
- identification and assessment of practicable and cost effective risk mitigation measures.

The methodology of risk assessment, the risk/hazard ranking system has been discussed with the relevant departments prior to the commencement of the detailed studies.

The study team discussed requirements with EPD and EMSD and held a meeting on methodology and study basis with EMSD in November ’97. Salient points from previous QRA studies involving all four Potentially Hazardous Installations (PHIs) were noted including the LPG storage involved, risk contour levels near the Route 9 alignment and the societal risk levels for the expected PHI conditions for the study period, post year 2000. The Riskprof ‘98 quantitative risk profiling model has been used for calculation.

It was noted that in view of previous detailed studies undertaken (The references in Appendix 9F), the Route 9 QRA should concentrate on assessment of the marginal impacts of Route 9 and not attempt to revise the basis of the PHI base risk assessments.

The Route 9 QRA would examine additional ignition risks to LPG releases and exposures of additional population in the vicinity to events from the PHIs.

Population data was obtained from the Census and Statistics Department (1996) for the Tsing Yi District and District S20 (Tsing Yi South) which showed a total of 15007 mostly resident in Housing Authority subsidised sale flats and private residential flats which are located beyond the range of effects.

The total population assigned to the Riskprof '98 model population files was 10,665 of which 8,589 were counted as present during various incidents. These included motorists on Route 9, Tsing Yi Road, Sai Tso Wan Road and those within the oil depots and neighbouring facilities. In accordance with societal risk practice, the internal industrial population of the facility involved in an incident is not counted in societal risk. The risk to these workers is considered in the individual risk assessment.

Initially, a total of eight population files were compiled for the societal risk calculations. These were for the four PHI sites, each excluding the site's own population in order to reflect the risk to surrounding populations only. Four files were created without Route 9 traffic and four with Route 9 populations.

In the latter, more detailed study of the Caltex and Shell sites, three periods were considered, i.e.

1. Day peak

2. Day off-peak

3. Night

This enabled a more accurate assessment of major risks as the estimated population and meteorological conditions and durations were applied for each period. The population data for these period are shown in Appendix 9E.

The CRPC site was also re-evaluated using the three period data to confirm that findings for the separation of CRPC and Esso from Route 9 held under daily variations of conditions.

9.3 Description of Route 9 Project

9.3.1 General

The Project is a dual three-lane trunk road linking North West Tsing Yi and West Kowloon with several link roads interfacing with other major trunk roads such as Route 16, Cheung Tsing Highway and West Kowloon Highway (WKH). Route 9 is expected to carry high traffic flows, in the region of 9000 vehicles/hour under the worst-case scenario. The proposed development includes the 1.2km twin tube Nam Wan Tunnel, the Stonecutters Bridge and open road sections at grade or on viaduct.

The Tsing Yi Island sections within this study area involve:

- Western Portal and Link Roads to North West Tsing Yi Interchange;
- Nam Wan tunnel and ventilation facilities; and

- Eastern Portal, CT9 Slip roads and Stonecutters Bridge.

The Tsing Yi reclamation works will be carried out by the CT9 developer as part of the CT9 reclamation.

9.3.2 Horizontal and Vertical Alignment

Most of the Route 9 carriageways will be located on viaduct with conventional concrete parapet safety barriers. This assessment assumes typical pavement widths and parapet barrier heights of approximately 1 metre.

Table 9.3.1 : Location of Population Centres Relative to Route 9 (R9)

ID	Description	Horizontal Distance	Elevation
TYTC	Hong Kong Technical College (Tsing Yi)	70m from ramp of R9 at East Tsing Yi	overlooking the ramp
MAY	Mayfair Garden	200m from ramp of R9 at East Tsing Yi	overlooking the ramp
MFC	Mei Foo Sun Chuen	180m from slip roads of R9	overlooking the slip roads
EPA	Adjacent Areas near East Tunnel Portal (such as Dow Chemicals, Factory Building, near CRPC)	underneath main carriage-way of R9, Tsing Yi east	25m below main carriage of R9
WPA	Adjacent Areas near West Tunnel Portal (office building at Caltex)	underneath main carriageway of R9, Tsing Yi west	40m below main carriage of R9

Location of population centres relative to Route 9 are shown in Table 9.3.1. The total length of Route 9 in the study area is some 7.6km including the Nam Wan Tunnel. Figure 9.3.1 shows the R9 alignment with a 1000m buffer zone encompassing the four PHIs.

9.3.3 Traffic

Traffic is a potential source of ignition as well as a target for risk effects from the nearby PHIs.

The peak hour flows and percentages of good vehicles, provided by the traffic and transport workstream were used to establish the worst-case scenario for assessment purposes. To give a clear picture for vehicle volumes in the study area, a series of representative road sections (1 to 4) has been identified with reference to the locations of the nearby or adjacent landuses. The details of each road section are summarised in Table 9.3.2 and Figure 9.3.1.

Table 9.3.2 : Road Section Details in Tsing Yi Study Area

Road Section	Road Network	Traffic [(1)] Data	Sensitive Landuses
1	R9 mainline between Stonecutters bridge west tower and Nam Wan Tunnel eastern portal	9010 veh/hr 36% GVs	new land for future use
2	R9 eastbound slip road from CT9 to R9	1606 veh/hr 59% GVs	new land for future use
3	R9 westbound slip road from R9 to CT9	1173 veh/hr 64% GVs	Hong Kong Technical College (Tsing Yi), Mayfair Garden, CRPC, Esso Oil Depot
4	R9 mainline from Nam Wan Tunnel western portal to Cheung Tsing Highway	7580 veh/hr 28% GVs	office buildings at Caltex, Shell Oil Depot

N.B: GV denotes Goods Vehicle

Data based on most conservative estimates available and subject to change

(1) The traffic flows were subsequently refined for the Final TIA, the flows were slightly lower than those used for the risk assessment, and not considered to have a significant effect on the findings of the QRA.

9.3.4 Nam Wan Tunnel

The risk of smoke entering the tunnel due to an accident resulting in fire at one of the oil terminals or flammable LPG release is identified as relevant to this risk study. The study assesses the risk in terms of consequence to check if harmful concentrations would reach the tunnel portals and, if so, whether risk levels are within acceptable limits or further measures are required.

9.4 Description of Potentially Hazardous Facilities

9.4.1 Location of Depots

Within a 1000m distance of the Route 9 route, there are four petroleum depots which store LPG in large quantities for which the potential for major hazard to or from Route 9 needs to be assessed. The route therefore is within the 1000m consultation zone for each of these terminals which are subject to the Potentially Hazardous Installations planning and licensing requirements of the EPD and EMSD (Figure 9.3.1).

These depots and the approximate distance to their LPG ship unloading jetties and LPG storage facilities is shown below:

Table 9.4.1 : Distance (m) to Route 9 from Depots

Depot	LPG Ship and Jetty	LPG Storage Facilities
Shell	700 - 900	200 - 300
Caltex	650 - 700	550 - 600
Esso	800 - 1100	850 - 1100
CRPC	700 - 1000	650 - 1000

Dangerous Goods (DGs) other than LPG include liquid petroleum fuels and oils. At CRPC, oil, solvents and chemicals such as toluene, acetone and styrene monomer are also stored and handled. The requirements, for appropriate separation between major inventories of hazardous materials such as LPG and other facilities, take account of the risks of accidental release and the risks to people at facilities nearby from fire, explosion or toxic effects. The potential for risk to be increased by causal factors such as initiating events, ignition and escalation is also considered. Factors which could impede mitigating measures include:

- traffic being stopped due to flammable release which could prevent access by emergency vehicles; and
- inability for people to escape from a hazardous area due to smoke and confinement of the R9 carriageway.

9.4.2 Storage Facilities

9.4.2.1 LPG Storage

LPG is stored at all four facilities (Table 9.4.2).

Table 9.4.2 : LPG Throughput and Storage

Depot	LPG Throughput (tonnes per year)	Storage Vessels	Storage Type
Shell	Information not available	4 vessels, total 3000 te	Mounded bullets
Caltex	37800 LPG	3 x 1000 te tankers 6-7 te	Spheres
Esso	Information not available	3 x 850 te	Future mounded bullets
CRPC	35000 LPG	3 x 700 te tankers 8 te	Cylinders, sand mounded bullets

9.4.2.2 Petroleum Storage

The CRPC terminal stores liquid petroleum products including leaded and unleaded gasoline, diesel, kerosene and oils. Flammable liquid storage adds to the risks at the terminal but does not contribute to off-site risk due to the distances to Route 9. Shell, Caltex and Esso also store and handle a range of petroleum liquids.

9.4.2.3 Chemical Storage

The products include toluene, isopropyl alcohol, acetone and styrene monomer.

9.4.3 Potentially Hazardous Operations

The terminal has an LPG cylinder filling station, fuel, oil blending facility and boiler for heating heavy fuel oils.

Large storage tanks could be damaged by flying objects or severe blast effects from use of explosives nearby. Use of explosives in tunnelling and foundation work will need to be rigorously controlled to prevent missile risk to storage tanks or terminal pipework. It is noted that the tunnel alignment and orientation is not in the direction of any of the oil terminals.

Smoke from a major fire at the terminals could reduce visibility and air quality on Route 9. Emergency response plans should be initiated by the operators / owners of PHIs in the event of a major fire because of the risks of smoke and possible explosion events from escalation to LPG facilities and fuel storage tanks. The possible need to close Route 9 to non-essential traffic and to provide tunnel safety through operation of ventilation systems would need to be included in the external emergency response plans for the terminals. Emergency response plans should be made available before regular Route 9 traffic operations commence.

Safety concerns arise principally from the increased population on Route 9 and potential for ignition from passing vehicles.

The numbers of people in the area due to use of the route within the hazard area for a major event such as a fireball, flashfire or jetfire or from projectiles from exploding vessels or equipment at a depot, will increase. In this respect it is important to consider that other roads and facilities exist closer to the depots and these already have increasing population and use. Whether the risk to people on Route 9 and in the vicinity will actually increase depends on the design including the vertical alignment, route traffic characteristics and the time of exposure.

Traffic densities and exposure duration may be significantly reduced by the addition of Route 9 compared with current frequent local traffic congestion.

Potential for ignition of a flammable LPG cloud due to passing vehicles may increase. Ignition of potential LPG releases is a usual concern for any traffic route in proximity to LPG facilities. At Tsing Yi, the events of concern to or from R9 are the major release events such as storage vessel rupture, which could result in large clouds.

Ignition of large flammable clouds, is likely with typical ignition probabilities of the order of 0.8 due to ignition from sources in the vicinity. Any cloud large enough to reach Route 9 would probably be ignited prior to reaching an ignition source on Route 9.

The elevation of Route 9 is above the normal height of dense flammable LPG clouds, particularly for the two closest depots, i.e. Shell and Caltex.

It may be expected therefore that the additional ignition risk due to Route 9 will be found to be very low, particularly as other roads at ground level between Route 9 and the depots would be encountered first.

9.4.4 Meteorological Data

Data was obtained for Tsing Yi from the "TYSOUTH" station. Windspeed, Stability Class, Weather Class and Wind Direction Percentage Frequencies (Tables 9.4.3 and 9.4.4) were available.

Table 9.4.3 : Windspeed and Stability Classes

Weather Class	Windspeed (m/s)	Pasquill Stability	% Occurring	
			Day	Night
I	1.0	D	50	50
II	2.5	B	100	0
III	3.5	D	50	50
IV	7.0	D	50	50
V	3.0	E	9	91
VI	1.0	F	7	93

Table 9.4.4 : Weather Class - Wind Direction Percentage Frequencies at "TYSOUTH", Tsing Yi Island

Direction	Weather Class					
	I 1.0m/sD	II 2.5m/sB	III 3.5m/sD	IV 7.0m/sE	V 3.0m/sD	VI 1.0m/sF
346-015	1.480	0.333	1.333	0.060	1.248	2.318
016-045	1.289	0.231	0.843	0.035	0.779	1.832
046-075	1.441	0.855	2.859	0.155	1.523	2.045
076-105	1.677	1.475	7.568	1.028	4.271	3.068
106-135	1.196	2.194	7.823	1.646	2.674	1.787
136-165	1.413	1.984	3.808	0.329	1.134	1.687
166-195	1.397	2.101	3.317	0.095	1.735	1.886
196-225	0.792	0.395	0.755	0.015	1.038	0.886
226-255	0.427	0.214	0.103	0.000	0.089	0.491
256-285	0.601	0.377	0.536	0.000	0.276	0.694
286-315	1.498	0.282	1.488	0.035	0.764	1.387
316-345	1.816	0.477	2.870	0.300	1.237	1.816
	15.027	**10.918**	**33.303**	**3.698**	**16.768**	**19.897**

Wind direction probability for each stability category taken from the Tsing Yi meteorological station data was converted to 16 point data for use in RiskProf '98. The method used for conversion was fractional conversion where base data in twelve directions was distributed simply, without smoothing, to 48 directions and then summed into the 16 main points. This was performed for all the stability/windspeed weather categories.

The sixteen point data obtained is presented in Table 9.4.5.

Table 9.4.5 : Tsing Yi Weather /Wind Frequency Data Converted to Sixteen Points

Direction	I 1.0m/sD (D1)	II 2.5m/sB (B2)	III 3.5m/sD (D4)	IV 7.0m/sE (D7)	V 3.0m/sD (E3)	VI 1.0m/sF (F1)
N	1.110	0.250	1.000	0.045	0.936	1.739
NNE	0.991	0.186	0.694	0.029	0.643	1.435
NE	1.024	0.407	1.388	0.071	0.863	1.454
ENE	1.110	0.719	2.733	0.225	1.486	1.662
E	1.258	1.106	5.676	0.771	3.203	2.301
ESE	0.957	1.556	5.835	1.157	2.205	1.500
SE	0.978	1.567	4.362	0.741	1.428	1.303
SSE	1.058	1.503	2.795	0.218	0.926	1.290
S	1.048	1.576	2.488	0.071	1.301	1.415
SSW	0.670	0.510	0.887	0.021	0.866	0.790
SW	0.457	0.228	0.322	0.006	0.423	0.516
WSW	0.342	0.181	0.131	0.000	0.090	0.394
W	0.451	0.283	0.402	0.000	0.207	0.521
WNW	1.011	0.223	0.997	0.022	0.512	0.954
NW	1.243	0.285	1.634	0.126	0.750	1.201
NNW	1.320	0.340	1.960	0.195	0.929	1.425
Total	**15.027**	**10.918**	**33.303**	**3.698**	**16.768**	**19.897**

Analysis of the probabilities for the south to west quadrant, in which all the oil terminals are located with respect to R9, showed that D3.5 and F1 were the predominant condition categories with percentage occurrences of 25% and 22% of the time that the wind blew in the direction of R9. These were then followed by D1, B2 and E3 with occurrences of 18%, 17% and 17% respectively as shown in Table 9.4.6.

Table 9.4.6 : Analysis of Weather Category Direction

Occurrence from oil terminals to Route 9 (South to West Quadrant)

Category	1.0m/s D	2.5m/s B	3.5m/s D	7m/s D	3.5m/s E	1.0m/s F	ALL
All directions	0.15	0.109	0.333	0.37	0.168	0.199	1.0
s-w quadrant	0.03	0.028	0.042	0.001	0.029	0.036	0.166
% of winds in sw quadrant	18%	17%	25%	1%	17%	22%	100%

The low occurrence of D7 and similarity of consequence results for E-D through the range 3 to 6 m/s enabled combination of the categories in these Stability Class D-E ranges, to simplify the assessment.

The four weather categories adopted for consequence results and weather input to RiskProf as shown in the Table 9.4.7.

Table 9.4.7 : Weather Categories

Category (Stab, m/s/)	D1	B2	D4	F1	ALL
Probability of cat'y	0.1503	0.1092	0.5380	0.1990	1.0000
Direction wind from	Probability of Direction given category				
N	0.0739	0.0229	0.0368	0.0874	0.0510
NNE	0.0659	0.0170	0.0254	0.0721	0.0399
NE	0.0681	0.0373	0.0432	0.0731	0.0523
ENE	0.0739	0.0658	0.0826	0.0835	0.0797
E	0.0837	0.1013	0.1795	0.1156	0.1437
ESE	0.0637	0.1425	0.1711	0.0754	0.1326
SE	0.0651	0.1435	0.1215	0.0655	0.1042
SSE	0.0704	0.1376	0.0732	0.0648	0.0782
S	0.0697	0.1443	0.0718	0.0711	0.0793
SSW	0.0446	0.0467	0.0330	0.0397	0.0376
SW	0.0304	0.0209	0.0139	0.0260	0.0196
WSW	0.0228	0.0166	0.0041	0.0198	0.0114
W	0.0300	0.0259	0.0113	0.0262	0.0187
WNW	0.0673	0.0205	0.0285	0.0479	0.0373
NW	0.0827	0.0261	0.0467	0.0604	0.0526
NNW	0.0878	0.0311	0.0574	0.0716	0.0619

Other key meteorological data used in the study was Average Ambient Temperature at 23ºC and Relative Humidity of 78%.

9.4.5 Local Topography

The four oil terminals are located on a coastal fringe of reclaimed land at elevations between 4 to 6 metres above mean sea level at the base of a steep hill, 334m high. The hill rises between the Caltex terminal on the west and the Esso and CRPC terminals on the South to SE to form a barrier comprising a hill (160m) near the south western tip of Tsing Yi dropping to 125m then rising up to the 334m summit. Route 9 Nam Wan tunnel is designed to pass below the summit. Route 9 runs to the northwest of the Shell and Caltex terminals and east of CRPC.

Tsing Yi Road is located around the base of the hill between the terminals and the slope. The road has been formed by cutting into the slope. Above the cut slopes the hill rises at a gradient of approximately 1 in 3.

The high terrain presents a significant barrier to heavy gas dispersion in the direction of the slope. Winds speeds from the terminals to Route 9 are characterised by low speeds of 4m/s or lower. LPG in its flammable range is heavier than air and would tend to slump into a low cloud along the reclaimed coastal fringe, draining into lower areas including the sea and drainage channels.

9.5 Hazard Identification

9.5.1 Hazards for Evaluation

A number of hazard scenarios are identified for further consideration. The hazards identified form the basis of the study. Some hazards may be found to have effects only over distances which do not reach Route 9 or its construction zone. Others may be found to be of such low frequency and effect that they do not contribute to risk at Route 9. The evaluation of these hazards in to their risk components is presented in the Sections 9.6 to 9.8.

The hazardous nature of LPG and other flammable petroleum products primarily involve the risks of fire and explosion. The development of these risks involves release of product from its containment and ignition of a flammable mixture and the effects of fire and explosion outcomes including jet fire, pool fire, flash fire, explosion and blast effects, and fireball. Damage may result from burns, ignition of other materials and resulting subsequent fire, e.g. of buildings, heat radiation, blast overpressure, missile damage, oxygen deficiency and smoke effects, etc.

Hazard identification involves examination of inventories of hazardous material, determining how release may occur, identifying sources of ignition and development scenarios to final undesired outcomes.

LPG releases for product stored in its liquefied state may be in liquid or vapour phase or in the 2-phases form where both states are present, depending on the location of the breach and characteristics of the discharge orifice or pipe.

The four terminals activities are concerned with ship unloading, bulk storage, loading into bulk tankers or cylinders and drums and transportation out of the terminal by road or sea.

The installations comprise :

- ship unloading facilities at jetties equipped with loading arms and hoses, jetty pipework with Emergency Shutdown valves for rapid isolation at the ship interface, as well as shore-line during unloading if a leak or rupture occurs, distribution pipework within the terminal to the storage vessels;
- storage vessels equipped with isolating and relief valves and fire protection systems. Leak detection systems are provided to warn if leaks occur. Storage vessels are protected by insulation at supports and deluge systems, if above ground as for Caltex, and by sand mounding in the case of more recent installations at Shell and CRPC;
- export pipework to the tanker loading bays and LPG cylinder filling facilities;
- export facilities to LPG barges.

The terminals also handle liquid petroleum products including gasoline and oil. These are stored in atmospheric storage tanks. Heavier oil products may be heated by hot oil systems on the site.

The hazard identification has been undertaken as a common exercise for all terminals based on industry standard equipment and practices. In the following steps of consequence assessment and frequency estimation, specific differences between the terminals are considered in specifying the source terms for release events and the

application of frequency rates and event outcome probabilities. The hazard identification is summarised in Table 9.5.1.

Table 9.5.1 : Hazard Identification

Section / Activity	Component	Initiating Event	Potential Outcomes
LPG Import	Ship LPG Tanks	Tank Rupture	pool fire, flash fire BLEVE, fireball
	"	Tank Leak	pool fire , jet fire flash fire, explosion
	Unloading	Arm/Pipe rupture	pool fire , jet fire flash fire, explosion
	"	Arm/Pipe leak	pool fire , jet fire flash fire, explosion
LPG Storage	Spheres, Cylinders	Vessel Rupture	pool fire, flash fire BLEVE, fireball
	"	Vessel leakage	pool fire , jet fire flash fire, explosion
LPG Export	Export bays	Pipe / arm leak	pool fire , jet fire flash fire, explosion
LPG Road Tankers	Tanker in terminal or on road	Vessel Rupture	pool fire, flash fire BLEVE, fireball
	"	Pipe leak	pool fire , jet fire flash fire, explosion

9.5.2 Other Hazards

Other hazards identified which were not specifically evaluated in this study but noted for possible consideration if found to be relevant were:

9.5.2.1 Major Oil Spillage on the Sea

A major oil spill could spread to the bridge on the eastern side of Tsing Yi Island. The bridge supports are expected to be on land reclaimed for Container Terminal uses.

During construction, it will be necessary to provide procedures and event action plans to cover rapid cessation of construction activities, particularly those activities involving ignition sources, such as welding, cutting and machinery operation, in the event of a flammable liquid spill in the vicinity. Such procedures and action plans should be prepared by the Contractor with advice from specialists and consultation with relevant authorities and the oil companies.

9.5.2.2 Dangerous Goods Transportation

Spillage from road tankers

Construction and operation of the Route 9 should not present any additional risks beyond those for which DG vehicles are currently designed and operated.

DG vehicles construction risks

Construction traffic impacts will need to be considered to avoid imposing significant delay times on DG vehicles. Regular delays would pose an additional local risk due to longer presence of DG vehicles in the area. Delays of greater than 15 minutes should be avoided where practicable to minimise the risks. Responsibility for management of traffic impacts will fall with the Contractor.

Use of explosives in tunnelling and foundation work will need to be rigorously controlled to prevent missile risk to vehicles including DG vehicles.

Heavy construction vehicle collision with DG vehicles will need to be avoided by proper segregation of construction activity and construction traffic. Such procedures will be the responsibility of the Contractor.

9.5.2.3 Petroleum Storage Facilities

Large storage tanks could be damaged by flying objects or severe blast effects from nearby use of explosives. Use of explosives in tunnelling and foundation work will need to be rigorously controlled to prevent missile risk to storage tanks or terminal pipework. It is relevant that the tunnel alignment and orientation is not in the direction of any of the oil terminals.

Major fire at the terminals could result in smoke; affecting visibility and air quality on Route 9. In the event of a major fire, the risks of smoke and possible explosion events from escalation to LPG facilities and fuel storage tanks, emergency response plans would be initiated. The possible need to close Route 9 to non-essential traffic and to provide tunnel safety through operation of ventilation systems needs to be included in the external emergency response plans for the terminals. Emergency response plans should be made available before regular Route 9 traffic operation commences.

Safety concerns within the study scope have been reviewed in Section 9.4.3.

9.6 Consequence Assessment

9.6.1 LPG Storage and Risk

Scenarios which may cause hazard within the study zone, i.e. the sections of the road alignment which fall within the 1000m radius consultation zone of each of the potentially hazardous installations (i.e. Shell, Caltex, Esso and CRPC Oil Terminals) were investigated and evaluated (Table 9.6.1).

Table 9.6.1 : Distance of PHIs and Typical Effect Distances

Depot	Distance (m) from LPG Ship and Jetty to Route 9	Distance (m) between LPG Facilities and Route 9	Effect Distances for LPG Flammable Clouds (m)	Effect Distances for Major LPG Fireball Events (m)
Shell	700 - 900	200 - 300	275	194- 245
Caltex	650 - 700	550 - 600	400	290- 380
Esso	800 - 1100	850 - 1100	275	194- 245
CRPC	700 - 1000	650 - 1000	275	194- 245

The largest risks in the study area are associated with the LPG storage facilities and ship unloading in the event of major release of LPG. Three risk events need to be considered,

i.e. Flammable vapour cloud reaching the Route 9 study area, fireball from vessel rupture and ignition and explosion effects. These are considered as follow:

9.6.2 Flammable LPG Vapour Extension Toward the Route 9 Alignment

The essential contributing factor for an LPG cloud to reach Route 9 is a large release of LPG. A 600 tonne release was considered as the base case for dispersion modelling (Table 9.6.2).

Variations evaluated were:

Instantaneous release:	Initial mixing/jet entrainment of 30% air No initial mixing / entrainment of air	
Jet release:	Unobstructed release through 200mm nozzle	
and	Coefficient of discharge for vapour of 0.9	
and	Coefficient for 2 phase flow of 0.61	
Ambient Temperature:	3 cases Average of	23°C
	High	28°C
	Low	13°C
Direction of release:	3 cases Vertical upward Horizontal downwind 30/ 45/ 60 degrees upward and downwind	
Height of cloud:	11 levels from Ground Level	
and	5m intervals to 50m high	

Time after release is an important factor. Release times exceeding an hour were considered as appropriate to evaluate maximum concentrations over time at levels and locations of interest, e.g. within flammable limits and below at alignment and elevations up to the vertical alignment of the proposed Expressway or Tunnel Portal.

The modelling established the most critical factors and their associated dispersion results. Concentrations are below the flammable range (approximately 1.9 to 9.5% vol/vol) at ground level Route 9. At traffic level the cloud is well dispersed to two orders of magnitude less approximately 0.005 of the Lower Flammoble Limit (LFL) at 20m and approximately 10-6 of the LFL value at 40m height. The effective cloud height to 10% glc varies from about 1 m to 12 metres at the nearest expressway location.

Table 9.6.2 : LPG Release Scenarios

Scenario	Atmospheric Conditions	Ambient Temp.	Distance Downwind	Concentration LPG in Air v/v	Time from Release (minutes)
600 te Vapour release	D 3 - 4 m/s	25 -28℃	300m 800m-1000m	1.0 - 1.1% (LFL/2) 0.7% (0.4xLFL)	4.5 to 45
600 te Liquid release	D 4 m/s	25℃	300m 500m	1.9% (LFL) 0.44 (LFL/4)	2.5

The worst case was the liquid release of 600 tonnes, which provides a high initial release rate with minimal initial dilution. The flammable cloud could extend to 275m downwind. However, concentrations at the height of the R9 Expressway are insignificant. The decrease in concentration with height is shown in the Table 9.6.3 (at 500m) and Table 9.6.4 (at 300m). These tables represent worst case scenarios, e.g. from ship tank ruptures or a major release from the Caltex unmounded storage. A 600 tonne release from the closest LPG facility, Shell Mounded Storage, would be a very low frequency event due to the containment and insulation provided by the mounding.

Table 9.6.3 : LPG Concentrations at 500m for 600 te Liquid Release

Height above Ground	Maximum LPG % vol	Fraction of glc
50m	1.4E-04	3.1E-04
45m	4.1E-04	9.3E-04
40m	1.2E-03	2.6E-03
35m	3.1E-03	7.1E-03
30m	8.0E-03	1.8E-02
25m	1.9E-02	4.4E-02
20m	4.4E-02	1.0E-01
15m	9.4E-02	2.1E-01
10m	1.8E-01	4.1E-01
5m	3.1E-01	7.1E-01
Ground Level	4.4E-01	1.0E+00

Table 9.6.4 : LPG Concentrations at 300m for 600 te Vapour Release

Height above Ground	Maximum LPG % vol	Fraction of glc
50m	8.01E-09	7.97E-09
45m	9.78E-08	9.74E-08
40m	1.08E-06	1.08E-06
35m	1.07E-05	1.07E-05
30m	9.45E-05	9.41E-05
25m	7.31E-04	7.28E-04
20m	4.89E-03	4.87E-03
15m	2.77E-02	2.75E-02
10m	0.12762	1.27E-01
5m	0.45155	4.50E-01
Ground Level	1.0043	1.00E+00

A horizontal release toward the expressway provides initial velocity and less air entrainment resulting in a cold low cloud extending downwind. Jets which angled into the air, e.g. at 10 degrees and above were diffused rapidly to below the flammable limits before slumping to ground. Levels at ground level and at elevations are shown in Table

9.6.4. The two Tables 9.6.3 and 9.6.4 from different modelling runs demonstrate the rapid reduction of concentration with increase in height.

During construction, concentration at ground level which may also accumulate in excavations below ground level have been considered. Results with concentrations at half the lower flammable limit (LFL) (approx. 1% vol) are considered as hazardous. A lower level than the LFL is adopted for further assessment to allow for uncertainties in the modelling, uneven terrain effects, potentially hazardous effects such as fuel enrichment of combustion engines and risk of involvement in fire or explosion due to effects outside of the normal flammable range, although this last factor is not expected.

Rupture of an LPG vessel with ignition of the rich cloud of vapour (BLEVE) or boiling liquid expanding vapour explosion results in a fireball which is of immediate risk to people in the vicinity, especially those outdoors. The fireball hazard is of particular concern for nearby and elevated targets exposed to the high heat radiation levels or flame intensity of the fireball.

The original fireball modelling was carried out using a model based on the fireball equations by Crossthwaite given in Appendix 9D. This model was used in previous studies by ERM. A limitation of that model is that it does not allow for the height of the observer or target exposed to the fireball.

The elevation of Route 9, near the Shell and Caltex terminals, means that people on Route 9 would be closer to the heat radiation source of a fireball from these terminals. The "TRCB" model developed by the Shell Thornton Research Centre, a leading UK research institution for heavy gas dispersion and fire modelling, has been used for further study to examine the effects to elevated targets. TRCB was used to recalculate fireball hazard distances for Shell and Caltex. In addition, three failure cases for "cold catastrophic failure" of the mounded LPG vessels at the Shell Terminal were also included. The hazard distances are given in Tables 9.6.5 and Table 9.6.6.

The distance to a heat radiation lethal dose level of LD50% is based on the heat radiation dose criteria for fireball effects suggested by Lees, which is built into the model.

In RiskProf99, the lethality/distance profile has also been re-calibrated based on the TRCB model results for the fireball scenarios, in order to accurately reflect the risks which may result in fatality.

One concern was that the risks to people at ground level need to be modeled for their elevation as a separate set of targets for the same fireball risk events as for Route 9, which was achieved by running discrete societal risk runs for:

- the 35 m average Route 9 elevation near Shell and Caltex; and
- ground level populations.

The results are then combined to provide overall results.

Understanding the contribution of the various events to risks on Route 9 required analysis of the results. The following were examined to show the respective importance of risk events and their impacts:

- FN Pairs shown separately and combined for fireball and flashfire events for the 3 time periods, Day (non-peak), Peak and Night;
- PLL (potential loss of life) contribution for the six types of risk scenario; and
- Individual risk contribution from each of the above types of risk scenario.

It was shown that flammable concentrations would not reach Route 9 at the elevations involved. Further, any ignition of a gas could in the direction of Route 9 would most likely occur at or near Sai Tso Wan Road, thus truncating the further development of the cloud before Route 9.

In order to avoid overestimation of risk to Route 9, from the larger release scenarios of cold catastrophic mounded LPG failure, the elevated population was excluded from the ground level flashfire effects.

The fireball hazard is reduced by the protection of LPG storage vessels with sand mounding. The BLEVE risk is mainly due to failure of the LPG containment to withstand high heat exposures such as jet fire impingement of direct LPG pool fire engulfment. The storage installations at Caltex and Esso are not mounded although the consultants have been informed that Esso will adopt mounded storage, prior to Route 9 construction.

Sand mounded pressurised LPG storage has been used since around 1979 (Primagas, Duisberg and others) with several major installations being installed during the 1980's (Shell-Jortl and Boralgas, Port Botany, 1984, etc.) without any reported major incident with this type of storage protection.

The Hazard Distances for Fireballs as calculated by the formulae given in Appendix 9D are presented in Tables 9.6.5 and 9.6.6.

Table 9.6.5 : Fireball Distances based on rupture at relief valve pressure

Mass	Fireball		Distance to 50% Fatality Level (outdoor exposure)			
	Dimensions		(TRCB Model)			
Release	Diam	Duration	Distance	Height	Distance	Height
(te)	(m)	(s)	(m)	(m)	(m)	(m)
1776	*702*	*29*		*0*		*0*
1500	620	44	465	0	465	0
1184	573	41	444	0	444	0
840	511	37	382	20		
600	455	33	348	35		
300	355	30	256	35		

Table 9.6.6 : Fireball Distances based on Cold Fracture Rupture at Normal Pressure

Mass	Fireball		Distance to 50% Fatality Level (outdoor exposure)			
	Dimensions		(TRCB Model)			
Release	Diam	Duration	Distance	Height	Distance	Height
(te)	(m)	(s)	(m)	(m)	(m)	(m)
600	378	38	267	35	245	0
300	298	33	203	35	162	0
120	214	26	140	35	217	0
8	90	17	n.a.	0	45	0
6	81	16	n.a.	0	41	0

9.6.3 Major LPG Accidents Involving Fireballs Worldwide

The following incidents involving BLEVE and Fireballs are noted. All involved above ground, un-mounded storage, and it should be noted that design improvements to minimise risk of such occurrences are now incorporated in modern LPG installations such as those at Tsing Yi.

- Feyzin, 1966
- Ignition on road probably by vehicle, 90 minutes to BLEVE
- 17 fatalities including 11 firefighters
- Mexico City, 1984
- 1-12 minutes from ignition to BLEVE
- Crescent City, 1970
- 70 minutes to BLEVE
- Cairns, 1987
- 15 minutes to BLEVE
- St. Peters, 1990
- Source of ignition and time to BLEVE are not known precisely but BLEVE occurred minutes after arrival of firefighters as they were evacuating to a safe distance after assessing the situation.

9.6.4 Explosion

LPG may be explosive within its flammable range if the immediate environment provides confinement or obstacles in the flame path to accelerate the flame propagation beyond those velocities associated with flash fire to those giving blast effects.

Semi-confined areas such as LPG cylinder filling sheds may provide sufficient confinement and congestion to produce explosion but the mass of LPG which could be released in a single incident is limited and ignition sources are controlled. In the event of an explosion in the cylinder filling area, injurious effects are likely to be contained within the radius of projectile material and overpressures above approximately 0.2 bar. Other areas within the terminals are mostly open and risk of explosion rather than flash fire is low. A probability of explosion of 0.01 given delayed ignition has been adopted for

external areas. However, the alternative outcome of flash fire has similar effect distances in terms of risk to human life, with 100% fatality assumed within the LFL range.

While a number of models are available, it is common practice to use a multi-energy model for calculating blast overpressures in confined areas. For this study a simpler TNT equivalent model was used to provide a range of distance values. In view of the low frequencies obtained, the vapour cloud explosion risk is not a significant contributor to risk levels at Route 9.

Typical distances to overpressure values are shown in Table 9.6.7.

Table 9.6.7 : Distances to Over Pressure Values

Vessel Inventory	Vapour Cloud Mass	0.34 bar	0.21 bar
6 te tanker	3.6	68m	91m
8 te tanker	4.8	74m	100m
10 te tanker	6.0	80m	100m
300 te tanker	180	245m	336m
500 te tanker	300	295m	400m
600 te tanker	360	313m	424m
1000 te tanker	600	372m	502m

9.7 Frequency Estimation

9.7.1 Previous Studies

The study is essentially concerned with identifying changes in risk level due to Route 9. Each of the PHIs have been studied previously to determine base risk levels and the major contributions to off-site risk.

Base failure rates have been taken from previous studies to provide consistency. The rates are similar to those typically used for such studies and these provide a reliable basis available for assessment.

9.7.2 Frequency Estimation Process

Frequency estimation involves distinct steps as follows:

9.7.2.1 Failure Case Definition and Evaluation

- Assessing failure scenarios which result in releases.
- A base frequency is assigned to each failure scenario.
- The base rate is multiplied by a factor to accord with the unit assessed, e.g. per vessel per year.
- The rate may be further modified to account for differences between the original data base and the specific application. This usually involves judgment, either wholly according to a single factor or by structured and selective analysis of relevant features, e.g. elimination of certain failure contributions due to design solutions, or selection from a range of values.

- The frequency rates are distributed across a range of release sizes by applying distribution factors, e.g. for tank contents, full, half full, etc, and hole sizes or release rates.
- The frequency obtained by the product of the base frequency and the various multiplying factors or probabilities is the frequency of the release event.

Three additional failure cases were added during the study to take account of "cold catastrophic failure" of the mounded LPG vessels. This failure case is concerned with the potential for a rupture of sudden major release from a vessel without the failure due to overheating which is the established Boiling Liquid Expanding Vapour Explosion (BLEVE) effect in which the vessel contents are released at relief valve pressure with heat energy to volatilize most of the contents in an over-rich flammable cloud or mist and vapour.

Cold catastrophic failure involves different ratios of release versus residual liquid. The lower vapour pressure and less available heat involved than for a heated BLEVE will lessen the effect distance. The mechanisms of failure are also more likely to be inherent material or manufacturing defect with possible brittle failure if low temperature ductility has been lacking or impaired by embrittlement. These cases were applied to the four mounded LPG storage vessels at Shell and to the LPG vessels at CRPC (existing) and Esso (future).

9.7.2.2 Event Outcome identification and evaluation

- Developing outcome scenarios appropriate to the release type, e.g. instantaneous, continuous, liquid or vapour.
- Assessing ignition scenarios, immediate or delayed.
- Determining end events which represent the range of possible outcomes and providing the branching paths and probabilities for each end event path.
- Calculating the end event frequency from the initiating release event frequency and branching probabilities.

A typical event tree is shown in Figure 9.7.1.

9.7.3 Population Assessment

Population estimates are taken from Tsing Yi census Data 1996 and previous studies. Construction workers are excluded as was the case for the CT9 Risk Assessment.

Industry population data provided by the Oil Terminals have been used where available. This includes data in Table 9.7.1.

Table 9.7.1 : Industry Population Data

Site Population	Shell		Caltex		Esso		CRPC Assumed from Previous Data	
Shift	**Day**	**Night**	**Day**	**Night**	**Day**	**Night**	**Day**	**Night**
LPG Depot	50	2	35	0	*		50	n.a.
Office	7		60	4	17	0		n.a.
Rest of Depot	80	5	60	4	80	10	110	n.a.

* *not itemised separately but included in depot total*.

Traffic populations have been estimated from the Project Traffic Data and Route 9 Local Area Traffic Model. This data is shown in Table 9.7.2.

Table 9.7.2 : Traffic Data for Route 9

Traffic Flow AM peak Hour, All Vehicles including buses.

		Route 3	Route 9	Tsing Yi Rd	Sai Tso Rd
Year 2006	Westbound	1660	4070	660	490
Year 2006	Eastbound	1060	3530	440	380
	Two-way	2720	7600	1100	870
Year 2021	Westbound	1992	4884	792	588
Year 2021	Eastbound	1272	4236	528	456
	Two-way	3264	9120	1320	1044

Assumed buses per hour per direction on Route 9 45

(Note 50% of buses on Route 3)

Two-way peak to two-way off-peak factor 0.78

Route 9 –Year 2006	Peak Bus	Peak All Other	Peak Both	OffPeak Bus	OffPeak All Other	OffPeak Both
Vehicle Occupancy	78	1.5		37	1.4	
Vehicles	45	7555	7600	45	5893	5938
Total Occupants	3510	11333	14843	1665	8250	9915
Overall Occ. Per Veh			**1.95**			**1.67**

Route 9 –Year 2021	Peak Bus	Peak All Other	Peak Both	OffPeak Bus	OffPeak All Other	OffPeak Both
Vehicle Occupancy	78	1.5		37	1.4	
Vehicles	45	9075	9120	45	7071	7116
Total Occupants	3510	13613	17123	1665	9900	11565
Overall Occ. Per Veh			**1.88**			**1.63**

Data from the above model was compiled to provide average peak design vehicle flows in the sections of interest. Occupancy rate for peak hours (7am - 10am and 4pm - 7pm) for off-peak hours for years 2006 and 2021 were averaged to provide average future traffic populations. Percentages of heavy goods vehicles were noted and 45 buses per hour on R9 /hour/direction were included in the occupancies considered (Table 9.7.3).

The occupancy of interest is the population present or likely to arrive within the impact area before evasive action can be taken. The major hazards of BLEVE fireball and flash fire are of short duration only, being of approximately 20 to 30 seconds and almost instantaneous respectively. The fireball fatality model assumes exposure outdoor for the full fireball period. Any driver subjected to fireball radiation or flash fire engulfment would be at additional risk of collision so all vehicles likely to be in the impact zone within the main duration have been considered.

We have estimated the vehicle and population density based on approach time of 20 seconds and 330m impact zone. The population density is then considered on a unit distance basis, i.e. 50m as used for the RiskProf grid. In the QRA modelling all population within each impact zone is considered in the calculations which will vary from case to case.

Table 9.7.3 : Traffic Flow and Population Exposed to Fireball or Flashfire events.

Traffic Units	Direction	Route 3	Route 9	Tsing Yi	Sai Tso Wan
veh/hr	W bound	1660	4070	660	490
veh/hr	E bound	1060	3530	440	380
veh/hr	Total	2720	7600	1100	870
Year 2006		**Persons passing PHI sites over 20 secs**			
Persons per vehicle		Route 3	Route 9	Tsing Yi	Sai Tso Wan
Off-peak	1.67	28	80	12	9
Peak Hr	1.95	33	93	13	11
Persons per 330m		Route 3	Route 9	Tsing Yi	Sai Tso Wan
@ 60 kph	1.67	28	80	12	9
@ 20 kph	1.95	100	279	40	32
@ 0 kph		128.7	80	29	21
Persons exposed over 330m and 20 seconds.					
Off-peak		57	159	23	18
Peak Hour		133	372	54	43
Year 2006		**Persons per 50m section**			
Off-peak		9	24	3	3
Peak Hour		20	56	8	6
Average		14	40	6	5
Year 2021		**Persons per 50m section**			
Off-peak		10	29	4	3
Peak Hour		24	68	10	8
Average		17	48	7	6
Years 2006-2021 average		**Persons per 50m section**			
Off-peak		10	27	4	3
Peak Hour		22	62	9	7
Average		16	44	6	5

Traffic population North West of the Junction at 827500E is approximately 55 persons per 50m section with Route 9 flows of 30 persons per 50m added. A “presence” factor of 0.5 is used to provide average densities across both carriageways from the estimated design peak flows in each direction throughout peak periods (8am - 9am and 5pm - 6pm) and high off-peak periods. An “exposure” factor of 1 (totally exposed) is used although some protection may be afforded by most vehicles. The population is centred at the grid centre. The “***RiskProf***“ program distributes the population proportionately to nearest grid points, if they are not coincident.

Coordinates shown are not exact but were fitted to approximate the alignment at major intervals.

The population data files used in the assessment for Day, Reak and Night hours are detailed in Appendix 9E.

9.8 Risk Assessment

9.8.1 General

The Hong Kong individual risk and societal risk criteria have been applied to the results. Individual risk contours represent the risk at locations. The risk to people who spend most of their time at a specific location, e.g. residents, home workers, gate-house watchmen, etc. may be well represented by these contours. Allowance can be made for people who regularly spend a significant part of their time at a specific location, e.g. workers where the working time fraction may be factored into interpretation of the criteria.

The transient aspect of individual exposure means that road users passing a hazardous industrial facility may be exposed to risk of any accidental hazard, such as flammable gas or BLEVE for a time of only seconds or possibly minutes during heavy traffic conditions.

The time fraction of exposure to risk is minimal compared with usual residential exposures. A commuter passing a facility for one minute twice a day for five days a week would be exposed for 0.1% of his time only. However, in community terms, transient populations must be counted for each individual person at that location. Another may replace the individual at that location but the number of exposed people remains the same.

The design of the Expressway in the vicinity of the terminals should avoid factors likely to contribute to collision such as higher speed limits and imminent merging or queuing. Emergency escape provision for pedestrians and emergency vehicles access is recommended.

Both Individual and Societal Risk have been assessed for the study purposes. The results are discussed as follow:

The consequence assessment found that flammable concentrations of LPG would not reach the Route 9 carriageways, due to the combined effects of horizontal distance, which in the cases of all terminals except Shell was above sufficient. In addition, the effect of elevation above ground level reduced risks further. The nature of flammable LPG clouds is that at flammable concentrations, i.e. above the Lower Flammable Limit of about 2% vol. LPG in air, the cloud is heavier than air and spreads as a low flat cloud usually 2m or less in height, once initial slumping has occurred.

The height of the Route 9 carriageway above the level of the LPG terminals and the distances of the alignment from the major hazard sources of storage and LPG jetties is also shown in Figure 9.6.1.

This study examined LPG release cases to find any situations in which flammable vapour would reach the elevated Route 9 carriageways. No instance of hazardous concentrations was discovered which would present concern for ignition at the Route 9 alignment. Ignition prior to dispersion below the flammable range is probable due to nearby roadways at grade and other ground level ignition sources. In these cases, flash fire effects would not reach the Route 9.

The consequence assessment looked at all reasonable variations of source term, storage conditions, directions of release including various angles from the horizontal. The maximum distances remained within 300m. Uncertainty of event determination and of

modelling is a concern within quantitative risk assessment, although the consequence models are those of the HG System (for **H**eavy **G**as modelling) as used widely and developed and validated by the Shell Thornton Research Centre and others for use on products such as LPG and petroleum gases.

These models include Spill, Aeroplume, Hegadas, Hegabox, PGPlume and TRCB. Most of the critical modelling was carried out using Aeroplume and Hegadas - T. The models allow for calculation of instantaneous, steady state and transient releases of LPG from pressure vessels as jets or spills, and their dispersion under atmospheric conditions.

As the terminals have previously been assessed by QRA, an argument was developed as follows:

- that if this study modeled the major LPG releases, which have been determined previously as the main off-site risks, and,
- found base case risk levels consistent with or higher than the previous studies,
- then the additional risk shown for the Route 9 proposal should not be underestimated.

This is considered to hold true even though the study is not as detailed in terms of lesser on-site risks.

In fact, due to the lack of flammability at Route 9, additional ignition does not arise. The assessment of Route 9 as a target for flash fire, jet fire, fireball, explosion and missile effects was then considered using both individual risk and societal risk measures. The results are presented in the following table and supporting IR contours and FN Curves.

Table 9.8.1 : Comparison of Results with Previous Assessments

PHI	Individual Risk		Societal Risk	
	Base Case	With Route 9	Base Case	With Route 9
CRPC	Similar results	no change	similar results	no change detected
Esso	Similar results	no change	similar results	no change detected
Caltex	Similar results	no change	similar results	no change detected
Shell	Similar results	no change	similar results	no change detected

Risk levels of concern were found in the area at Shell and Caltex due to combined risks of storage and the LPG road tankers leaving the Depots.

Major fireball effects from above ground storage tanks involved in intense heating or from ship tank explosion could have limited effect at the Route 9 distance but would be below the 50% fatality levels in all cases other than for LPG road tanker trucks. In this respect, Route 9 is no more at risk than any other carriageway. The risk of vulnerable people exposed to fireball radiation as assessed using probit equations for fireball exposure has resulted in a small number of fatalities being counted in the societal risk assessment.

The data used for the study was limited and previous reference levels have been retained for consistency. Key information has been requested from the operators and incorporated where provided.

In view of the proximity of Route 9 to Shell and Caltex at Sai Tso Wan Road, a traffic study of tanker movements including departure / arrival times, provision of turning lanes, traffic volumes and speeds would be advisable to determine if improvements to the Shell and Caltex terminal exits, Sai Tso Wan Road and the Tsing Yi Road - Sai Tso Wan Road junction would be recommended to reduce risks due to LPG tanker movements.

The risks involve the Route 9 overhead traffic in event of a rising fireball from a heavy vehicle accident causing tanker rupture and the construction stage if traffic congestion is caused with high numbers of people trapped in the vicinity.

9.8.2 Application to Route 9: (non suitability for comparisons between PHIs)

The risk assessment results reported in this section relate strictly to the Route 9 effects. The results are not intended to provide complete assessments of the four PHIs. Such an aim would require detailed assessment of the piping equipment, isolating systems, management systems, minor storage including portable LPG cylinders and the like.

9.8.2.1 Level of Consistency with Previous Studies:

Key failure case events from previous studies carried out over a period of ten years have been reviewed and adopted where considered appropriate to this study. To demonstrate a degree of consistency of results for individual risk contours and FN curves with the previous more detailed studies of each facility, key values consistent with the previous studies of each terminal been adopted where reasonable to do so.

It has therefore not been practicable, nor was it our intention, to maintain a standard set of inputs, common to all four PHIs.

9.8.2.2 Exclusion of Liquid Petroleum Facilities:

The petroleum facilities, other than LPG, have not been assessed quantitatively since events within these liquid storage facilities are not considered capable of impacting seriously on the Route 9 facility. Smoke and missile effects are possible but unlikely to be fatal in the first case and of low event frequency and impact probability in the latter case.

The previous studies identified the LPG facilities as those presenting off-site impacts, while recognising the petroleum facilities as adding to knock-on effects and on-site risk levels.

The following comment on risk assessment arises from examining risk levels from all facilities onto Route 9, which arise principally from flash fire, fireball radiation and explosion overpressure from major releases in the storage, import and export areas.

Key factors include proximity of the route to the facilities, size of releases, and wind and weather probabilities.

Only the Shell and Caltex facilities have significant potential for impact on Route 9. For Shell, these results remain within the Government PHI Interim Risk Guidelines, both in terms of Individual Risk levels and Societal Risk.

Route 9 population risk exposure is examined in terms of both individual and societal risk.

9.8.2.3 Individual Risk (Figures 9.8.1 –9.8.7)

The criteria for individual risk is satisfied firstly in that Route 9 do not infringe on areas where individual risk levels are above the prescribed levels. The highest Individual Risk level at Route 9 from the PHIs found in this study was in the section West of the portal near the Caltex and Shell terminals, as shown below:

- Individual Risk Criteria level 10×10^{-6} per year
- Point closest to Shell 9.7×10^{-6} per year
- Junction with Route3 2.1×10^{-6} per year
- West Portal 1.5×10^{-6} per year

The main contribution to the highest level of risk above, near Shell is from flash fire, which if it occurred would involve a low flame close to ground level which would flash rapidly back to the source of release followed by a jet or fool fire within the terminal. Involvement of the elevated Route 9 structure or carriageway is not likely. The risk that transitory heat or smoke would create a significant hazard is assessed in the societal risk calculations and found to be at a level which is acceptable if kept as low as reasonably practicable.

These above section and all other sections of Route 9 are below the Individual Risk criteria level of 10×10^{-6} per year proposed in the interim guidelines for areas continuously occupied. The exposure time fraction for a twenty-second pass twice a day for six days a week is 0.0004. The time-factored exposure therefore is 1/2500 of the criteria level.

9.8.2.3.1 Example 1: Average exposure:

The average Individual Risk frequency of $<10 \times 10^{-6}$ per year over the section near Shell times the exposure time fraction, 0.0004 of the an average person exposed for twenty seconds twice a day for six days a week, gives a risk of less than 4×10^{-9} per year.

9.8.2.3.2 Example 2: Most exposed individual

A highly exposed individual hypothetically travelling continuously on Route 9 may spend 10% of his time in the PHI exposed sections. For six days a week this would give an exposure of 2.3×10^{-7} per year.

Therefore considering even the most exposed individual travelling on Route 9 the Individual Risk Criteria is clearly satisfied.

The Route 9 section east of Tsing Yi and north east of the **CRPC** and Esso LPG facilities does not show any significant contribution to PHI risks.

The Individual risk contours also show that sections of Sai Tso Wan Road and Tsing Yi Road are close to or above the 10×10^{-6} per year Individual Risk level.

These are:

- the section adjacent to the Shell Terminal LPG Storage where the 10×10^{-6} per year contour is along the Shell boundary,

- on Tsing Yi Road South East of Caltex where the level is 28 x 10^{-6} per year,
- on Tsing Yi Road between Esso and **CRPC** terminals with a peak at 18 x 10^{-6} per year at the CRPC exit.

These levels exist at present and are not influenced by Route 9. They are included for completeness of the study and reference.

9.8.2.4 Societal Risk (Figure 9.8.8 – 9.8.11)

Societal risk assessment shows the most significant increase due to Route 9 population to result from the section close to the Shell facility. Existing risk levels from Shell are within the lower and upper bounds of the societal risk criteria, where risks may be considered acceptable if found to be **A**s **L**ow **A**s **R**easonably **P**racticable (**ALARP**). The additional Route 9 risks increase the FN curve fractionally toward the upper bound. As such it is required that measures be examined to mitigate the risks as far as practicable. Recommendations are proposed relating to traffic movements in the vicinity and means of closing and clearing Route 9 in an emergency situation such as potential, imminent BLEVE.

For the Caltex facility, the study found levels within PHI criteria bound. The Route 9 population increases the FN curve by up to 30% for two to five fatalities and is insignificant beyond that.

The Caltex LPG facility has above ground storage spheres which contribute to the risk of BLEVE fireball. Replacement of these spheres with mounded storage may be an option. However, according to a study commissioned in 1994 by EMSD, the replacement would only mariginally reduce the level of risk and the cost was in the order of $200 to $300 millions and therefore would not be cost effective. It is recommended that placement of BLEVE walls on Route 9 to provide protection to users be considered. The need and extent of the BLEVE walls should be further investigated in the detailed design stage.

9.8.2.5 Significance of PHI risk to Route 9 Users

It has been assumed that the Esso facility will replace its above ground storage spheres with mounded spheres or bullets before the construction or operation of Route 9.

The size and location of this mounded storage has not been finalised. However, it is assumed that the size of this storage will be such as to achieve acceptable results for the Esso facility boundaries and immediate societal risk targets. The storage and jetty area should be such that there will be negligible impact on Route 9 which is more distant from the Esso site than the other three terminals.

9.8.2.6 Analysis of Risks

9.8.2.6.1 Shell:

The results of the contribution to risk to Route 9 from the Shell LPG installation is shown in Table 9.8.2 (PLL Ranking: Shell Depot).

Analysis of results showed 81% of the potential loss of life (PLL) as expected fatalities/yr, was associated with flash-fire events, while the remaining 19% was fireball and explosion.

88.5% of the PLL was also associated with large releases from the storage installation (Events C101 to C402).

Of the remainder, 10.5% was from LPG Road Tankers (Events D105 to D107) and 1% from ship events.

These results reflect the proximity of the Route 9 alignment to the Shell LPG storage installation. There is however, some conservatism in the fatality estimates as the flash fire would occur within the flammable portion of the LPG cloud close to ground level. The Route 9 carriageways are from 20 to 50 metres above ground locations where flash fire could be expected to reach. Motorists are therefore outside the flame envelope but could be affected by smoke and a short duration heat wave. Multiple vehicle accidents resulting from panic, surprise or distraction could be expected. These have not been quantified separately in this analysis but are considered to be included in the fatality estimates, as the same group is involved in risk from either fire or vehicle accident.

90.79% of the PLL involved over twenty fatalities; 6.95% involved between 11 and 20 fatalities; 1.3% involved 3 to 5 fatalities and others comprised less than one percent.

The Societal Risk FN Curves for the Shell Risk to Route 9 are shown in Figure 9.8.8.

The risks are in the ALARP range and an increase due to Route 9 can be observed. The study does not allow for increases in traffic which could still occur without Route 9. Such traffic increase on Route 3 would have the same effect as Route 9. Traffic on roads at ground level in the vicinity would be more exposed leading to a similar level of risk.

9.8.2.6.2 Caltex:

Caltex is of particular interest as the site uses above ground LPG spheres which are potentially capable of BLEVE and fireball effects. The closest distance from the spheres to Route 9 is 540m, which reduces the risk to passing motorists to a level which is unlikely to cause many fatalities.

The contribution from Caltex to the Route 9 societal risk is shown in Figure 9.8.9.

The effect of Route 9 is to marginally increase the exposure of a vulnerable fraction of the motorists on Route 9 who may be effected by a major BLEVE fireball. Route 9 is beyond the 50% fatality distance for persons exposed outdoors to fireballs of the size expected from the LPG storage at Caltex.

9.8.2.6.3 Emergency Response and Mitigation

No allowance has been made in the QRA for mitigating actions such as closing Route 9 prior to a BLEVE occurring. Preventing traffic from passing or approaching a hazard zone and clearing existing traffic would require prompt emergency response, but may obstruct necessary evacuation routes. To determine the effectiveness of emergency assessment and response would require further examination of likely times to BLEVE, the emergency initiation and response priorities, evacuation routes, available communication systems, and traffic control measures on Route 9 and in the vicinity.

9.8.2.6.4 CRPC:

The results for CRPC show that there is negligible effect for Route 9. This is due to the distance and elevation of Route 9 from the CRPC site. There are also numerous ignition

sources which any flammable cloud would be likely to encounter before approaching the Route 9. It is unlikely however that flammable concentrations or lethal radiation thermal levels would reach anywhere near Route 9 (Figure 9.8.10).

9.8.2.6.5 Esso:

Esso, adjacent to CRPC is further from the Route 9 alignment than the other three terminals. Esso however presently has above ground storage spheres which increases the risk of BLEVE and fireball. The study assumes that these spheres will be replaced with mounded storage of quantity and layout which will virtually eliminate the BLEVE risk. The QRA results show that for a mounded LPG installation there should minimal, if any, contribution to risk at Route 9 or increase to risks at the Esso site (Figure 9.8.11).

While not included in the QRA study brief, a point to note may be the structural integrity of the cut slope at the Dow Chemical facility, particularly for shock or vibration from tunnelling near the Eastern Portal.

Table 9.8.2 : Fatality Group (Number of fatalities from any single event)

Risk Events contributing to Route 9 fatalities from Shell LPG Depot
Values shown are Potential Loss of Life (PLL) in expected fatalities per year

							Cumulative %	
PLL	**1-2**	**3-5**	**6-10**	**20 +**	**ALL**	**Total**	**Storage**	**LPG Tr**
C401FFD4	0.0E+0	0.0E+0	0.0E+0	1.5E-5	1.6E-5	9.86%	9.86%	
C301FFD4	0.0E+0	0.0E+0	0.0E+0	1.4E-5	1.5E-5	9.25%	19.11%	
C101FFD4	0.0E+0	0.0E+0	0.0E+0	1.3E-5	1.4E-5	8.63%	27.74%	
C201FFD4	0.0E+0	0.0E+0	0.0E+0	1.3E-5	1.4E-5	8.63%	36.37%	
D107FBND	0.0E+0	0.0E+0	0.0E+0	6.7E-6	6.7E-6	4.13%		4.13%
C401FFB2	0.0E+0	0.0E+0	0.0E+0	4.6E-6	4.9E-6	3.02%	39.39%	
C201FFB2	0.0E+0	0.0E+0	0.0E+0	4.2E-6	4.6E-6	2.84%	42.22%	
C301FFB2	0.0E+0	0.0E+0	0.0E+0	4.3E-6	4.6E-6	2.84%	45.06%	
C401FFD1	0.0E+0	0.0E+0	0.0E+0	4.4E-6	4.6E-6	2.84%	47.90%	
C301FFD1	0.0E+0	0.0E+0	0.0E+0	4.2E-6	4.4E-6	2.71%	50.61%	
C401FFF1	0.0E+0	0.0E+0	0.0E+0	4.0E-6	4.4E-6	2.71%	53.32%	
C101FFB2	0.0E+0	0.0E+0	0.0E+0	3.8E-6	4.2E-6	2.59%	55.91%	
C201FFD1	0.0E+0	0.0E+0	0.0E+0	4.0E-6	4.2E-6	2.59%	58.50%	
C301FFF1	0.0E+0	0.0E+0	6.0E-8	3.8E-6	4.2E-6	2.59%	61.09%	
C201FFF1	0.0E+0	1.8E-8	0.0E+0	3.8E-6	4.1E-6	2.53%	63.61%	
C101FFD1	0.0E+0	0.0E+0	0.0E+0	3.7E-6	3.9E-6	2.40%	66.02%	
D107FBND	0.0E+0	0.0E+0	0.0E+0	3.5E-6	3.6E-6	2.22%		2.22%
C101FFF1	0.0E+0	1.8E-8	0.0E+0	3.0E-6	3.4E-6	2.10%	68.11%	
C402FFD4	0.0E+0	0.0E+0	0.0E+0	2.7E-6	2.9E-6	1.79%	69.90%	
C102FFD4	0.0E+0	0.0E+0	0.0E+0	2.5E-6	2.7E-6	1.66%	71.57%	
C202FFD4	0.0E+0	0.0E+0	0.0E+0	2.5E-6	2.7E-6	1.66%	73.23%	
C302FFD4	0.0E+0	0.0E+0	0.0E+0	2.5E-6	2.7E-6	1.66%	74.89%	
D107FBND	0.0E+0	0.0E+0	0.0E+0	2.4E-6	2.5E-6	1.54%		1.54%
D107FBND	0.0E+0	0.0E+0	0.0E+0	0.0E+0	2.1E-6	1.29%		1.29%
C202EXND	0.0E+0	0.0E+0	0.0E+0	9.8E-7	1.0E-6	0.62%	75.51%	
C202EXND	0.0E+0	0.0E+0	0.0E+0	9.8E-7	1.0E-6	0.62%	76.13%	
C402EXND	0.0E+0	0.0E+0	0.0E+0	9.5E-7	9.7E-7	0.60%	76.72%	
C402EXND	0.0E+0	0.0E+0	0.0E+0	9.5E-7	9.7E-7	0.60%	77.32%	
C302EXND	0.0E+0	0.0E+0	0.0E+0	9.4E-7	9.6E-7	0.59%	77.91%	
C302EXND	0.0E+0	0.0E+0	0.0E+0	9.4E-7	9.6E-7	0.59%	78.51%	
C402FFB2	0.0E+0	0.0E+0	0.0E+0	7.9E-7	8.6E-7	0.53%	79.04%	

							Cumulative %	
PLL	1-2	3-5	6-10	20 +	ALL	Total	Storage	LPG Tr
C102EXND	0.0E+0	0.0E+0	0.0E+0	8.4E-7	8.6E-7	0.53%	79.57%	
C102EXND	0.0E+0	0.0E+0	0.0E+0	8.4E-7	8.6E-7	0.53%	80.10%	
C202FFB2	0.0E+0	0.0E+0	6.5E-9	7.4E-7	8.1E-7	0.50%	80.60%	
C302FFB2	0.0E+0	0.0E+0	6.5E-9	7.4E-7	8.1E-7	0.50%	81.09%	
C402FFD1	0.0E+0	0.0E+0	0.0E+0	7.6E-7	8.0E-7	0.49%	81.59%	
C401EXND	0.0E+0	0.0E+0	0.0E+0	8.0E-7	8.0E-7	0.49%	82.08%	
C401EXND	0.0E+0	0.0E+0	0.0E+0	8.0E-7	8.0E-7	0.49%	82.57%	
C301EXND	0.0E+0	0.0E+0	0.0E+0	7.8E-7	7.9E-7	0.49%	83.06%	
C301EXND	0.0E+0	0.0E+0	0.0E+0	7.8E-7	7.9E-7	0.49%	83.55%	
C302FFD1	0.0E+0	0.0E+0	0.0E+0	7.3E-7	7.7E-7	0.47%	84.02%	
C102FFD1	0.0E+0	0.0E+0	0.0E+0	7.1E-7	7.6E-7	0.47%	84.49%	
C202FFD1	0.0E+0	0.0E+0	0.0E+0	7.2E-7	7.6E-7	0.47%	84.96%	
A103FBND	7.6E-7	0.0E+0	0.0E+0	0.0E+0	7.6E-7	0.47%		
C201EXND	0.0E+0	0.0E+0	0.0E+0	7.5E-7	7.6E-7	0.47%	85.43%	
A103FBND	7.6E-7	0.0E+0	0.0E+0	0.0E+0	7.6E-7	0.47%		
C201EXND	0.0E+0	0.0E+0	0.0E+0	7.5E-7	7.6E-7	0.47%	85.90%	
C101EXND	0.0E+0	0.0E+0	0.0E+0	7.4E-7	7.5E-7	0.46%	86.36%	
C101EXND	0.0E+0	0.0E+0	0.0E+0	7.4E-7	7.5E-7	0.46%	86.82%	
C402FFF1	0.0E+0	3.7E-9	0.0E+0	7.1E-7	7.1E-7	0.44%	87.26%	
C102FFB2	0.0E+0	2.0E-9	0.0E+0	5.9E-7	6.7E-7	0.41%	87.67%	
C302FFF1	8.0E-10	0.0E+0	0.0E+0	5.2E-7	5.4E-7	0.33%	88.00%	
D107FBND	1.4E-8	4.1E-7	0.0E+0	0.0E+0	4.3E-7	0.27%		0.27%
C202FFF1	0.0E+0	0.0E+0	0.0E+0	3.8E-7	4.1E-7	0.25%	88.26%	
C102FFF1	0.0E+0	0.0E+0	0.0E+0	3.8E-7	4.0E-7	0.25%	88.50%	
D104FFD4	0.0E+0	0.0E+0	0.0E+0	2.2E-7	2.2E-7	0.14%		0.14
D104FFD4	0.0E+0	0.0E+0	0.0E+0	1.5E-7	1.5E-7	0.0925%		0.0925
D107FBND	1.5E-7	0.0E+0	0.0E+0	0.0E+0	1.5E-7	0.0925%		0.0925
D107FBND	1.1E-7	0.0E+0	0.0E+0	0.0E+0	1.1E-7	0.0678%		0.0678
D107FBND	1.1E-7	0.0E+0	0.0E+0	0.0E+0	1.1E-7	0.0678%		0.0678
D104FFD4	0.0E+0	0.0E+0	0.0E+0	9.5E-8	9.5E-8	0.0586%		0.0586
D107FBND	9.3E-8	0.0E+0	0.0E+0	0.0E+0	9.3E-8	0.0573%		0.0573
D104FFD4	0.0E+0	0.0E+0	0.0E+0	7.5E-8	8.1E-8	0.0499%		0.0499
D104FFF1	0.0E+0	0.0E+0	0.0E+0	6.5E-8	6.5E-8	0.0401%		0.0401
D105FFD4	0.0E+0	0.0E+0	0.0E+0	6.4E-8	6.4E-8	0.0395%		0.0395
D104FFD1	0.0E+0	0.0E+0	0.0E+0	6.1E-8	6.1E-8	0.0376%		0.0376
D104FFD1	0.0E+0	0.0E+0	0.0E+0	5.8E-8	5.8E-8	0.0358%		0.0358
D104FFB2	0.0E+0	0.0E+0	0.0E+0	4.9E-8	4.9E-8	0.0302%		0.0302
A101FBND	0.0E+0	3.7E-9	4.1E-8	0.0E+0	4.5E-8	0.0277%		
A101FBND	0.0E+0	3.7E-9	4.1E-8	0.0E+0	4.5E-8	0.0277%		
D104FFF1	0.0E+0	0.0E+0	0.0E+0	3.4E-8	3.4E-8	0.0210%		0.0210
A102FBND	3.3E-8	0.0E+0	0.0E+0	0.0E+0	3.3E-8	0.0203%		
A102FBND	3.3E-8	0.0E+0	0.0E+0	0.0E+0	3.3E-8	0.0203%		
D104FFD1	0.0E+0	0.0E+0	0.0E+0	2.9E-8	3.2E-8	0.0197%		0.0197
D104FFB2	0.0E+0	0.0E+0	0.0E+0	2.2E-8	3.1E-8	0.0191%		0.0191
D104FFB2	0.0E+0	0.0E+0	0.0E+0	2.9E-8	2.9E-8	0.0179%		0.0179
D104FFF1	3.0E-10	0.0E+0	0.0E+0	2.0E-8	2.8E-8	0.0173%		0.0173
D104FFB2	0.0E+0	2.0E-10	0.0E+0	2.7E-8	2.7E-8	0.0166%		0.0166
D104FFF1	0.0E+0	0.0E+0	0.0E+0	2.5E-8	2.5E-8	0.0154%		0.0154
D104FFD4	1.0E-10	0.0E+0	0.0E+0	2.3E-8	2.3E-8	0.0142%		0.0142
D104FFD1	0.0E+0	0.0E+0	0.0E+0	1.9E-8	1.9E-8	0.0117%		0.0117
D105FFD1	0.0E+0	0.0E+0	0.0E+0	1.7E-8	1.7E-8	0.0105%		0.0105
D105FFD4	0.0E+0	0.0E+0	0.0E+0	1.3E-8	1.3E-8	0.0080%		0.0080

							Cumulative %	
PLL	**1-2**	**3-5**	**6-10**	**20 +**	**ALL**	**Total**	**Storage**	**LPG Tr**
D104FFD1	1.0E-10	0.0E+0	0.0E+0	1.0E-8	1.0E-8	0.0062%		0.0062
D105FFF1	0.0E+0	0.0E+0	1.3E-9	8.7E-9	1.0E-8	0.0062%		0.0062
D105FFB2	0.0E+0	0.0E+0	0.0E+0	6.2E-9	9.2E-9	0.0057%		0.0057
D105FFD4	0.0E+0	0.0E+0	0.0E+0	0.0E+0	8.1E-9	0.0050%		0.0050
D105FFF1	0.0E+0	0.0E+0	0.0E+0	5.4E-9	5.4E-9	0.0033%		0.0033
D105FFB2	0.0E+0	0.0E+0	0.0E+0	4.7E-9	4.7E-9	0.0029%		0.0029
D105FFD1	0.0E+0	0.0E+0	0.0E+0	4.2E-9	4.2E-9	0.0026%		0.0026
D105FFD1	0.0E+0	0.0E+0	0.0E+0	0.0E+0	1.8E-9	0.0011%		0.0011
D104FFB2	0.0E+0	0.0E+0	0.0E+0	0.0E+0	1.7E-9	0.0010%		0.0010
D104FFF1	0.0E+0	0.0E+0	1.6E-9	0.0E+0	1.6E-9	0.0010%		0.0010
D105FFD4	0.0E+0	1.4E-9	0.0E+0	0.0E+0	1.4E-9	0.0009%		0.0009
D104FFD4	8.0E-10	0.0E+0	0.0E+0	0.0E+0	8.6E-10	0.0005%		0.0005
D105FFD1	0.0E+0	4.0E-10	0.0E+0	0.0E+0	4.5E-10	0.0003%		0.0003
D104FFD1	2.0E-10	0.0E+0	0.0E+0	0.0E+0	2.3E-10	0.0001%		0.0001
D105FFB2	1.0E-10	0.0E+0	0.0E+0	0.0E+0	1.0E-10	0.0001%		0.0001
Total	2.1E-6	4.6E-7	1.6E-7	1.5E-4	1.6E-4	100%	88.5%	10.5%
Percent	1.3%	0.3%	0.1%	6.9%	91.3%	100%		

Notes: Events are based on Failure cases: A Ship, B unloading arms, C Mounded storage, D Road tanker loading and transport. FF is flash fire, FB is Fireball, Ex is explosion. D4 is Pasquill stability category D and wind speed of 4 m/s. ND is non-directional.

9.9 Conclusions And Recommendations

9.9.1 General

The study brief arises from designation of consultation zones for the Tsing Yi PHIs and associated planning requirements. The purpose of the study is to ensure that developments within significant proximity to PHIs are examined to identify potential to increase risks and any requirements for risk reduction measures.

The risk assessment has examined the existing PHI terminal facilities in terms of storage capacity and proximity for LPG events which could present risk to the proposed Route 9 terminals or be adversely affected by the ignition risks on the route from vehicles or during construction.

The study is based on a coarse model of the depots main LPG storage and potential sources or major release. The study did not detail all of the facilities or operating systems although salient points from previous studies were noted and allowed for in the study.

This coarse level has provided results relevant to the LPG risks which are generally consistent with those of more detailed studies carried out previously (Ref 1, 2, 3, 4, 5 & 6, see Appendix 9F). This provided a base case on which to examine the specific impacts, if any, from or upon Route 9.

9.9.2 Route 9 Alignment Proximity to Terminals

The Route 9 proposed alignment across South Tsing Yi Island passes within the 1km radius consultation zone for each of four potentially hazardous installations (PHIs).

The four PHIs are the South Tsing Yi LPG depot and jetty facilities for Shell Oil, Caltex Oil, CRPC Oil and Esso Oil.

The nearest LPG storage is within the Shell Terminal at 200 m from the Route 9 alignment. However, in this section Route 9 is elevated relative to potential release points (mounded facilities, relief valves, and ship manifolds) from approximately 20m above the level of the Shell Site to 60m and more as the Route 9 rises to meet Route 3.

9.9.3 Risk Assessment Elements

Three essential elements of risk were reviewed;

- energy sources with capability to cause harm;
- people or property capability of sustaining harm;
- and proximity between objects with these first and last properties.

It is established that each of the PHI LPG facilities has the potential capability to cause off-site harm and to suffer damage and injury to its own occupants from external damage to critical components.

Proximity between Route 9 and the PHIs ranges from 200m to 1000m and more, which is within range of major LPG Release effects, particularly BLEVE Fireball, Explosion and flash fire.

The task of the QRA process is to identify and evaluate the potential impacts in relation to Route 9 and hazardous sources within the PHIs in accordance with the HK SAR's PHI Interim Risk Guidelines, as acceptance criteria.

9.9.4 Separation for Structural Safety

The proposed separations between Route 9 and the PHIs are sufficient to ensure that the PHIs are not endangered from risk of collapse or dropped object from the elevated structure during operation. During construction, heavy cranes and piling rigs and any use of explosives will need to be controlled to avoid accidental collapse or projection onto the Shell mounded LPG storage facility which is close to Sai Tso Wan Road. Other LPG facilities are well clear of any Route 9 structural risks.

9.9.5 Ignition Potential for Flammable Releases from the PHIs

An identified potential concern in the study brief was risk to the four PHIs from ignition sources during construction and operation of Route 9.

The study has determined using heavy gas dispersion modelling for instantaneous and continuous releases of LPG that the route is beyond the distance expected for flammable concentrations resulting from accidental releases from the terminals.

In addition to the horizontal distances, the Route 9 carriageways in the vicinity of the terminals is elevated to above 20 metres and up to 60 metres or more, which is above the effective height of flammable LPG clouds that could be expected.

Ignition is therefore not an issue of concern for the traffic on Route 9.

During construction, where ignition sources may be located at ground level, the distances are still beyond the flammable range. Additional safety would be provided by erection of

construction screens around areas with ignition sources, such as welding and cutting, near to the terminals.

9.9.6 Risk Exposure of Route 9 Traffic Population

Additional population in the vicinity of the Shell and Caltex terminals increases the numbers of people who may be at risk from effects of flash fire, fireball engulfment or radiation and explosion originating from the LPG facilities or LPG transport from the terminals.

Route 9 population risk exposure is examined for both individual and societal risk.

9.9.6.1 Individual Risk

The criteria for individual risk is satisfied. Firstly, Route 9 does not infringe on areas where individual risk levels are above the prescribed levels. The highest Individual Risk level at Route 9 from the PHIs found in this study was in the short section West of the portal near the Caltex and Shell terminals, as shown below:

(a) Individual Risk Criteria level 10×10^{-6} per year

(b) Point closest to Shell 9.7×10^{-6} per year

(c) Junction with Route3 2.1×10^{-6} per year

(d) West Portal 1.5×10^{-6} per year

These above section and all other sections of Route 9 are below the risk criteria level of 10×10^{-6} per year proposed in the interim guidelines for areas continuously occupied. When further considering the time fraction exposure of the individuals travelling on Route 9, the Individual Risk Criteria is clearly satisfied.

Individual risk levels have also been considered for the adjacent terminals Shell and Caltex; Esso and CRPC and for the four PHIs together. The contours are shown in Figures 9.8.1 to 9.8.7. Cumulative risks occur due to overlap between the terminals but not to a level which alters compliance with criteria.

9.9.6.2 Societal Risk

9.9.6.2.1 Shell

Societal risk assessment shows the most significant increase due to Route 9 population to result from the section close to the Shell facility.

Existing risk levels from Shell as determined both previously (Ref. 5) and in this study are within the lower and upper bounds of the societal risk criteria. This is the band where risks may be considered acceptable if found to be **A**s **L**ow **A**s **R**easonably **P**racticable (**ALARP**).

The additional Route 9 risks increase the FN curve fractionally toward the upper bound. As such it is required that measures be examined to mitigate the risks as far as practicable. Recommendations are proposed relating to traffic movements in the vicinity and means of closing and clearing Route 9 in an emergency situation. The design of Route 9 should incorporate features which would allow it to be closed and cleared quickly in case of emergency.

The study finds that inclusive of Route 9 population, the individual and societal risk at the Shell LPG facility remains within the Hong Kong Risk Guideline.

9.9.6.2.2 Caltex

For the Caltex facility, the study found levels within the upper PHI criteria bound.

Inclusion of the Route 9 traffic population increases the FN curve by up to 30% for two to five fatalities and is insignificant beyond that.

The Caltex LPG facility has above ground storage spheres which contribute to the risk of BLEVE fireball. The QRA study found that Route 9 does not increase the fatality risk from the Caltex LPG Spheres, as the Route 9 alignment is beyond the distance at which fatalities from direct fireball effects from these spheres would be expected. However, the study found that risks around Caltex would increase overall due to predicted future traffic increases in surrounding roads and the proximity of LPG road tankers to Route 9. The future increase in traffic in surrounding roads is not the result of Route 9 but of consideration of the planning period. The study noted that the risks from Caltex are in the ALARP region of the Hong Kong Risk Guidelines and that practicable risk reduction measures to reduce the risk should be considered. The risks at the terminal have previously been determined in the detailed ERM QRA Study (Reference 2) to be within the Hong Kong Guidelines. It is recommended that placement of BLEVE walls on Route 9 to provide protection to users be considered. The need and extent of the BLEVE walls should be further investigated in the detailed design stage.

The study concludes that with Route 9, the individual and societal risk at the Caltex LPG facility will remain within the Hong Kong Risk Guidelines.

9.9.6.2.3 CRPC

The Route 9 section east of Tsing Yi and north east of the CRPC LPG facilities does not show any measurable contribution to CRPC PHI risks.

Truck transportation of LPG along Tsing Yi Road presents a low level (~1E-7 /yr) risk at the undercrossing with Route 9. Due to the height of Route 9 this is not significant and is comparable to many other transportation route crossings.

The risks at the terminal have previously been determined in the DNV Technical QRA report (Reference 3) to be within the Hong Kong Guidelines.

The study concludes that with Route 9, the individual and societal risk at the CRPC LPG facility will remain within the Hong Kong Risk Guidelines.

9.9.6.2.4 Esso

The Route 9 section east of Tsing Yi and north east of the Esso LPG facilities does not show any discernible or measurable contribution to Esso PHI risks. The risks at the terminal with mounding LPG storage as proposed have previously been determined in the Mouchel QRA Report (Reference 5) to be within the Hong Kong Guidelines.

The study concludes that with Route 9, the individual and societal risk at the Esso LPG facility will remain within the Hong Kong Risk Guidelines.

9.9.6.2.5 Combined

The combined risks to Route 9 from all PHIs is the sum of the risks to the Route 9 population from Shell, Caltex, CRPC and Esso.

While it may be argued that the PHI Interim Risk Guideline criteria does not relate directly to this, it is noted that the cumulative risk is still below the upper guideline.

9.9.7 Other Risks

While not included specifically in the QRA study brief, a point to note may be the structural integrity of the cut slope at the Dow Chemical facility particularly for shock or vibration from tunnelling near the Eastern Portal.

Another concern was whether concentrations from major accidental releases would be sufficient to enrich inlet mixtures causing racing of engines, but the levels involved at the elevations of the route were too low for any such effects.

Fireball or flash fire from a catastrophic incident may result in vehicle accidents on the Expressway. These could include vehicles stopping, colliding or catching fire. Harm to the occupants from the immediate fire effects is unlikely, as they would be partly shielded in most cases. People in open vehicles may be exposed to hot gases and burn effects. In most cases escape would be possible after the short duration of the fire effect.

9.9.8 Other Conclusions

The Hong Kong individual risk and societal risk criteria have been applied to the results.

Transportation of LPG tankers has been included in the vicinity of the terminals and Route 9 for completeness.

Societal risk criteria is not well developed for transportation risks where several inputs may be required to complement criteria based on risk alone (rather than a comparison of benefits and costs of risk). Populations involved may vary significantly, both in terms of the total population exposed along a route, as well as in the vicinity of a PHI, and includes other motorists who are exposed for brief periods while using the roads for the benefits involved.

The design of the Expressway in the vicinity of the terminals should avoid factors likely to contribute to collision such as speed limit reduction or queuing. Emergency escape provision for pedestrians and emergency vehicles access is recommended.

The risks to be considered in this regard involve:

- the Route 9 overhead traffic in event of a rising fireball from a heavy vehicle accident causing tanker rupture; and
- the construction stage if traffic congestion is caused with high numbers of people trapped in traffic in the vicinity.

The risks due to proximity of the Route to Shell and Caltex at Sai Tso Wan Road requires more detailed study after details of current facilities and tanker movements are known.

A traffic study of the Shell and Caltex terminal exits, Sai Tso Road Wan and the Tsing Yi Road -Sai Tso Wan Road junction is recommended. This should be undertaken when

detailed designs are available to determine whether traffic flows at the depot exits need to be improved to reduce risks due to LPG tanker movements.

9.9.9 Recommendations

Construction cranes and piling rigs and any use of explosives to be controlled to avoid accidental collapse or projection onto the Shell mounded LPG storage facility which is close to Sai Tso Wan Road.

It will be necessary to provide procedures and event action plans to cover rapid cessation of construction activities.

The design of Route 9 in the vicinity of the terminals to avoid or minimise factors likely to contribute to collision such as sudden speed reduction or queuing.

Emergency escape provision and emergency vehicles access to be provided.

Placement of concrete BLEVE wall could be considered after evaluation of cost implications and design and construction constraints.

A traffic study of the Shell and Caltex terminal exits, Sai Tso Wan Road and the Tsing Yi -Sai Tso Wan Road junction, to determine whether traffic flows at the depot exits need to be improved to reduce risks due to LPG tanker movements, should be conducted at the detailed design stage.

The design of Route 9 should incorporate features which would allow it to be closed and cleared quickly in case of emergency.

In case of a major accident at an oil terminal, suitable liaison should be established between the Fire Services Department, the oil terminals and Route 9 Control Room.

The responsibilities for implementing these recommendations are stated in the Implementation Schedule of Section 11.